DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 530

# CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1911

PART I.—METALS AND NONMETALS EXCEPT FUELS

WALDEMAR LINDGREN
CHIEF GEOLOGIST

OHIO STATE UNIVERSITY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

QE 75
B9
no. 530-531
Copy 2

OHIO STATE
UNIVERSITY

# CONTENTS.





152881

# ILLUSTRATIONS.

# CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1911.

## PART I. METALS AND NONMETALS EXCEPT FUELS.

WALDEMAR LINDGREN, *Chief Geologist.*

## INTRODUCTION.

This volume is the tenth of a series that includes Bulletins 213, 225, 260, 285, 315, 340, 380, 430, and 470, "Contributions to economic geology" for 1902, 1903, 1904, 1905, 1906 (Pt. I), 1907 (Pt. I), 1908 (Pt. I), 1909 (Pt. I), and 1910 (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, and 1910 are Bulletins 316, 341, 381, 431, and 471. Bulletin 531 will form Part II of the "Contributions" for 1911.

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, and 520.

# GOLD AND SILVER.

## NOTES ON THE GOLD LODES OF THE CARRVILLE DISTRICT, TRINITY COUNTY, CALIFORNIA.

By Donald Francis MacDonald.

### INTRODUCTION.

In the fall of 1909, the writer spent 10 days in the Carrville district, Trinity County, Cal., and, incidental to other work, gathered some data on its mining geology. A paper on the gold gravels [1] was published, but baggage and notes were burned before anything on the geology of the gold lodes was written. In November, 1910, another visit to the district was made, but inclement weather handicapped the work somewhat. Other pressing duties have retarded the preparation of this paper. The growing economic importance of this mining district merits notice, and it is hoped that this brief report will direct attention toward it, to the end that mining in general may be benefited.

For kindly interest, assistance, and valuable data the writer is indebted to Messrs. David Goodale, of the Headlight mine; Matthew MacIlwaine, of the Dorleska; W. L. Chapmen, of the Golden Jubilee; J. H. Porter, of the Bonanza King; Jack Reid, of Windy Camp; Earnest A. Wagner, of the Wagner properties; V. B. Allen, of Allens Camp; and many others in the district. Mr. Waldemar Lindgren, chief geologist of the Survey, very kindly made microscopic examination of some rock sections for the writer, and Mr. E. R. Lloyd, also of the Survey, gave helpful criticism of this paper. Articles by Diller,[2] Hershey,[3] Hughes,[4] and Stines [5] have furnished helpful information.

Trinity County, lying in northwestern California, is a region of high mountains separated by valleys some of which support productive ranches. Its mountain slopes are clothed with a magnificent stand

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

[2] Diller, J. S., The auriferous gravels of the Trinity River basin, California: Bull. U. S. Geol. Survey No. 470, 1911, pp. 11-29; The Bragdon formation: Am. Jour. Sci., 4th ser., vol. 19, 1905, pp. 379-387.

[3] Hershey, O. H., Gold-bearing lodes in California: Am. Geologist, vol. 25, 1900, pp. 76-96; Sierran valleys of the Klamath region: Jour. Geology, vol. 11, 1903, p. 155.

[4] Hughes, A. F., Stripping a vein by hydraulicking: Min. and Sci. Press, Dec. 11, 1909, p. 788.

[5] Stines, N. S., Geology of the Coffee Creek mining district: Min. and Sci. Press, July 6, 1907, p. 25.

of pine and fir except where rugged crests spotted with glittering snow rise far above the dark green of forest and valley. In winter deep snow covers the higher lands, but in summer the climate is dry, bracing, and invigorating, so that the region, especially Carrville and Coffee Creek, is attaining popularity as a summer resort.

The villages of Carrville and Trinity Center are the distributing points for the region. They are 32 miles northwest of Delta, the nearest railway station, and 56 miles northwest of Redding, the largest distributing point in the northern Sacramento Valley. A daily stage connects the villages with Delta and there is a stage and freight service to Redding by way of the mining towns of French Gulch and Old Shasta. A wagon road leads northward into Scott Valley and another one westward to Minersville and Weaverville. The Le Moine Lumber Co. has a logging railroad from Lamoine station, on the Southern Pacific Railroad, to a point within 12 miles of Trinity Center, and it is said that this road may be extended to Trinity Center or to Carrville. The divides and drainages of the area, also the chief mining locations and their relation to land subdivisions, are shown on Plate I. It will be observed that the main lines of travel and the greatest marks of human interest are along Trinity River and its chief tributary, Coffee Creek. Trinity River rises 20 miles north of Carrville, among the rugged 8,000-foot peaks of the Scott Mountains, and Coffee Creek has its source in the Salmon Mountain divide near the northwest corner of the district. Many of the large tributaries of these streams head in old glacial cirques and flow through steep rocky gorges to join the main streams far below, each in its swift descent giving ample opportunity for water power. Farm produce and fresh vegetables can be grown in the district, game and fish are plentiful, the climate is good, and the geologic conditions are very promising, so that on the whole it is a very pleasant land for the prospector.

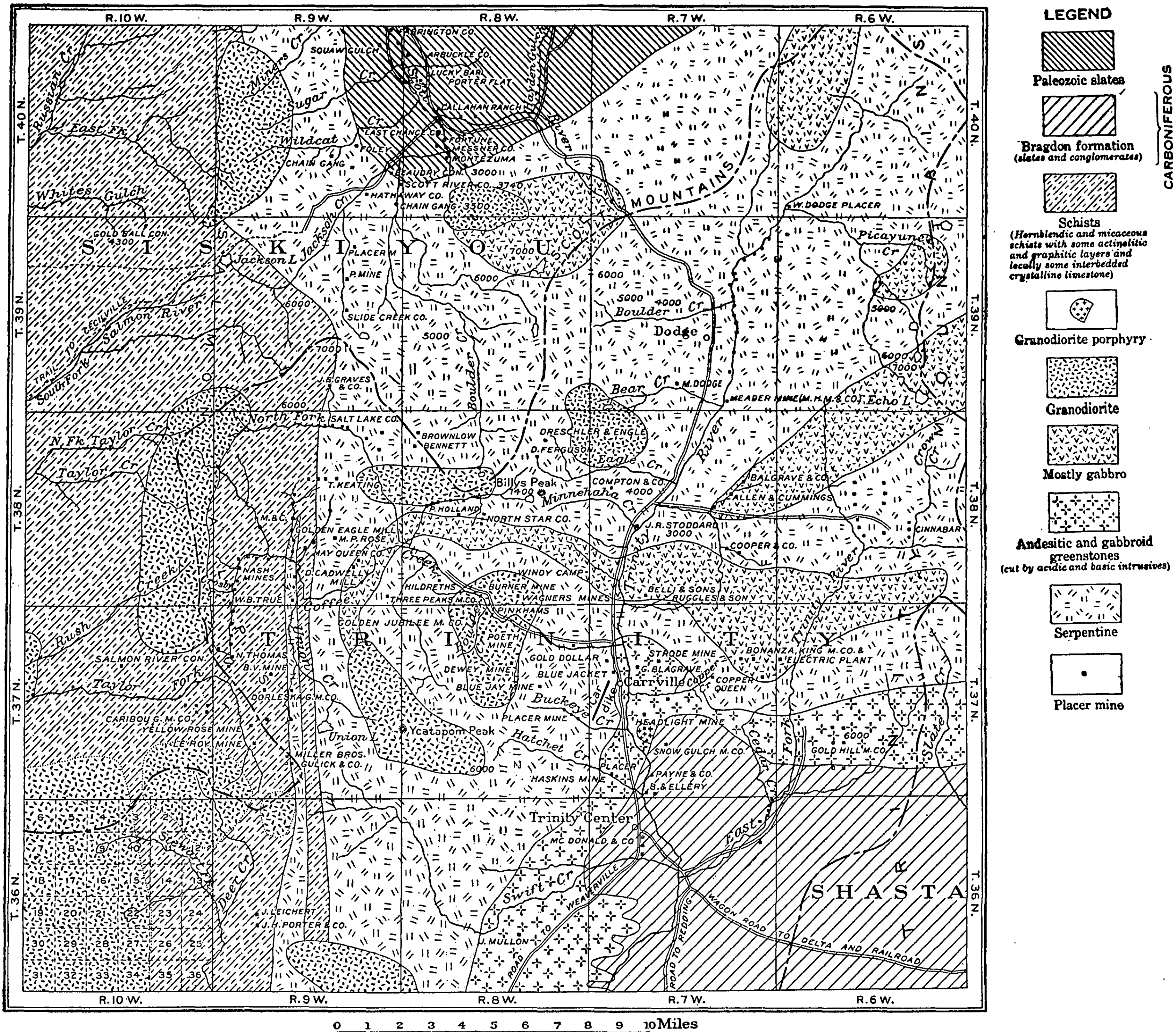
## GEOLOGY.

The region has a complex geologic history. For detailed information regarding its geology and that of the surrounding country the reader is referred to the papers by Diller and Hershey already cited. Briefly, the rocks consist of (1) a schist series, (2) a complex of greenstones, (3) wide areas of serpentines, (4) a slate-conglomerate series, (5) granitic batholiths, and (6) basic dikes. The distribution of these rocks is shown in outline on Plate I.

### SEDIMENTARY ROCKS.

The oldest rocks, the schist series, occur in the western part of the area, mostly west of a north-south line drawn along the axis of the Union Creek valley. Hershey[1] has divided this schist series into

[1] Hershey, O. H., Am. Geologist, vol. 27, No. 4, pp. 225-245.




**MAP OF PORTIONS OF TRINITY AND SISKIYOU COUNTIES, CAL., SHOWING APPROXIMATELY THE CHIEF MINING LOCATIONS AND THE SURFACE GEOLOGY.**

Compiled from notes, Land Office plats, and a manuscript sketch map furnished by Mr. M. MacIlwaine, of Dorleska. The geologic data were obtained in part in the field and in part from a manuscript geologic map of Trinity County, made by Mr. O. H. Hershey, dated January 16, 1901, and kindly loaned the writer by Mr. J. S. Diller, of the Survey. (See Diller, J. S., Klamath Mountain section, California: Am. Jour. Sci., 4th ser., vol. 15, 1903, pp. 342–362.)

(*a*) the Abrams formation, a grayish muscovite schist containing irregular bands of white quartzose material and locally some thin layers of blue and white crystalline limestone, and (*b*) the Salmon formation, a hornblende schist locally showing graphitic and actinolitic layers and some highly crystallized limestone lenses. These schists are considerably sheared and contorted and seem to represent highly metamorphosed sediments which Hershey thinks may probably be of Algonkian age.

A slate-conglomerate series occurs in the southeast corner of the area. It is the Bragdon formation of Hershey and of Diller,[1] and is probably of early Carboniferous (Mississippian) age. It consists of fine-grained dark to dark-gray slates with some beds of sandstone and conglomerate. This formation extends from about Trinity River on the west to the Southern Pacific Railroad on the east. Its northern boundary is approximately an east-west line through Carrville, from which it extends southward beyond French Gulch. It contains the gold deposits of French Gulch and Deadwood and those in the vicinity of Minersville.

## IGNEOUS ROCKS.

The oldest igneous rocks are a complex of andesites and gabbros of several distinct types but all so intimately associated with one another that it was impossible to differentiate them in the short time of the writer's visit. This greenstone complex presents puzzling problems in crystallization, for within an area of a few hundred square yards may be found rocks which vary in texture and composition from very fine grained andesites to very coarse grained gabbros. These greenstones outcrop as a fringe half a mile to a few miles wide bordering the Bragdon formation. The part of this fringe between Minersville and Trinity Center lies west of Trinity River. North of Trinity Center it crosses to the east side of the river and extends north as far as the mouth of Coffee Creek. The rock is locally ore bearing.

Next younger are the intrusive acidic rocks. These occur not only in small masses and dikes but also in large masses up to several miles in diameter, cutting schists, greenstones, and locally slates. These masses consist mostly of coarse-textured light-gray granodiorite, locally called granite. Microscopically the rock is granular and contains quartz, feldspar, flakes of biotite, and large grains or rough prisms of hornblende, with local variation in the relative amounts of the last two minerals. The feldspars are plagioclase (andesine) in well-developed and roughly prismatic grains, in a cementing mass of orthoclase and quartz. The quartz content varies locally. Magnetite and apatite are present as accessory minerals, and secondary alteration has produced some sericite and epidote. These rocks contain important ore bodies.

[1] Diller, J. S., Am. Jour. Sci., 4th ser., vol. 19, 1905, pp. 379–387.

Another important intrusion of acidic rock is the granodiorite porphyry,[1] locally called "Headlight porphyry," which cuts the greenstones in large irregular dikes and branching masses. It has a marked porphyritic or "bird's eye" texture and is associated with the Headlight, Blue Jacket, Gold Dollar, Strode, and other ore deposits. No definite relation has been established between these dikes and the large granodiorite masses a few miles to the north, but they are thought to be offshoots from the same magmatic mass. Microscopically this porphyry shows an abundance of large, well-defined andesine crystals; large quartz grains, some of which are rounded, corroded, and fractured; variable amounts of prismatic hornblende; and flakes of biotite. The groundmass is microgranular to granular and consists of quartz, orthoclase, plagioclase, accessory pyrite, and magnetite, and a little secondary chlorite and needles of uralitic hornblende. Hydrothermal action has produced calcite, sericite, and a little epidote. A considerable variation in texture and composition characterize this rock. Locally hornblende prisms are conspicuous, especially near the center of the mass, but near the contacts biotite flakes are much in evidence and very little hornblende occurs. Quartz seems to be more plentiful where the hornblende is scarce. It was thought at first that there were two distinct intrusions, one rich in biotite and the other in hornblende, but subsequent work failed to establish this, so the variation is thought to be the result of magmatic differentiation.

Certain dikes and masses, intimately associated with this porphyry, are comparatively rich in quartz and nearly barren of ferromagnesian minerals. These are believed to represent aplitic dike phases, though they are in the main much larger, less rich in quartz, and less clear cut than most aplitic dikes. They are not known to have any special mineralizing significance.

The large serpentine areas of the region are thought to be altered peridotite intrusions. Near the Lily of the Valley tunnel serpentine dikes branching from the main mass cut the granodiorite, showing that they are later than the granitic rocks. The boundaries between the granodiorite and serpentine where observed are zones of shearing. The mineralizing influence of the serpentine is shown at the Copper Queen mine, where it has favored the precipitation of copper sulphides. It was intruded in latest Jurassic or earliest Cretaceous time.

Basaltic dikes are very important, especially where they cut the porphyritic rocks, for there they are generally "ore makers." They are conspicuously fine grained and dark green in color and, like the

[1] This rock is probably the same as that described as dacite porphyry by Iddings (Bull. U. S. Geol. Survey No. 150, 1898, p. 233) and Diller (Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906).

serpentine and gabbro rocks, form a red soil. Locally they contain finely divided pyrite and some secondary quartz. Under the microscope they show lime-soda feldspars, much chloritized augite, a few magnetite grains, and some uralite and zoisite. Where the dikes dip at low angles, as at the Headlight and Copper Queen properties, the upper parts have been replaced. This indicates that downward-moving solutions found them relatively impervious and characterized by chemical affinity for certain dissolved substances, causing the solutions to part with several of these substances, depositing gold; pyrite, and quartz, and taking in exchange some nonmetallic dike material. Such a phenomenon is known as replacement or substitution.

Lamprophyre dikes are numerous in the district. Those in the granodiorite have about the composition of vogesite and have in general a northeast-southwest trend. The amounts of hornblende and biotite vary so that the dikes range in composition from camptonite to kersantite. A large lamprophyre dike outcropping at the Dorleska and Yellow Rose mines has on one side about the composition of camptonite and shows aggregates of hornblende needles with some suggestion of radial grouping, hence the local name "crow's-foot porphyry;" on the other side the ferromagnesian mineral is, in the main, biotite, so that the rock is a kersantite, grading into vogesite. Microscopically many of these dike rocks show long prisms of greenish hornblende and some biotite in a fine granular mass consisting of orthoclase, plagioclase, a little quartz, some augite altered into green hornblende, accessory magnetite, and some secondary sericite and epidote. These rocks have a direct relation to at least two ore deposits, the Dorleska and the Yellow Rose.

With the intrusion of the lamprophyre dikes the igneous history of the district seems to have closed, but not the earth movements; their later activity is recorded in numerous faults and shear zones. Most of the shear zones that were observed trend about N. 30° E. Some of them are mineralized and are of considerable value to the prospector in locating ore deposits.

In summary, then, we find that the Carboniferous slates were probably deposited on an old eroded greenstone surface and that both were later cut by granitic intrusions. It is interesting to note that in the cycle of igneous activity the great masses of acidic rocks were formed after a period of far more basic greenstone eruptions had closed. These acidic granodiorites were followed by the extremely basic peridotites from which the serpentine was derived, and these again by the slightly more acidic lamprophyre dikes. The acidic intrusions are a notable factor in the geologic story of this region, and around them are grouped the phenomena of primary mineralization.

The intrusions of granodiorite probably occurred in the same general epoch as those of the Sierra Nevada—that is, in the earliest Cretaceous or latest Jurassic.

## ORE DEPOSITS.

### TYPES OF DEPOSIT.

The ore deposits of this district are characterized by variety of form. Though nearly all have the general unity of being gold lodes, yet they may be arranged into five separate groups, or types, each distinct from the others, and the members within each group having a strong resemblance to one another. These types are (1) the Headlight type, (2) the Golden Jubilee type, (3) the Dorleska and Yellow Rose type, (4) the Strode and Bonanza King type, and (5) the Blue Jay type.

The Headlight type, so called because best exemplified in the Headlight deposit, is at present most important. The country rock is the greenstone complex cut by large irregular dikes of granodiorite porphyry, basalt, and lamprophyre. The ores occur as a replacement of basaltic and other basic dikes where they cut or are closely associated with the porphyritic masses. The ore is, in the main, highly oxidized and sheared, and its value is generally not over $7 a ton except where there are small rich pockets. The mineralization locally extends a short distance into the porphyry in more or less irregular form, and where the dikes lie at a low angle the replacement seems to have been most active on their upper sides. Small amounts of pyrite and some chalcopyrite are present in the less sheared and therefore less oxidized parts, but not in sufficient quantity to interfere with cyanidation of the ores. Because of their occurrence in large, more or less sheared masses, those ores are cheaply mined and milled. The Headlight is the best example of the type, but there are other deposits which, though they may vary somewhat in form, yet have the same general class of ore and are characterized by similar geologic conditions. These are the Blue Jacket, the Gold Dollar, Carr's iron-capped dike, and some of the Ramshorn properties. A subgroup under this heading consists of the Copper Queen and True Blue deposits, which are similar to the Headlight in form and may be on a continuation of the Headlight lode. They differ from that deposit, however, in that they are not closely associated with "bird's eye" porphyry and in that the Copper Queen lode is partly in a large serpentine mass which seems to have favored the deposition of copper minerals. The irregular form of this type of deposit and the soil mantle which commonly obscures the outcrops render it difficult for the prospector to get a correct idea of the probable limits of his lode; hence development work is often improperly planned.

The Golden Jubilee type of deposit is very important and distinctive. It consists of fissure veins and narrow well-defined shear zones in granodiorite, close to the northwestern edge of a very large granitic intrusion. These veins nearly all trend N. 30° E. and are paralleled by many and cut by a few small lamprophyre dikes. It is not uncommon for one of the vein walls to be formed by a small lamprophyre dike, and it is said that in the vicinity of such contacts values are higher than elsewhere. The lodes of this type vary in width from a few inches to a few feet and contain some locally enlarged ore shoots, especially at fissure intersections. It is noteworthy that the granodiorite near these deposits is in contact with a large mass of younger serpentine, that this contact is at right angles to the trend of the veins, and that as distance from the contact increases the veins are on the whole, larger and the values less. Near the contact they are smaller, more numerous, richer, and more pockety. Oxidation is confined to a comparatively shallow zone, except where it has followed postmineral shear planes to maximum depths of about 200 feet. The gold is associated with iron oxide and pyrite, and tellurides are not uncommon. The ore varies in richness and high-grade pockets are found, especially in the shear-zone type of these deposits. Calcite was observed with the quartz and crushed country rock, and the sulphides and tellurides present render the ore less amenable to treatment than the more oxidized Headlight material. Crushing and amalgamation to recover coarse gold, with concentration and cyanidation of tailings and slimes, has so far proved the most satisfactory treatment. The concentrates are hauled by wagon to the railroad and sent to the smelter. They are, in the main, high enough in grade to pay a good profit in spite of the cost of mining and marketing, which averages over $40 a ton. These deposits, which are best exemplified by the Golden Jubilee mine and the group of properties near it, present simpler problems for the prospector than those of the more complex Headlight type.

The Dorleska and Yellow Rose type of lode, best illustrated by the Dorleska and Yellow Rose mines, includes also the Thomas Keating and other smaller properties. It comprises mineralized shear zones in and along the contacts of large lamprophyre dikes, where these dikes cut serpentinized basic rocks. These lodes are partly direct deposits in shear planes and partly a widening out of such planes by replacement processes, especially where side fissures come in. They are more or less pockety and contain some shoots of very rich ore. Tellurides are reported and in the main the ores are similar to and require about the same treatment as those of the Golden Jubilee group, but a larger percentage of the gold content could probably be recovered by crushing and amalgamation.

The Strode and Bonanza King type is best exemplified by the deposits at these two mines. They are essentially sheared fissures veins which cut the greenstone complex, have locally enlarged ore shoots, and may have small parallel and branching stringers. Lamprophyre dikes occur in their vicinity, and at the Strode property, at least, a large mass of granodiorite porphyry outcrops near by. The values in the ore shoots are, in the main, fairly high and are recovered by crushing and amalgamation at both properties, supplemented by cyanidation of tailings and slimes at the Bonanza King. These deposits are fairly clear cut and comparatively easily followed by the prospector.

The fifth type of lode, the Blue Jay, is best represented by the Blue Jay property, which is especially famous for its rich pockets. It is characterized by the irregular shearing and fissuring of a large mineralized dike or elongated mass of fine-grained dark-greenish metabasalt and of small associated masses of granodiorite porphyry, all of which cut a country rock of greenstone and serpentine. Time to make a study of mineralizing conditions was not available, but primary mineralization seems to have left finely divided pyrite in the dike mass, and some rich pockets have accumulated where shear zones and fissures cut the mineralized areas of the dike. The great bulk of the dike mass outside of these narrow fissures is of too low grade to mill.

## HYDROTHERMAL ACTION.

Hydrothermal alteration is not especially marked in this district. In the country rock near the veins, however, as well as in the veins, small amounts of secondary quartz and calcite have been deposited and the feldspars have undergone some sericitization. In the more sheared lodes alteration seems to have gone beyond the sericitization stage and formed considerable kaolin. The ferromagnesian minerals have been considerably altered near the deposits, especially in the basaltic dikes, where so much chlorite has been developed as to give the rocks a greenish color. In some of the rocks chlorite and quartz occupy the place of disintegrated feldspar crystals; there is some uralite, mostly after pyroxene, and small amounts of epidote and zoisite. A thin section of replaced dike material from the Headlight mine showed extreme alteration. This material consisted in the main of aggregates of crushed quartz and grains, veinlets, and streaks of pyrite. Sericite was extensively developed and probably some kaolin occurs, but practically no calcite, although secondary calcite was seen in the porphyry near the lode. The original character of the rock was almost completely masked and most of the larger grains of quartz were crushed and deformed. A thin section of wall rock from an ore shoot in the Strode mine showed a crushed and roughly schistose structure. It was semiopaque from the kaolin present and showed lenses of crushed quartzitic fragments, veinlets of calcite, and small scattered cubes of pyrite.

The large areas of serpentine are alteration products from basic igneous rocks, and the so-called "iron caps" and "iron dikes" are the result of oxidation or "rusting" by surface waters carrying atmospheric oxygen downward along cracks and fissures. Similar oxidizing processes work on the dark iron silicates and where these are plentiful, as in the darker rocks, weathering into red soil results. Dark-brown powder or almost black stains in the oxidized ore indicate the presence of manganese oxide, which is usually a favorable indication of values.

## SUMMARY OF THE CHIEF MINERALS OF THE DISTRICT.

*Gold.*—Gold occurs in quartz, in pyrite, in the oxidized products of pyrite, in mineralized pockets of country rock as irregular grains and threads, and in the form of tellurides. A considerable proportion of the free gold is coarse enough to see and amalgamates readily, but much of it is so fine as to be invisible and can be recovered only by cyanidation.

*Silver.*—Silver occurs in very small amount, probably in alloy with gold.

*Pyrite.*—Pyrite is present in small primary crystals disseminated through dike material and country rock, in primary form in most of the unoxidized ores, and in local masses and kernels in partly oxidized ore, where it suggests secondary enrichment.

*Chalcopyrite.*—Chalcopyrite is the primary ore of the Copper Queen and is present in small quantity, where not reached by oxidation, in the Headlight and other mines.

*Chalcocite.*—Chalcocite, the dark sulphide of copper which has locally enriched the upper part of the Copper Queen lode, is a secondary mineral derived from chalcopyrite.

*Copper carbonate.*—The bright-green mineral, copper carbonate, is sparingly present in the weathered portion of the Copper Queen.

*Limonite.*—The iron oxide or iron rust which stains much of the ore near the surface and near crushed zones is limonite. Large cubes of it, after pyrite, occur in the Golden Jubilee and contain high gold values. Locally it cements together brecciated fragments of rock.

*Manganese oxide.*—The dark-brown powder or stain commonly associated with iron oxide and in places with rich pockets of ore is manganese oxide.

*Quartz.*—Quartz is present in original grains and crystals in the porphyry, the granodiorite, and most of the lamprophyre dikes, as a replacement product in some of the dikes and as vein-filling material.

*Feldspar.*—Andesine occurs in phenocrysts in the porphyry and in fairly well defined crystals in most of the other igneous rocks. Orthoclase occurs in the groundmass of the porphyry and among the smaller generation of crystals in the granodiorite and some of the lamprophyres. No clear case of secondary feldspar was noted.

*Chlorite.*—Chlorite is abundant in all the basaltic dikes and tinges them green. It is present to some extent in most of the igneous rocks near lodes and is a secondary mineral.

*Magnetite.*—Magnetite occurs in minute grains in many of the igneous rocks; also in small secondary grains derived from the alteration of ferromagnesian minerals.

*Calcite.*—Veinlets and small irregular masses of calcite occur in many of the ore deposits, and calcite is disseminated in small amounts through some of the country rock near them.

*Sericite.*—Minute foils and shreds of sericite replace feldspar and invade quartz grains in or near the ore bodies.

*Kaolin.*—In small local areas of ore and country rock the feldspars have been reduced to white powdery kaolin.

*Uralite.*—Uralitic pyroxene and hornblende were found in small amounts.

*Epidote and zoisite.*—Locally some epidote and zoisite were observed, especially in some of the basic rocks near the ore deposits.

## NOTES ON PROSPECTING.

With the decline of placer mining the early prospector turned from gravel bars and benches to find the source of the gold among the mountains. He believed that the gold came from fissure veins and that all deposits worth while were of the fissure-vein type. His development work was therefore planned in terms of hanging wall and footwall, and where these did not occur he selected the nearest fissure or joint plane and called it a wall bounding his deposit. Thoughts of limiting depths to his valuable ore rarely darkened the fair horizon of his dreams. That these "fissure vein" ideas filtered down even to some of the present generation of mining men is shown by at least one case in this district. A few years ago a company got an option on a property which showed a good outcrop and spent many thousands of dollars driving tunnels to tap the deposit at depth. The "fissure vein" in this instance happened to be a large, almost flat contact deposit, and the expensive tunnels were in the country rock well below it. The property was "turned down," of course, and the district pronounced poor, but to-day that property is paying a rich reward to more discriminating and more scientific miners.

The outcrops of the district are in part prominent and in part inconspicuous. The prominent croppings are "iron-capped" dikes and lodes rendered more resistant than the surrounding rock by the quartz which they contain. The lodes of the Headlight type and other lodes filled with hard quartz are characteristic and are usually of rather low grade at the surface. On the other hand, the outcrops of the lodes that have undergone shearing since deposition are inconspicuous and can be recognized at the surface only by careful search. Ordinarily such lodes may be traced on the surface by panning. In hunting for these veins little gulches and gullies should be panned and any values obtained should be traced up to their source. Mineralized quartz float is also most likely to appear in streams below a lode and may be found in the wash up to the point where the stream crosses the vein. In answer to the question, Where is the most likely place to prospect? the following may be said: The contacts of all "bird's eye" porphyry outcrops should be searched by the prospector, especially where this porphyry is cut by dikes of dark-green fine-grained rocks. The outer zone of all granite areas should be examined, and all large dikes of the Dorleska type are worthy of close search. The region between the Headlight and the Copper Queen properties should be carefully prospected for a continuation of the Headlight mineralized dike. Mineralization similar to that at the Headlight continues to the southwest of that mine. When a location is made the prospector should find out what type of deposit he has, in order to plan development work to the best advantage. Of course he can not figure on ore values until ore has actually been developed on three sides and carefully averaged samples across his ore body at 5 or 10 foot intervals have been taken. From the average assay value of these samples, occasional assays which run far above the general average having been rejected, he can estimate the gross value of his ore block. Before the net value of his "ore in sight" can be estimated, the prospector needs to know what process will give best and most economical extraction. This knowledge should be obtained by sending samples of both oxidized and sulphide ores to reliable ore-testing plants and having reports made on them. Oxidized ores such as those of the Headlight and ores that are nearly free of copper and contain little pyrite will ordinarily be found suitable for cyanidation. The telluride and sulphide ores, such as most of those in the granodiorite area, will probably be best treated by crushing and amalgamation to recover the coarse gold, concentration, and then cyanidation of tailings and slimes. It is of the highest importance, however, that every ore be tested before any plan of treatment is adopted. Where pyrite and chalcopyrite are present in large amount, pyritic smelting might be adopted, as such an operation requires but a small percentage of coke, the heat being furnished largely by oxidation of the sulphides. If the process to be used will extract 85 per cent of the gold, then the remaining 15 per cent which can not be recovered must be deducted from the gross value of the ore in sight. Other charges to be deducted are costs of mining and milling, costs of marketing bullion and concentrates, 10 to 12 per cent of the value of the plant for yearly depreciation, interest on capital tied up in the venture, etc. These items pertain to the business end of developing a property but constitute a phase of mining which the up-to-date prospector should know and which is clearly explained in detail by several comparatively new and valuable technical books on mining advertised in the leading mining journals.

## PAST OUTPUT AND FUTURE PROSPECTS.

It is very difficult to get at the total output of the quartz mines of the district. From opinions obtained from different persons, each knowing something of some of the properties, it is estimated that the production has been close to a million dollars. The production of the county since 1890 is given below:

*Production of gold and silver in Trinity County, Cal., 1890 to 1904.*

[From reports of the Director of the Mint.]

| Year. | Gold and silver. | | Total silver. | Total gold. | Total gold and silver. |
|---|---|---|---|---|---|
| | Placers. | Lode mines. | | | |
| 1890 | | | $258 | $1,192,789 | $1,193,047 |
| 1891 | | | 2,248 | 1,327,786 | 1,330,034 |
| 1892 | | | 168 | 1,446,603 | 1,446,771 |
| 1893 | | | | 1,122,994 | 1,122,994 |
| 1894 | | | 1,072 | 1,012,665 | 1,013,737 |
| 1895 | | | 257 | 1,166,745 | 1,167,002 |
| 1896 | | | | 1,296,330 | 1,296,330 |
| 1897 | $722,858 | $355,773 | 259 | 1,078,372 | 1,078,631 |
| 1898 | 578,514 | 281,055 | 314 | 859,255 | 859,569 |
| 1899 | 371,943 | 219,653 | 1,086 | 590,510 | 591,596 |
| 1900 | 324,233 | 263,939 | 16,567 | 571,605 | 588,172 |
| 1901 | 327,114 | 360,237 | 2,668 | 684,683 | 687,351 |
| 1902 | 389,757 | 330,785 | 550 | 719,992 | 720,542 |
| 1903 | 333,471 | 275,342 | 2,085 | 606,728 | 608,813 |
| 1904 | 364,068 | 210,881 | 135 | 574,814 | 574,949 |
| | 3,411,958 | 2,297,665 | 27,667 | 4,251,871 | 4,279,538 |

*Production of gold and silver in Trinity County, Cal., from 1905 to 1910.*

[From Mineral Resources of the United States.]

| Year. | Gold (value). | | | Silver (fine ounces). | | |
|---|---|---|---|---|---|---|
| | Lode mines. | Placer. | Total. | Lode mines. | Placer. | Total. |
| 1905 | $351,826 | $424,209 | $776,035 | 3,759 | 2,218 | 5,977 |
| 1906 | 147,164 | 413,679 | 560,843 | 1,881 | 2,584 | 4,465 |
| 1907 | 180,120 | 355,196 | 535,316 | 1,271 | 2,364 | 3,635 |
| 1908 | 185,634 | 417,310 | 602,944 | 4,057 | 3,998 | 8,055 |
| 1909 | 151,782 | 368,264 | 520,046 | 2,144 | 2,283 | 4,427 |
| 1910 | 126,768 | 374,083 | 500,851 | 2,037 | 1,592 | 3,629 |
| | 1,143,294 | 2,352,741 | 3,496,035 | 15,149 | 15,039 | 30,188 |

The future prospects of the district are believed to be very good and it is thought that before long several small to moderate-sized gold properties will be put on a paying basis. Of course a branch railroad connecting with the Southern Pacific Railroad would greatly benefit the district. Such a railroad would derive income not only from the quartz and placer mining interests but from the rich agricultural lands in the valley bottoms and from the lumber business. It is true that much of the timber is within the Trinity National Forest, but the ripe product is sold off at intervals and this together with the timber from private holdings makes the lumbering industry important.

## DESCRIPTION OF MINES.

### HEADLIGHT TYPE.

#### HEADLIGHT MINE.

*Situation and geologic relations.*—The Headlight is the youngest producer and at present the most important mine in the district. It is 3 miles north of Trinity Center and 1½ miles southeast of Carrville, the nearest post office. The present workings are in the NW. ¼ sec. 21, T. 37 N., R. 7 W., on the eastern slope of the Trinity Valley 600 feet above Trinity River. The property is owned by the Trinity Gold Mining & Reduction Co.

The geology of the mine is complicated, but figures 1, 2, and 3 show the general geologic relations. Soil covering and hydrothermal action have obscured the details, hence some modifications of the views here expressed may be necessary as development work affords new data. The rocks in the sequence of their age are andesitic greenstones, slates, granodiorite porphyry or "bird's eye" porphyry, fine-grained greenish basaltic dikes, and lamprophyre dikes of about the composition of vogesite. These rocks have already been described, but it may be noted here that the porphyry intrusion cuts andesitic greenstones, is several hundred yards in diameter, has obscure boundaries, shows a hornblendic and a biotitic facies, and is cut by lamprophyre dikes and by ore-bearing greenish metabasaltic dikes.

*Ore deposit.*—The Headlight has a conspicuous "iron-capped" outcrop. In form the lode is a large, comparatively flat-lying body, 40 feet thick and having a surface exposure of 2.1 acres. (See fig. 1.) The ores are of low grade, averaging about $6 a ton, and the values are fairly evenly distributed. Faulting has largely broken up the mass, making it more irregular and giving ready access to oxidizing surface waters. This ore body might be put in the category of contact deposits, for it occurs where a basaltic dike cuts porphyry; it is of the replacement type, because it largely replaces the basaltic dike and the adjacent porphyry. It is thought that no mineralization exists where the dike passes into the slates, although there is no definite evidence of this. Also it is not known whether the dike at the left-hand end of figure 2 is a faulted-down portion of the dike in which the main body of ore occurs, or another similar intrusion. The evidence of slip faulting, as shown in figure 2, as well as the iron-stained mineralized character of the dike, points toward the former of these alternatives. Near the dry gulch southwest of the mine iron oxide and considerable secondary quartz mark the outcrop of this dike, at intervals, for several hundred feet. This corner of the property looks favorable for new ore bodies, and it is likely that the company will shortly begin systematic prospecting here. Extension of the lode toward the northwest may also be revealed by further development.

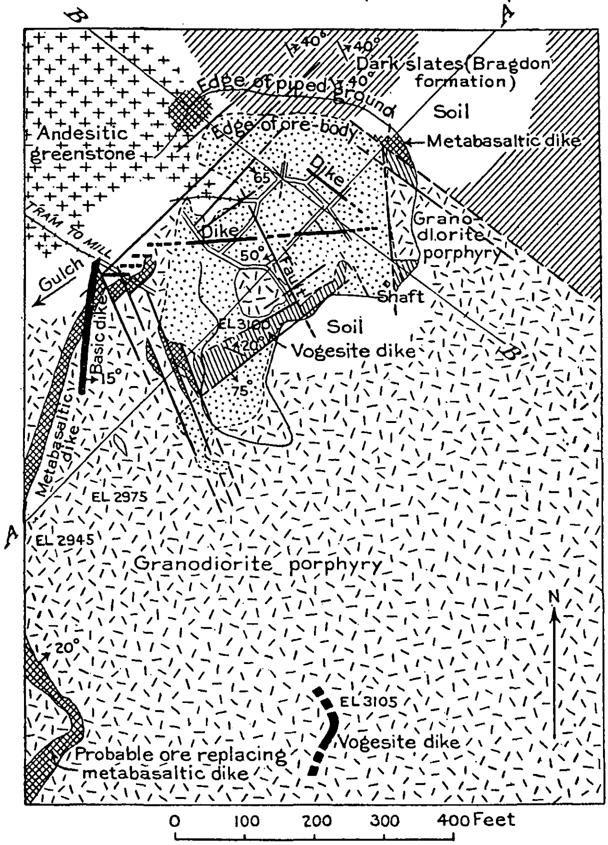



FIGURE 1.—Sketch map showing geologic relations of Headlight ore body, Trinity County, Cal. *A–A′*, *B–B′*, lines of sections, figures 2 and 3.

The ore contains free gold with a little silver and is in the main oxidized and much iron stained, except where a few kernels and small areas of pyrite with some chalcopyrite have not yet been altered. The gold is finely divided and is easily recovered by cyanidation. The gangue materials are quartz, partly replaced country rock, iron oxide in considerable quantity, and small amounts of calcite and manganese oxide.

The genetic history of this deposit is not clear in all its stages, but the following is a summary of the chief facts pertaining to it: (*a*) It occurs as a replacement deposit in a basaltic dike where this dike cuts a larger dike of granodiorite porphyry, in a country rock of andesitic greenstones, which is in contact with slate. The whole complex is cut by lamprophyre dikes. (*b*) Remnants of the bottom part of the ore dike remain unmineralized and these have undergone some shearing parallel to the dike. This is evidence that descending solutions effected at least the final mineralization. (*c*) The ore dike is best mineralized near its contact with the vogesite dikes, although the latter are not mineralized except along local shear zones. It is believed that the vogesite dikes played little part in the mineralization except that, being more impervious than the rocks which they cut, they somewhat obstructed and deflected the mineralizing solutions. Though no conclusive evidence on the matter was found, it is thought that the basaltic dikes were planes of weakness which yielded to shearing and thus afforded easy access to the acidic mineralizing solutions from the granite porphyry.

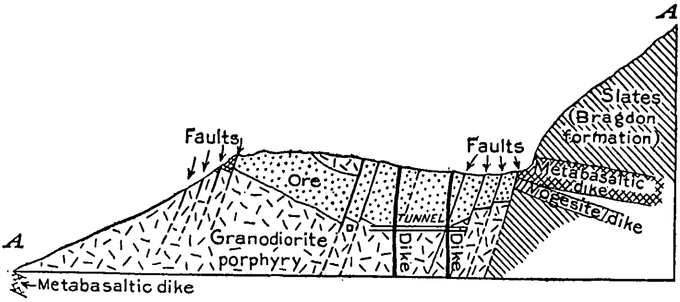



FIGURE 2.—Northeast-southwest section through Headlight ore body, along line *A–A′*, figure 1.

*Mining.*—The conditions as regards timber, water power, and topography are exceptionally favorable near the mine. The extent of the work, both in underground development and in the area of overburden removed, is shown in figure 1. Since the time of visit, however, much more has been accomplished. The work is carried on from two levels, the upper, more extensive one immediately beneath the main body of the ore, and the other 50 feet lower, beneath a faulted-down corner of the ore mass.

The methods of mining and development work are worth careful study. It is noteworthy that instead of trying to find the limits of the outcrop by shaft sinking and open trenching, Mr. Goodale used a small giant with a 2½-inch nozzle, under a head pressure of about 350 feet, to remove the overburden and lay bare the ore body.[1] This method was aided by blasting simultaneously sets of eight to ten 6-foot holes, placed 7 feet apart. It was very successful and removed overburden at a cost of less than 2 cents a cubic yard. The broad, flat form of the lode made the work of maximum importance.

[1] Hughes, A. F., Stripping a vein by hydraulicking: Min. and Sci. Press, Dec. 11, 1909, p. 788.

This deposit is worked by a system of tunnels immediately below the ore body, from which upraises extend through the ore to the surface. Beginning at the top these upraises are enlarged and caved into the shaft to form a system of "glory holes." The sheared and oxidized condition of the ore causes a minimum expense for drilling, caving, and milling. From the upper level the ore is trammed to a chute and ore bin leading to the lower level, and thence it drops into 6-ton cars which bring it to the ore bins at the mill a few hundred yards distant.

*Milling.*—The ore is treated in a new 10-stamp mill which crushes it in a cyanide solution, and in a cyanide plant with a capacity of 200 tons of sands and slimes each day.

*Power.*—The company owns its own hydro-electric plant, which is located in the Trinity Valley nearly 2 miles north of the mine. A 3 by 4 foot flume 9,000 feet long brings a maximum flow of 3,000 cubic feet a minute from Coffee Creek and delivers it under a head pressure of 107 feet. The plant is designed to generate a maximum of 470 horsepower, which is amply sufficient for power and lighting at the mine, mill, and sawmill.

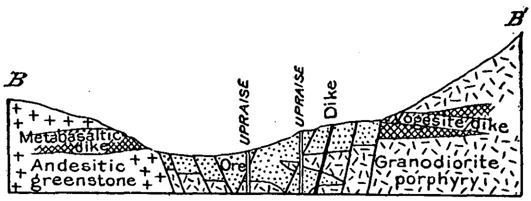



FIGURE 3.—Northwest-southeast section through Headlight ore body, along line *B-B'*, figure 1.

*Costs.*—The costs established at this mine are important as a basis of comparison for other properties. Conditions are more favorable than at other mines of the district, still the practice successfully established here will be of great benefit to mining men wishing to estimate the cost of developing other properties. Wagon haulage from Delta, 32 miles, costs 1 cent to $1\frac{1}{4}$ cents a pound; from Redding, 56 miles, $1\frac{1}{4}$ to $1\frac{1}{2}$ cents a pound. The estimated cost of mining by the glory-hole method is 40 cents a ton; of tramming, 10 cents a ton. The cost of milling the present daily average of 225 tons is, for labor, $33; chemist, $4; cyanide, $103.50; lime, $23; power, $9; zinc, $10.75; filtering, $4; miscellaneous, $10; depreciation of milling plant at 10 per cent a year, $34.50; total, $231.75, or $1.03 a ton. The actual milling costs since the mill was opened have been found to range between 85 cents and $1.05 a ton, depending on local variations in the consumption of cyanide. Electric power, which when purchased usually costs $6 a horsepower a month, costs here only $1, the hydro-electric power plant being installed by the company. The high freight rates, however, $20 a ton on cyanide, lime, and mill supplies, go far to offset the low cost of power. The cost of cyanide here is 23 cents a pound and the average consumption is 2 pounds to the ton of ore. The total cost, then, for mining, tramming, and milling this ore is about $1.53 a ton. In figuring the net value of the ore in sight, a 90 per cent extraction was allowed, though in practice it is lower than this; also, 10 per cent off per year was allowed for depreciation of plant and 10 per cent interest on the capital locked up in the development of the property. Other general items of cost are 9,000 feet of 3 by 4 foot flume; lumber, $4,834.50; cost of building, $3,933.50; cost of grading, trestles, and foundations, $3,601; water wheels, generators, and power house, complete, $12,000; power line, 9,000 feet long, $1,292; head gate, concrete, penstock, turnouts, etc., $1,500; substation transformers and equipment, $2,827.50; total cost of hydro-electric power plant, about $30,000; total cost of mill and power plant, $156,000.

*History.*—The property was first opened by Frank Fletcher and his associates in 1900. They erected a cyanide plant for wet crushing and direct treatment, but over 50 per cent of slimes were produced in their mill and, as no provision had been made for treating these, the venture was not successful. The slimes are said to have contained $7 to $11 a ton; the sands averaged $4.80, making an average of $6 a ton for the ore. Later the plant burned and the owners let the property stand idle. In 1907 a Philadelphia company spent considerable money in development, but the work did not reveal the extent and value of the ore body. During the money crisis of the fall of 1907 the property reverted to the owners. The present company took hold about the beginning of 1909 and has turned this low-grade property into a prosperous mine.

*Production and future prospects.*—The old mill is thought to have turned out about $5,000 before it was destroyed, and the new mill was only starting at the time of visit. The ore now in sight is said to be sufficient to keep the plant running for several years.

### BLUE JACKET PROPERTY.

*Introduction and geology.*—The Blue Jacket property, owned by the Adams Exploration Co., is about one-fourth of a mile northwest of Carrville and consists of four claims and a mill site. Figure 4 shows something of the complicated geologic conditions. The mapping of the boundaries, except those in the underground workings, is not necessarily exact, because the outcrops are much obscured by soil, weathering, and hydrothermal action. The rocks in the order of their age are andesitic greenstones, granodiorite porphyry or "bird's eye" porphyry, aplite, serpentine, and a few small green metabasaltic lamprophyre dikes. These rocks have already been described, but it may be added that the aplitic material here is cream colored, is hydrothermally altered, and contains quartz, probably largely secondary, in small irregular aggregates, little veinlets, and larger veins. Green basaltic dikes and lamprophyre dikes are numerous and vary from less than an inch to a few feet in width.

*Ore deposits.*—The mineralization is associated with the sheared and hydrothermally altered parts of the diorite porphyry and aplitic rock. It is said that the contacts of the basaltic dikes and some of the lamprophyre dikes with these rocks, especially where these contacts are sheared, carry high values. A 2½-foot quartz vein cuts the porphyry and aplite (see fig. 4), trends northeast approximately parallel with the dike system in tunnel *a*, and dips steeply northwest. The vein contains ore of very low grade, but it is said that gold occurs in the gouge locally formed along its sides. So far no well-defined ore body has been developed, but the mineralization of the porphyritic and aplitic rocks has geologic significance as well as prospecting value.

At the time of visit exploration work was going on and pannings from the little shear zones and gouge streaks in the "rotten porphyry" showed colors. The important question, however, is how large a mass of this fractured and hydrothermally altered porphyry will be rich enough to pay to mine. The deposit is not of a vein type but seems to consist in an impregnation of the hydrothermally altered porphyry and aplitic rocks near the serpentine contact, where they were opened by fissuring and jointing and cut by little dikes. The nonexistence of any definite lode does not argue against the property; on the contrary, if any considerable mass of the mineralized porphyry averages over $5 a ton the success of the mine is assured. The gold is all free, with considerable iron oxide stain. A little pyrite still remains in the less crushed places, though oxidation to the lowest workings, 150 feet below the surface, is pretty complete.

*Mining and milling.*—The conditions of timber and water power are favorable. The topography is such that backs of 165 feet may be obtained from the main tunnel, which is about 150 feet above the Trinity River valley. The surface equipment consists of a rock breaker and a 3½-foot Huntington mill driven by a 16-horsepower engine. This mill was being put in at the time of visit and was expected to have a capacity of 10 tons per 24 hours. There is more than 1,000 feet of underground workings on the property, about half of which was put in by the present company, and further development was in progress at the time of visit. Cheap methods of mining could be used here, because if any large body of porphyry is found to be sufficiently mineralized it can be mined by the "glory hole" method at a cost of probably less than 50 cents a ton.

*History and future prospects.*—Gold was first discovered on the Blue Jacket ground in 1897 by G. L. Carr. He confined his attention, however, to exploring the quartz vein through tunnel *b* and in some open cuts but found it too low in grade to pay. The present company got

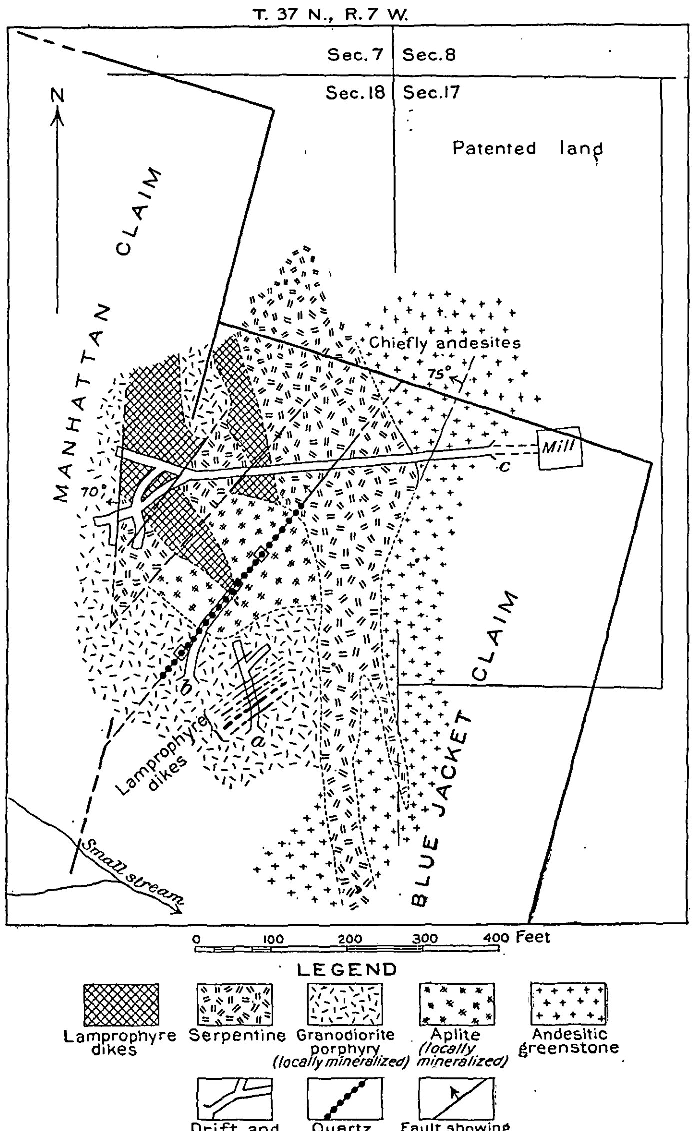



FIGURE 4.—Sketch map showing geologic relations at the Blue Jacket property, Trinity County, Cal., *a*, *b*, *c*, Tunnels.

control in 1909. The future depends on whether a large enough mass of the altered porphyry and aplite will be found to contain gold to the extent of over $5 a ton.

### GOLD DOLLAR GROUP.

The Gold Dollar group of claims, the property of Miss Pansey Safford, of Carrville, is located about three-fourths of a mile north of Carrville, half a mile west of the main road, and about 400 feet above the Coffee Creek valley. A small mass of granodiorite porphyry cuts serpentinized basic rocks and is cut by an aplitic dike 25 feet thick. (See fig. 5.) The porphyry and aplite have been highly altered by hydrothermal action, but surface material considerably obscures the outcrops, so that the contacts as shown in figure 6 are exact only where exposed in the workings. The vein is a quartz filled, subsequently sheared fissure vein 2½ feet wide, which trends N. 70° W., and is nearly vertical. It cuts both the basic and the acidic rocks and is close to the contact of the two, though it is not yet known whether the mineralization is equal in the two varieties. The ore contains free gold associated with a little pyrite and iron oxide. It would probably be amenable to cheap treatment, but more development work is needed to reveal its extent.

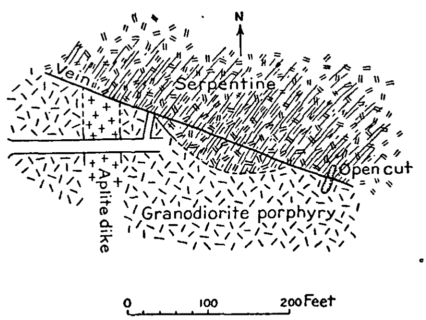



FIGURE 5.—Sketch plan showing geologic conditions at Gold Dollar claims, north of Carrville, Cal.

### CARR'S IRON-CAPPED DIKE.

A large mineralized dike a few hundred yards west of and 300 feet higher than Carr's Hotel, Carrville, is owned by the Carr estate. It is fine-grained greenish metabasaltic rock which cuts serpentinized rocks and has some more or less obscure outcrops of granodiorite porphyry associated with it, especially along the footwall. It trends N. 30° E., dips 45° or more westward, and is traceable on the surface for more than a mile. The dike has been locally replaced by quartz and iron pyrite. Postmineral shear planes, many of which trend N. 40° W. and dip steeply westward, have given access to oxidizing solutions that have stained the mass with iron oxide.

The very large size of this dike and the fact that it nearly everywhere contains a little gold have given it considerable local importance. If its length, say 5,000 feet, is multiplied by its average width, almost 60 feet, and by the depth exposed where it is cut by the creek below Carr's, 100 feet, we get the enormous mass of 2,500,000 tons. Even 25 cents a ton profit on this quantity would render it a very valuable property. It is well situated topographically for mining, because it parallels the Trinity Valley at an elevation of several hundred feet above the river and could be worked by tunnels and "glory holes" at comparatively low cost. Probably much of the ore could be cheaply treated by cyanidation, though some of it might require concentration. It is thought that any returns over $3 a ton which it might yield would be profit. However, so far no ore which would average near this sum has been found. It is believed that a search should be made for ore bodies where "bird's-eye" porphyry masses are in contact with or are close to this dike, and that shear zones in the dike itself should be carefully prospected.

### RAMSHORN DISTRICT.

The setting in of winter weather prevented a visit to the Ramshorn district, but the following general information regarding it was kindly given by Col. V. B. Allen. The Ramshorn basin is 9 miles northeast of Carrville, on the headwaters of Ramshorn Creek. The chief claims are located in secs. 14, 15, 22, and 23, T. 38 N., R. 7 W., at elevations ranging from 3,200 to 7,000 feet. The country rock is mostly andesite and gabbro, cut by serpentine belts and by granodiorite porphyry similar to that at the Headlight. The Golconda vein lies between serpentine and porphyry, trends northwest and southeast, and dips 70° SW. It maintains a thickness of 5 feet and an average value in gold and copper and iron sulphides of $9 a ton. It is said that the district gives considerable promise.

### COPPER QUEEN PROPERTY.

The Copper Queen property is on the head of Copper Creek, some 3 miles east of Carrville, and 2 miles northeast of the Headlight mine. The country rock is andesitic greenstone, in contact with serpentine, both cut by an almost horizontal metabasaltic dike, and the whole intruded by lamprophyre dikes which trend N. 70° W. and dip 80° W. (See fig. 6.) Figure 7 shows a cross section of the ore body as it appears from the rather meager data which the obscured outcrops reveal.

The ore body replaces the upper part of the green fine-grained metabasaltic dike and the country rock just above it. Where this dike cuts serpentine the ore is rich in copper and carries some gold; where it is in contact with andesite the copper veins are small. It is not known whether the gold values are the same in these two formations or whether they vary with the copper content. The primary minerals are chalcopyrite and pyrite; the secondary minerals dark chalcocite and some green carbonate; and the gangue materials quartz, some calcite, and chloritized, highly altered basaltic dike rock. The rich chalcocite of the upper part of this deposit bears witness to the secondary enrichment processes that have been active here. The richest ore seems to be on the western or hanging wall of the small lamprophyre dikes where they cut the ore body. This local enrichment seems to be due to the formation of flat V-shaped, relatively impervious troughs which have impeded the descent of the mineralizing solutions and thus induced deposition.

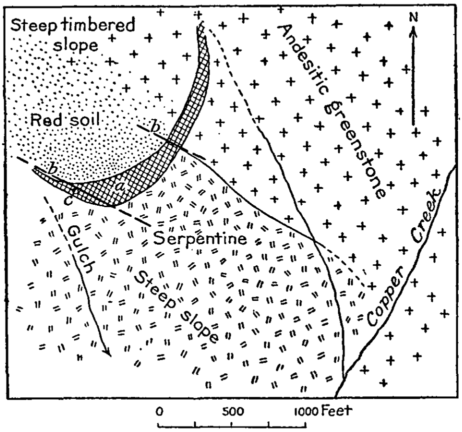



FIGURE 6.—Sketch plan of Copper Queen lode, 3 miles east of Carrville, Cal. *a*, Metabasaltic dike largely replaced by ore, lying nearly flat and outcropping on slope; *b*, lamprophyre dikes; *c*, small shaft.

The development work which has been done is not sufficient to demonstrate the extent of the ore, so that no definite value can be placed on the property at present. The deposit may be irregular in form and somewhat difficult to follow. Conditions are very favorable for mining; timber and water power are at hand, and the slope insures drainage, dumpage, and backs. The ore would have to be concentrated and the concentrates shipped or smelted on the spot. Mining, concentrating, shipping, smelting, and other charges would probably amount to about $40 a ton, so that the concentrated product shipped would have to be worth considerably more than this to pay expenses. The future of this property depends on whether or not the high-grade ore which now locally appears at the surface will be found to be sufficiently extensive when the lode is opened.

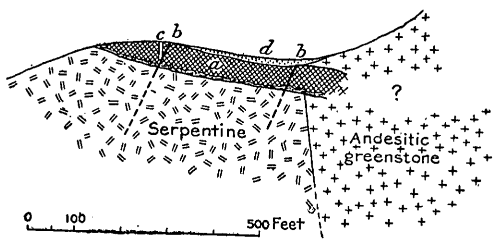



FIGURE 7.—Approximate north-south cross section of Copper Queen lode. *a*, Metabasaltic dike largely replaced by ore, fragments of dike material being left along bottom part; *b*, lamprophyre dikes; *c*, small shaft in chalcocite and chalcopyrite ore; *d*, red soil covering.

## TRUE BLUE PROPERTY.

The True Blue prospect, a few hundred yards northwest of the Headlight mine, is owned by George Le Blanc. The country rock is andesitic greenstone, of which the outcrops are somewhat obscured by soil mantle. The ore body is a low-grade, almost flat-lying quartzose iron-stained mass, bearing some likeness to the Headlight ore deposit. It is possible that this True Blue is a continuation of the Headlight deposit, but no granodiorite porphyry was found associated with it. The outcrops and red surface soils are said to give encouraging results, but the prospecting work, so far, has not properly tested the ground. The tunnel, several hundred feet of which is completed, seems to be below the ore body and of little value in the way of development. Systematic surface trenching and sampling, or surface sluicing, would do much more to test this ground than all the underground work that has been done.

### GOLDEN JUBILEE MINE.

The Golden Jubilee mine, the property of the Golden Jubilee Mining & Milling Co., is situated 5 miles northwest of Carrville, near the junction of Coffee and Boulder creeks, and embraces nine claims, which stretch over nearly a mile of vein. The country rock is granodiorite, cut by some lamprophyre dikes of about the composition of vogesite. The outcrops are not prominent, largely on account of the postmineral shearing, which has somewhat broken the vein material. The vein is a fissure filling with ore shoots, separated by narrow pinches. These shoots or lenses vary from 3 to 16 feet in maximum thickness and extend 30 to 150 feet in horizontal direction, with an average of about 25 feet from the end of one to the beginning of the next.

The veins trend N. 30° E., dip 75° E., and consist of quartz, crushed country rock, and some calcite and iron oxide. The values are free gold, associated with iron oxide and pyrite, and gold tellurides. Some crystals of galena were observed, and very large cubes of iron oxide, after pyrite, said to assay as high as $3 a pound, occur in the upper workings. Pyrite corresponding to these cubes has not been found in the mine. Oxidation has followed some of the postmineral fissures to extreme depths of 250 feet, but the average depth is much less than this. The vein is larger and the ore said to be richer in the vicinity of a lamprophyre dike, which is exposed in tunnel No. 4 and has been jogged some 30 feet by vein faulting. Mining conditions are favorable, and the topography is such that the lower workings can be made to develop nearly a thousand feet of backs. A wagon road extends to the mine. Several thousand feet of tunnels and several hundred feet of upraises and stopes have been made. It is said that there are over 2,000 tons of ore blocked out which will average $7 a ton in gold and that there are other ore shoots which will assay over $30 a ton. Because of the sulphides and tellurides which they contain these ores do not give up their gold as readily as those of the Headlight group. In practice fairly good results have been obtained by crushing and amalgamation to remove coarse gold, concentration to remove sulphides, and cyanidation of slimes and tailings. The concentrates are said to average about $120 a ton, and are therefore rich enough to ship in spite of the high cost of haulage and other charges.

The mill equipment consists of an older part, two Huntingtons and a cyanide plant, and a newer part, a 10-stamp 30-ton cyanide mill.

The mine has been worked at intervals for 15 years. At first it was merely a shipper of rich ore, then the two Huntingtons and small cyanide plant were installed, and as this equipment became inadequate the new 10-stamp mill and cyanide plant were added. Litigation is said to have resulted in the closing of the property a few years ago, but operation may be resumed before long. It is stated on good authority that the old records of the mine show a production of over $25,000 and that the earliest production was not recorded.

### WAGNER PROPERTIES.

*Location and country rock.*—The properties owned by the Wagner Mining & Milling Co. are on the northeast slope of Coffee Valley, extending from Coffee Creek a thousand feet up the slope. There are five claims in the group, all in sec. 34, T. 38 N. R. 8 W.; also 320 acres of patented land near by. The country rock is granodiorite cut by numerous small lamprophyre dikes, many of which parallel the lodes and several of which form the hanging walls of veins. The serpentine contact is only a few hundred feet to the northeast.

*Ore deposits.*—The ore deposits are all of the fissure-vein or narrow sheared-zone type. Their outcrops are mostly inconspicuous, on account of the postmineral shearing which they have undergone. The average trend of the lodes is N. 30° E., and they dip eastward, in the main steeply. Cross fissures trend about northwest, but these are not important, except that some enlarged ore shoots occur where they intersect the main veins. The lodes vary from narrow shear zones to ore bodies several feet wide, and though values as high as $100 a ton are found in pockets and small shoots the average value of the ore is not high. Oxidation has not gone deep except along well-sheared fissures; probably 50 feet is the average depth. The gold in the oxidized zone is free and occurs with some iron oxide. Below this it is associated with pyrite and in the telluride form. The vein material is quartz, crushed country rock, and a little iron oxide and calcite. There are several different veins on the property.

*Black Warrior vein.*—The best-known vein on the claims, though perhaps not the most valuable, is the Black Warrior. It is the flattest vein in the district, dipping 35° E., and is of uneven thickness, though 17 inches is perhaps close to the average. Locally it has been jogged by faulting, as shown by figure 8. The fault plane is almost vertical, the dip of the vein giving the apparent horizontal displacement. The lode has been worked on two levels, the lower reached by crosscuts Nos. 1 and 2 and the upper by crosscut No. 3. Of these, No. 1 is 225 feet long and connects with 70 feet of drift and 125 feet of raise; No. 2 is 435 feet long and connects with a 320-foot drift and a 75-foot raise to the upper level. No. 3, on the upper level, is 48 feet long and connects with 170 feet of drift and 72 feet of upraise to the surface. Some stopes have also been worked.

*Mizpah veins.*—The Mizpah veins are in the southeast corner of the group near Coffee Creek and consist of a series of small parallel veins and dikes, as illustrated in figure 9. Of these, lode A is the southernmost, lode B is 125 feet north of A, and lode C is 50 feet north of B. In lode A ribbon structure is developed, showing five different reopenings and quartz fillings, separated by thin films of country rock. The small veins on the footwalls of dikes are evidence of deposition by ascending solutions. Lode C (fig. 9) shows, in plan, a change of direction, but the evidence in the tunnel does not show whether there are two intersecting veins or one vein jogged by successive shearing. About 300 feet northwest of lode C there is another small parallel vein, lode D. The development work on this group consists of 70 feet of drift on lode A, nearly as much on lode B, and 50 feet of crosscut and 150 feet of drift on lode C. The workings in lode D were caved in and could not be entered.

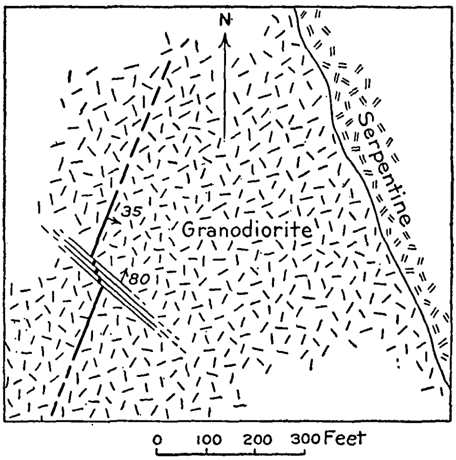



FIGURE 8.—Plan of Black Warrior lode, Trinity County, Cal., showing jog faulting.

*Other veins of the Wagner group.*—Other important veins near the Black Warrior are as follows: On the Red Flag claim, 1,700 feet south of the Black Warrior, a 30-inch vein is separated from a smaller parallel vein by 20 feet of country rock. A lower tunnel, 80 feet long, crosscuts both of these, and 30 feet of drifting has been done on the larger vein. An upper tunnel of 20 feet has opened the smaller vein. These workings are in the oxidized zone and reveal free gold in ore said to have a high value. The Brush Brothers vein, a few hundred feet farther southeast, varies in width from 20 to 30 inches and is considerably oxidized and sheared. It is opened by a 20-foot drift which shows ore that is said to be of fairly high grade. The Reindeer vein parallels the veins above described and is probably a northeast continuation of the Red Flag vein zone. The development work consists of 200 feet of drifting and a 15-foot shaft in the granodiorite and serpentine contact. The vein is 2½ feet wide and gives returns, especially from the shaft in the crushed contact material, that are said to be high.

*Plant.*—In 1899 the owners, having made some headway in development work, built a mill. It consisted of a Gates crusher, 12 stamps of 620 pounds each, three concentrating tables, and a slime table, all driven by water power, and designed to treat 14 to 16 tons of ore in 12 hours. This plant ran five months, the concentrates being shipped to the Keswick smelter; then a snowslide swept the plant away. That it was not a success is shown by the large amount of gold in the tailings. The 1,000 tons of these that are ponded are said to average over $10 a ton. Experiments have been carried on to find a treatment suitable to this ore, and at the time of visit it was thought that the Clancey process might be installed. The power plant has a 1½-mile ditch which will deliver a maximum of 400 miner's inches of water to a penstock 500 feet above the water wheel. This generates power that is more than sufficient for all the needs of the plant.

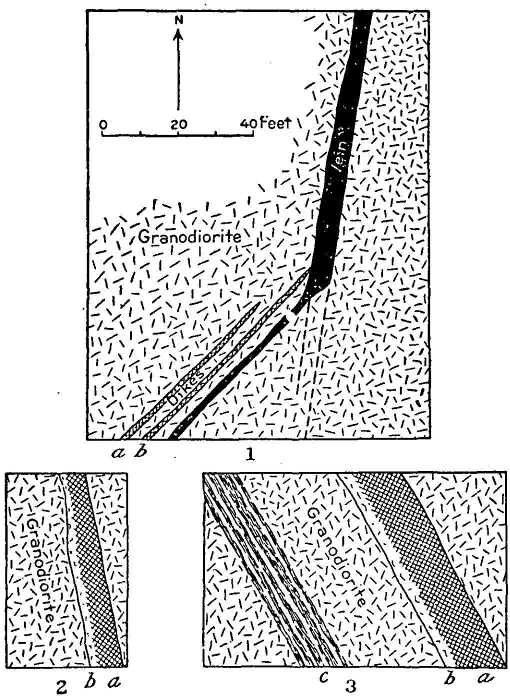



FIGURE 9.—Plan and cross sections of some lodes in the Mizpah group, Wagner properties, Trinity County, Cal. 1, Plan of part of lode C, showing parallel dikes (*a* and *b*) and change in direction of vein or intersection of two veins. 2, Cross section of lode B; *a*, lamprophyre dike, 6 inches; *b*, quartz vein, 3 inches. 3, Cross section of lode A; *a*, lamprophyre dike, 24 inches; *b*, quartz vein, 4 inches; *c*, ribbon quartz vein, 22 inches, consisting of five different fillings separated by thin partings of country rock.

*History.*—In 1890 Frank Bighouse discovered the Mizpah group. Three years later the Brush Brothers discovered the vein which bears their name. The following year Amos Hill opened the Reindeer claim, which he sold to Wagner & Son in 1895, about the time they had located the Black Warrior property. E. A. Wagner found the Red Flag vein in 1897, and subsequently all these properties came into the hands of Wagner & Son.

*Production.*—Since their discovery these properties are said to have produced over $8,000. With a successful method of ore treatment they may give profitable returns in the future.

## POETH MINE.

The Poeth property, recently incorporated as the Gold Ridge Mining & Milling Co., is on the west side of Boulder Creek, a few hundred yards from the Golden Jubilee mine. The country rock is granodiorite cut by a few lamprophyre dikes. The chief veins, two in number, are parallel, 175 feet apart, and of the fissure type. Their outcrops are not prominent, probably on account of the postmineral shearing which they have undergone. The north vein seems to be the smaller, but it is not yet well opened; the south vein shows narrow pinches and ore shoots several feet wide, the average width being nearly 3 feet. Oxidation has not gone below 25 feet, except along certain shear zones. The development work is confined chiefly to the southern lode and consists of a 40-foot crosscut, 75 feet of drift, a 45-foot upraise, and a 100-foot shaft. The chief minerals are gold, both free and in the form of tellurides, some pyrite, and locally some iron oxide. The vein consists mostly of quartz, with a little crushed country rock, and some calcite. The values are said to be high, and some rich pockets have been found. A shipment of 5 tons of carefully picked ore is said to have averaged into the thousands of dollars a ton; and a second shipment of 6 tons is said to have brought, without sorting, $21 a ton. The concentrates are high enough in grade to bring a good profit in spite of the high cost of shipping. Mining conditions are favorable, especially with regard to timber and water power. A wagon road extends into the property.

The lodes were discovered in 1900 by John Poeth, who has done most of the development work and still has an interest in the property. The installation of a small plant that will successfully treat the ore will probably greatly enhance the value of the claims.

## BURNER MINES.

The Burner group of four claims, recently acquired by the Coffee Creek Mining & Milling Co., is a mile north of the Jubilee mine, on the northeast slope of Coffee Valley a hundred feet or more above the valley bottom. The country rock is granodiorite cut by lamprophyre dikes, the serpentine contact being only a few hundred feet distant. The veins are not of the large fissure type, like those of the Dewey and the Golden Jubilee, but are small parallel stringers, with ore bodies developed at fissure and dike intersections. The vein system trends about N. 30° E. and dips steeply. The veins are smaller, richer, and more pockety than those which occur farther away from the serpentine contact. The vein material is mostly quartz with a little mineralized country rock. It contains gold, free and in the form of tellurides; pyrite is common and some galena is present. Oxidation extends only a few yards below the surface.

The property is opened by 17 small tunnels and shafts. The longest tunnel is 200 feet long, but the present company is starting a main adit to crosscut as many of the ore veins as possible, and, as planned, it will have maximum backs of 600 feet. Some ore recently sacked, it is said, averaged $300 a ton. The mining conditions are very favorable and there is a wagon road to the property.

A crushing and cyanide plant is projected and the ore treatment will be crushing and amalgamating to get the free gold, then concentration to remove the sulphides, and cyanidation of the slimes and tailings. The concentrates will probably be hauled out by wagon to the railroad. Rich pockets are said to have yielded several thousand dollars since the discovery of the property.

### LILY OF THE VALLEY GROUP.

The Lily of the Valley property, locally known as Windy Camp, is under the management of Reid Brothers and lies on the northeast slope of Coffee Valley, 1,200 feet above Coffee Creek, at an elevation of 4,500 feet. The country rock is granodiorite cut by several lamprophyre dikes and by dikes from the main serpentine mass, which is close at hand, but separated from the granodiorite by a large shear zone along the contact. The Lily of the Valley vein is a narrow shear zone which locally widens out into ore shoots that are somewhat related to fissure intersections and to lamprophyre dikes. It trends about northeast, is nearly vertical, averages 10 inches in thickness, and is made up of quartz, crushed country rock, and some calcite. The ore contains free gold, with tellurides reported. Some pyrite is present, grading into iron oxide at the surface. Assays from the lamprophyre dikes near the ore body are said to show gold values of $1 to $2.60 a ton. The average tenor of the ore shoots is said to be $25 a ton, but some assays have registered values more than ten times as high. Timber and water power are readily available and the slope insures good backs, drainage, and dumpage. A wagon road extends to the lower part of the property. The development consists of 125 feet of lower tunnel, mostly on the vein, with a 23-foot upraise at the face; also a 75-foot upper tunnel, with a 30-foot winze, from the bottom of which extends a 20-foot drift.

Another deposit on this group of claims is known as the Hill-Farmer lode. It is a fissure vein in the granodiorite, trends northeast, is about vertical, averages 15 inches in thickness, and is said to give an average assay of $7 a ton near the surface. It is about 445 feet east of the Lily of the Valley workings and is developed so far only by an open cut.

A small mill, consisting of a 3½-foot Huntington and a cyanide plant designed to treat 10 tons each 24 hours, has recently been purchased for this group. A quarter-mile ditch carries a maximum of 40 inches of water, which discharges under a 175-foot head against a Pelton wheel. This will generate some 30 horsepower, a third of which will be required to run the present plant. The extraction by cyanidation is said to be 90 per cent.

### DEWEY PROPERTY.

The Dewey property is on Little Boulder Creek, 1½ miles southwest of Coffee Creek. The country rock is granodiorite, cut by some lamprophyre dikes, one of which locally forms the southeast wall of the lode. The serpentine contact is not far distant. The vein is a large, clear-cut quartz fissure filling which has been very little broken up by the small amount of postmineral shearing which it has undergone. It trends N. 30° E., dips 85° E., and averages 4 feet in width. Oxidation extends only a few feet below the surface except where it reaches down along fissures to depths of 20 feet or more. The ore is of low grade. The gold is associated with pyrite and some crystals of chalcopyrite and, on the surface and in some of the postvein fissures, with iron oxide. The vein material is largely quartz, with some siderite and calcite.

The development consists of a 130-foot crosscut tunnel which taps the main vein 65 feet below the surface; from this a 100-foot drift has been run southward and a 50-foot drift northward. The property was discovered in 1899 and was purchased by James Medary and T. S. Leever, its present owners, in 1902. Soon after the discovery an arrastre was put in, and a considerable quantity of oxidized croppings was worked, giving a yield, it is said, of $700. No system of treatment for the sulphide ores has yet been installed. This is one of the largest and clearest cut veins observed in the district.

### OTHER PROSPECTS.

Among the prospects not visited because of lack of time are the claims of the Nash Mercantile Co., in the Copper district. It is reported that the vein is 2 feet wide and that it assays well, carrying gold with a considerable amount of copper. Not far from these is the Morning Star claim, which is said to have a well-defined vein that averages $7 a ton in free gold near the surface.

## DORLESKA AND YELLOW ROSE TYPE.

### DORLESKA AND YELLOW ROSE MINES.

The Dorleska and Yellow Rose properties were visited in the fall of 1909, but the data then gathered were lost in a fire. A second visit was prevented by a snowstorm, which cut short the work that was being done in the district in the fall of 1910. The facts here presented are derived from memory and from some notes furnished by Mr. MacIlwaine, superintendent of the Dorleska. The treatment is not adequate for the importance of the properties.

Both of these mines are at an elevation of 6,550 feet, one on each side of the Coffee Creek and Salmon River divide, near its summit. They are reached by a trail up Coffee and Union creeks from the end of the wagon road north of the Jubilee mine; also by trail up Swift Creek from Trinity Center. The distance from Trinity Center by the latter route is 16 miles, and by the former 26 miles.

The country rock is a serpentine mass, cut by large and small lamprophyre dikes. A few hundred feet north of the ore deposits is a series of highly metamorphosed schists, thin limestone, and limy shales. A lamprophyre dike 50 feet or more thick cuts the basic country rock in a direction N. 16° E. and dips about 75° W. Near the Yellow Rose mine the east side of this dike contains hornblende prisms and is the "crow's-foot porphyry" of the prospector. The west side shows biotite and some quartz. Near the Dorleska mine, however, these relative positions of the dike material have been reversed. The dike is paralleled by the schist contact and by a fault zone of considerable magnitude.

The ore deposits of these mines are similar. The fault zone is mineralized along the footwall of the composite dike, which is also locally mineralized where cut by side fissures. Rich shoots of clayey material, which dip 45° N., characterize some of the fissure intersections. The ore contains gold, with some silver, associated with pyrite. Tellurides and a little galena are reported.

The conditions affecting mining are favorable. The mines require but little timbering, lumber sufficient for all mine purposes is available, and the slope is such that backs can easily be developed. Over a thousand feet of drift and upraise work has been done on each property.

The milling equipment at the Yellow Rose consists of a Huntington, driven by steam, with a capacity of 7 tons in 24 hours. At the Dorleska there are two 5-stamp batteries and a Huntington mill, driven by steam, with a total capacity of 30 tons in 24 hours. The Huntington mills are especially well adapted to the talcose ores.

The Yellow Rose was discovered by Messrs. Hill and Farmer in September, 1897, and shortly afterward Mr. Lawrence located the

Dorleska. These men were "pocket hunters" and they worked some rich pockets on both properties, treating the ore in arrastres and later at the Dorleska in a small 5-stamp mill. A few years later new interests acquired the properties and they were very active for a time, producing some high-grade ore. Recent changes have been made among the holders and new plans for development work are reported.

It is said that the Yellow Rose has produced $100,000 and the Dorleska $200,000 since discovery. The large extent of lode which is yet to be explored before the workings of the two mines join indicates that much ore-bearing rock is still undeveloped.

#### OTHER PROPERTIES.

Several properties of more or less promise occur in the general vicinity of the Dorleska and Yellow Rose mines. They are mostly associated with dikes and shear zones in serpentinized rocks. Their ores carry free gold and are said to contain some small rich pockets, as well as larger bodies of lower-grade ore. Of these Thomas Keating's property, a few miles north of the Dorleska and characterized by similar geologic conditions, has already produced considerable gold. It has recently been acquired by a company which has put in a small plant for treating the free-gold ores, so that the property now bids fair to become a producer.

Not far distant from this are properties owned by Mr. MacIlwaine and others, some of which are promising prospects. South of the Yellow Rose are some prospects which have very inconspicuous outcrops but give free gold by panning the adjacent soil. Many of these are well worth investigation and on the whole the field is very interesting for the prospector.

### STRODE AND BONANZA KING TYPE.

#### STRODE MINE.

The Strode mine is half a mile northeast of Carrville, on the steep eastern slope of the Trinity Valley, about 700 feet above Trinity River. The country rock is a complex of andesitic greenstones cut by some small masses of granodiorite porphyry; by dikes of aplitic rock, one of which is parallel to and not far distant from the vein; by dikes of fine-grained green metabasalt; and by a few lamprophyre dikes.

The vein occupies a fissure and is paralleled by smaller veins of the same type, the whole somewhat sheared and locally having the appearance of a double vein. It trends N. 60° W., is nearly vertical, and averages about 2 feet in width but is locally considerably wider. The ore contains gold, associated with iron oxide, a little manganese stain, and, in the less sheared parts, pyrite. The gangue is largely quartz, with some crushed country rock and a little calcite. The value of the ore taken out is said to be high, especially in some of the ore shoots. Mining conditions are favorable and a good wagon road leads to the workings. From the mine the ore is hauled by wagon to a 3-stamp battery, where the gold is recovered by crushing and amalgamation. The property has been worked more or less regularly in a small way for several years and is said to have yielded good profits. Though working in 1909 it was not active in the later part of 1910. It is believed by those familiar with the district that this mine still contains valuable ore.

#### BONANZA KING MINE.

The Bonanza King mine is well known in the district but was not visited in 1910 on account of snow. The notes from the writer's previous short visit were destroyed by fire, hence the brief description here given is quite inadequate to the importance of the property. The mine is about 4 miles east of Trinity Center on the face of a steep mountain slope some 1,200 feet above Trinity River. The country rock is a complex of andesitic and gabbroic greenstones, cut by lamprophyre dikes. The lode is a mineralized shear zone, locally well defined and in places widening out into large ore shoots. These shoots are mostly located at fissure intersections and some of them are very rich, one having yielded, it is said, about $80,000. The ore contains gold, with a little silver and considerable pyrite. The development consists of several thousand feet of tunnels, drifts, and stopes, and well-equipped tramways. An aerial tram a few thousand feet in length brings the ore down to a 30-stamp mill and cyanide plant.

This mine became very prosperous shortly after the discovery because of the finding of an exceptionally rich ore shoot. After the exhaustion of this shoot the returns were not so high. A few years ago the failure of a trust company in San Francisco involved the property and it was turned over to a receiver who allowed it to stand idle pending the straightening out of the financial tangle. In 1910 it was reported that work might be resumed shortly.

### BLUE JAY TYPE.

#### BLUE JAY MINE.

The Blue Jay mine is on Morrison Gulch, 1¾ miles west of Carrville, and is owned by the Blue Jay Mining Co. The visit to it was necessarily hurried and only a general idea of it is here presented. The country rock is serpentine cut by small masses of granodiorite porphyry, by lamprophyre dikes, and by a large dike of fine-grained green metabasalt. Shear zones are numerous, many of them trending northeast. The ore is in the metabasaltic dike in local fissures and shear zones, at the intersections of some of which rich pockets occur; in fact, the property is known as a producer of rich pockets. The pockets contain coarse free gold with some iron oxide and a little manganese oxide staining the clayey material in which they occur. Pyrite is peppered through certain parts of the dike and it is said that some gold is associated with the pyrite. In some portions of this dike the mineralized shear zones are spaced closely enough to permit mining and treating the whole dike mass. Prospecting with this end in view might be well worth while. The mining conditions, especially slope for back and dumpage, also water power and timber, are very favorable and at the time of visit active development work was in progress.

The property was discovered in 1892 by the Graves Brothers, who took out $60,000 in a few days from a very small pocket. This caused a "gold rush" and in 1893 thousands of gold seekers went into the Coffee Creek district, but a few months later there was an ebb tide of disappointed men. A year after the excitement had subsided the property was idle, and it remained so until a few years ago, when some lessees took out what were said to be good returns. Recently another company has started development work, from which it is hoped that this mine, which had such a spectacular beginning, may yet become a steady producer.

# A PRELIMINARY REPORT ON THE GEOLOGY AND ORE DEPOSITS OF CREEDE, COLORADO.

By W. H. Emmons and E. S. Larsen.

## INTRODUCTION.

### LOCATION AND TOPOGRAPHY.

The Creede mining district is situated in Mineral County, southwestern Colorado, near the eastern border of the elevated region generally known as the San Juan Mountains. The town of Creede is situated on Willow Creek a few miles above its junction with the Rio Grande. The area shown on the map of Creede and vicinity published by the Geological Survey is about 4½ miles east and west and 5¾ miles north and south. The lowest portion of this area, about 1 mile below Creede, is 8,700 feet above sea level, and the highest is the summit of Nelson Mountain, near the north border of the area, which is 12,029 feet above sea level. The country consists mainly of steep slopes, although the uplands include some small, comparatively level stretches. Like most of the mountainous area of the San Juan the region is timbered and well watered. It is served by a broad-gage branch of the Denver & Rio Grande Railroad. The district is more accessible than many other camps of the San Juan region, and rates for shipping ore are lower.

### FIELD WORK AND ACKNOWLEDGMENTS.

The geology of Creede and vicinity has been mapped by E. S. Larsen, who for several years has been associated with Whitman Cross in the study of the general geology of the San Juan Mountains. Mr. Larsen spent several brief periods in the study of the geology of the region near Creede incidental to work in the San Cristobal quadrangle, the border of which lies a short distance west of Creede, but the larger part of his work was done during the summer of 1911. W. H. Emmons was detailed to study the underground workings and the ore deposits, and spent about seven weeks, from July 28 to September 15, 1911, in this work.

The survey of the district has not yet been completed. This report is merely a preliminary statement of the principal conclusions and may later have to be modified. The thanks of the writers are

due to the mining operators of the district for friendly cooperation and support, especially to the officers of the Solomon mines and Messrs. S. B. and Albert Collins for the use of mine maps and to Mr. William Barnett for many favors.

## HISTORY AND PRODUCTION.

In the eighties the upper portion of the valley of the Rio Grande was a route of transportation between Wagon Wheel Gap and the flourishing camps near Silverton and Lake City. This route passed very near the present site of Creede and nearer still to Sunnyside, a small camp about 2 miles west of Creede. Some of the Argonauts halted on the way long enough to prospect the steep mountain slopes along the valley and, finding encouraging indications, located several claims. J. C. McKenzie and H. M. Bennett located the Alpha, at Sunnyside, April 24, 1883, and with James A. Wilson pegged out the Bachelor claim, near the present site of Creede, July 1, 1884. Some prospecting was done in the middle eighties, principally at Sunnyside, and futile attempts were made to work the ores in arrastres. There is no record of any new discoveries from 1886 until August, 1889, when N. C. Creede, E. R. Naylor, and G. L. Smith located the Holy Moses mine on Campbell Mountain. The following summer Mr. Creede located the Ethel and C. F. Nelson located the Solomon claim. The mining district that was formed was called the King Solomon district; it is east of and nearly contiguous to the Sunnyside district.

When it became generally known that Mr. Creede had sold an interest in the Holy Moses mine to D. H. Moffat, of Denver, prospecting was renewed with great vigor, and in June, 1891, several prospectors from Del Norte discovered the Last Chance mine on Bachelor Mountain. This was on the Amethyst or "Big" vein, upon which the Bachelor claim had been located six years before, but the two locations were nearly three-fourths of a mile apart. Soon after the location of the Last Chance Mr. Creede located the Amethyst claim, which joined it on the north, and within a few months the Amethyst vein was pegged for a distance of nearly 2 miles along its strike.

The railroad from Wagon Wheel Gap was extended to the district in 1891, and the first train arrived at Creede on December 16 of that year. It is credibly reported that the town housed 10,000 people in the early nineties. The district has been producing almost continuously since the advent of the railroad, and the daily tonnage in the nineties was large. During some of these years silver was at a very low price, but the mining operations were profitable nevertheless. The production has declined somewhat in recent years, and in 1910 it was $1,036,286.[1] No record has been kept for some of the mines, and

[1] Mineral Resources U. S. for 1910, pt. 1, U. S. Geol. Survey, 1911, p. 424.

the total production can not be stated accurately, but on the basis of data obtained from several reliable sources the total production is estimated at $37,500,000. This includes, in order of their value, silver, lead, gold, and zinc. About half this sum was paid as dividends, notwithstanding the low prices at which the metals were marketed. The Creede district is probably the most productive silver camp in the United States developed after the great slump in the price of silver. The mines on the Amethyst vein supplied over 90 per cent of the total production and paid an even larger proportion of the dividends. If the silver had been marketed at the same prices, the production of the Amethyst vein would compare very favorably with that of any other silver deposit in the United States except the Comstock lode.

## MINING AND TREATMENT OF ORE.

The larger part of the ore of Creede was partly or completely oxidized. Such ore is not suitable for mechanical concentration and was shipped without dressing to smelters. The most of it went to the plant of the American Smelting & Refining Co. at Pueblo.

In the lower levels of the mines on the north end of the Amethyst vein, especially in the Amethyst and Happy Thought mines, large bodies of sulphides suitable for concentration were encountered. This ore was dressed in the Humphrey mill at North Creede. The Humphrey and Amethyst mills are of the same general type, the equipment including crushers, rolls, classifiers, jigs, tables, and canvas plants. The zinc blende and galena are readily separated, giving clean and satisfactory concentrates, and the pyrite is not so abundant as to reduce the grade of zinc concentrates greatly. Gold and silver are recovered mainly with the lead concentrates or in the slimes. Two smaller mills, the Solomon and the Ridge, are located on East Willow Creek about 1½ miles above North Creede. The ore of the Solomon vein is very soft and is crushed by rolls without preliminary breaking in a jaw crusher. Only the Humphrey and Solomon mills were in operation in the summer of 1911, the Amethyst having been closed early in that year.

Conditions are favorable for cheap mining, as the veins are nearly everywhere of good width and have been subjected to very extensive fracturing and crushing since they were formed, so that much of the work has been done with pick and shovel. One of the largest stopes was milled from the bottom without preliminary blasting or breaking the ore. At present all the stoping is done by hand. Owing to the fractured condition of the rock the miners find their labors lighter than in many neighboring districts.

The mines on the Amethyst vein and those on the Solomon are served by deep adits. The topography is so rugged that these gain depths of 1,000 to 1,400 feet within comparatively short distances.

The mines contain large quantities of water, which is drained through the adits and is used for milling. Although several deep shafts have been put down, all the mining is done at present through the adits.

## GEOLOGY.

### GENERAL FEATURES.

Creede lies within the great Tertiary volcanic area of the San Juan Mountains, and, so far as known, no rocks other than the Ter-

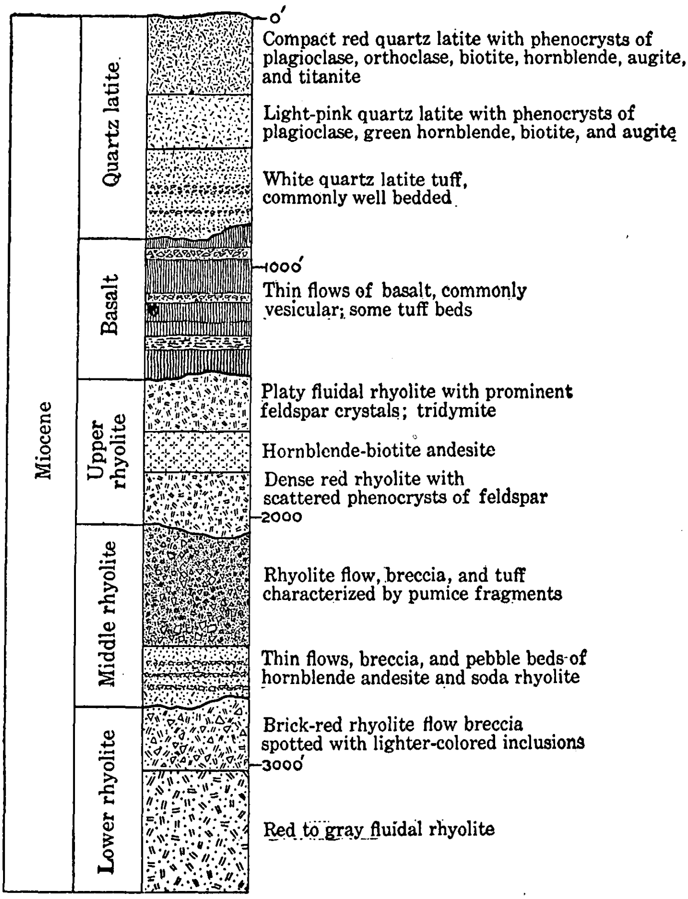



FIGURE 10.—Generalized columnar section of rocks on ridge east of Rat Creek, near Creede, Colo.

tiary volcanics are exposed within a radius of many miles. All the rocks of the area shown on the map of Creede and vicinity are thought to be included in the Potosi volcanic series, which is the third series of the Tertiary volcanic rocks thus far recognized in the region.

The rocks of this area are naturally separable into several divisions and most of these divisions are separated by erosion surfaces. Each division is generally made up of two or more flows or other subdivisions. Figure 10 is a generalized columnar section representing the succession of the rocks as seen on the ridge east of Rat Creek. This section does not show the quartz latite of McKenzie Mountain, which overlies a very irregular surface of the other rocks, nor the lake beds in the Rio Grande valley, nor the rhyolite near the Equity mine. The exact positions in the column of the latter two are not known.

## THE ROCKS.

*Lower rhyolite.*—The lower rhyolite consists of two divisions, the lower of which is very prominently developed in the canyon of Willow Creek above Creede. Over 1,000 feet of this flow is shown in that canyon, although its base is not exposed. It extends on the slopes nearly to the summits of both Mammoth and Campbell mountains. The upper contact of the flow dips rather steeply to the north, so that it is not exposed above Phoenix Park on East Willow Creek, and it continues for only a short distance above Weaver on West Willow Creek. To the east it extends beyond Dry Gulch. This flow is exposed also on the east side of West Willow Creek just above the Equity mine. Another area of the same flow outcrops near Sunnyside and makes the lower slopes about Rat and Miners creeks and crosses to the west into Shallow Creek. A short distance beyond Shallow Creek it passes under other flows. This division of the volcanic series forms one or both walls of most of the lodes of the district. It is a normal rhyolite in composition. Its aphanitic groundmass incloses inconspicuous phenocrysts of glassy orthoclase and a very few of biotite and plagioclase. It is generally gray, pink, or red in color and has a prominent fluidal structure. Thin bands of dense dark-colored material alternate with irregular or lenslike bands of porous, lighter-colored material.

Overlying this fluidal rhyolite is a later rhyolite flow which has a thickness of over 1,000 feet where exposed east and southeast of Phoenix Park. On Mammoth Mountain, just south of the Mollie S. mine, are two small outcrops of this flow which in places are in faulted contact with the underlying rhyolite. Campbell Mountain is likewise capped by this flow. In the hanging wall of the Amethyst vein it is but a short distance below the surface. It outcrops just west of the Commodore mine and continues along the upper slopes of the hill into Windy Gulch. It occupies also the upper slopes on both sides of Miners Creek. This upper division of the lower rhyolite is commonly dark brick-red in color and has a dull bricklike luster. Fluidal structure is inconspicuous, but inclusions and irregular or lenslike blotches of a color and texture slightly different from the mass of the rock are characteristic. It is very similar in its mineral composition and texture to the underlying rhyolite.

*Middle rhyolite.*—In Windy Gulch below Bachelor are thin flows, breccia beds, and tuff overlying the lower rhyolite. The material of these deposits is a red soda rhyolite, which contains abundant crystals of glassy orthoclase and white microperthite and some quartz and biotite in a fine-textured groundmass. This soda rhyolite continues northward and forms the hanging wall of the Amethyst fault nearly to the Last Chance mine. It is here termed the middle rhyolite. On Rat Creek, just west of Bulldog Mountain, the lower rhyolite is overlain by several hundred feet of thin flows and breccia beds of hornblende andesite which are thought to occur at the same horizon as the soda rhyolite.

Above the hornblende andesite on the south slopes of Bulldog and McKenzie mountains there is a considerable thickness of rhyolite tuff and flow breccia. The rock is light pink in color, is characteristically porous, and contains prominent irregular fragments of pumice and of some other rocks. It contains a few crystals of orthoclase and biotite in a glassy or finely crystalline groundmass.

*Upper rhyolite.*—The two rhyolite flows of Bulldog Mountain are red in color and contain rather abundant phenocrysts of orthoclase, less plagioclase, and a little biotite in a fine spherulitic groundmass. Platy fluidal structure is everywhere developed. The upper flow has more abundant phenocrysts and contains much tridymite in the gas cavities. The flows have been recognized on both sides of Rat Creek, on Bulldog Mountain, and near Bachelor. A faulted block of these flows occurs east of Rat Creek and northeast of Sunnyside, and another small outcrop was found under the basaltic division in West Willow Creek, just above the mouth of Deerhorn Creek.

*Basaltic division.*—Overlying an eroded surface of the flows of Bulldog Mountain is a series of thin flows of basaltic rocks, with associated tuff and breccia. These rocks are commonly dark red or dark gray and are as a rule vesicular and amygdaloidal, especially in the upper portions of the flows. Everywhere they are somewhat altered and show few conspicuous crystals. The groundmass is fine grained to glassy and incloses phenocrysts of plagioclase, augite, altered olivine, and iron ore. Just east of the mouth of Deerhorn Creek, on West Willow Creek, there is some fine-textured thin-bedded basaltic tuff associated with the flows. The division is most prominently developed just north of Bulldog Mountain, where it attains a thickness of about 500 feet. Other small outcrops were found on the south slopes of McKenzie Mountain, at several places on upper Rat Creek, and on West Willow Creek just above the mouth of Deerhorn Creek.

*Quartz latite.*—Unconformably overlying the basaltic division is a series of closely related flows and tuff beds of quartz latite. At the base of these rocks north of Bulldog Mountain and on the lower slopes of Nelson Mountain is several hundred feet of fine-grained tuff. The tuff is overlain by several flows of quartz latite. These flows are confined to the northern part of the area covered by the map of Creede and vicinity. They form Nelson Mountain and the ridges on both sides of Rat Creek and extend north, east, and west beyond the area under consideration. The rock of these flows is characterized by rather abundant phenocrysts of plagioclase and some quartz, hornblende, augite, and orthoclase in a spherulitic groundmass.

*Augite-quartz latite of McKenzie Mountain.*—The youngest flow of the area is the augite-quartz latite which caps McKenzie Mountain. A small isolated body outcrops on the east side of Rat Creek east of Butte and is well exposed in the road cuts. Its base is very irregular, as it flowed over a rugged surface. The rock is red and is usually porous. It contains larger and more abundant phenocrysts than any of the other flows and consists of crystals of plagioclase, biotite, and green augite in a spherulitic or glassy groundmass.

*Rhyolite flow near Equity mine.*—On Deerhorn Creek above the Captive Inca mine and extending to the north and northeast beyond the Equity mine is a thick flow of rhyolite. Near the Equity mine it is in faulted contact with the lower rhyolite. At the ridge northeast of the Equity mine and north and east of the two faults it overlies the lower rhyolite, but its relation to the other rocks is not known. It occupies the position of the second rhyolite flow of the lower rhyolite and resembles that flow somewhat but is not believed to be a part of it. The rock is rather dense and has a greenish or reddish color. Flow structure is not prominent. It has a few phenocrysts of plagioclase, orthoclase, biotite, quartz, and altered augite in a fine spherulitic or granophyric groundmass.

*Lake beds.*—Miocene lake beds occupy the valley of the Rio Grande and extend up the north slopes to the mouths of the canyons at Sunnyside and Creede. The material of the lake beds is commonly well bedded and well sorted. In the lower part it is made up of rather large, irregular fragments of rhyolites similar to those of the lower rhyolite with a less amount of other rocks. Higher up the material is finer, more worn and rounded, and the top is a white shaly rhyolitic tuff. Within the lake beds, especially in their upper part, are abundant irregular or lenslike bodies of travertine. This material represents the deposits of springs, probably hot springs, partly in and partly about their vents, formed during the deposition of the lake beds. This travertine is light gray or brown, but much of it is stained with limonite. It contains numerous vugs and is commonly cellular. Chalcedony and coarsely crystalline calcite are abundant in the vugs and in veinlets.

On the Hayden map of this region the limestone of the lake beds was mapped as "Lower Carboniferous" and the tuff part was called Green River, but a careful study of the two has shown that they are intimately associated and of contemporaneous age. Fossil plants collected near Sevenmile Bridge and near Wasson have been determined by F. H. Knowlton as belonging to the well-known flora of Florissant, Colo., which he now considers to be of Miocene, probably upper Miocene age. These lake beds were deposited in a very rugged basin of the lower rhyolite, but their exact relation to the other rocks of the area is not known.

*Intrusive rocks.*—The intrusive rocks of the area include rhyolite porphyry (quartz porphyry), quartz monzonite porphyry, and basalt. Small intrusive masses of rhyolite porphyry have been observed in several of the mines and on the hill east of the Corsair mine. A dike of quartz monzonite porphyry occurs on the ridge just south of the Alpha mine and at some places forms one wall of the Alpha fault. Similar dikes are more prominent higher in the valley of Miners Creek, and one was found on Rat Creek about a mile above its mouth. A small dike of basalt is exposed about 2 miles above the mouth of Rat Creek.

*Glacial deposits.*—The upper parts of all the larger valleys have been glaciated and the terminal moraines of the old glaciers of Rat Creek and of both forks of Miners Creek are partly within the Creede area. The lower limit of glaciation can be easily recognized by the abrupt change in the character of the valleys, which are broad and U-shaped above that point but are sharp gorges below. The glacial deposits are easily recognized from the fragmental character of the rocks and the hummocky, undrained character of the surface. Much useless prospecting has been done in the glacial deposits, especially to the south and east of Deerhorn Creek. In such deposits surface indications are no criteria as to what is below, and at some places the bedrock is covered to a considerable depth.

*Landslides.*—Large landslide areas are rather abundant in the district. They are most likely to be found where a hard, resistant bed is underlain by softer beds, such as tuffs, and where the slopes are steep. Northwest of Bulldog Mountain a large landslide extends from a point about a hundred feet below the saddle to and across the bed of Rat Creek. It is joined by the débris of another landslide from the northeastern slope of McKenzie Mountain. Farther up Rat Creek are other large landslides. West of West Willow Creek, opposite the Captive Inca mine, is a large landslide which covers the slopes for 500 feet or more and extends along them for about a mile and a half. On the southwest slope of Nelson Mountain is another landslide, and considerable prospecting has been done in it.

*Talus and alluvium.*—Talus covers large portions of the lower slopes in nearly all parts of the area and obscures much of the geology. Small areas of alluvium occur in some of the valleys.

## STRUCTURE.

The lavas in general dip gently to the north, but the lake beds south of Creede dip gently to the south. It is not known to what extent these structures are original or to what extent they represent actual tilting of the beds.

Complicated block faulting is the most important structural feature of the region. The location and mapping of the faults is made very difficult by the lack of good exposures in many critical places, the thickness and irregularities of the flows, their close similarity in appearance, and the lack of any good horizon marker. Any statements about the faulting are therefore subject to revision. The Amethyst fault is easily located from the Bachelor mine to the Park Regent mine, but beyond that point glacial drift and landslide débris cover it for over a mile, and the area beyond has not been carefully studied. The fault strikes west of north and dips in general from 50° to 75° SW. The footwall of the fault is of the lower flow of the lower rhyolite. For a short distance north of the Commodore mine the rhyolite breccia forms the hanging wall, but to the north the rocks which outcrop are higher in the section and flows of the upper rhyolite probably form the hanging wall.

At the Equity mine is a fault which trends about N. 75° W. and which throws up the lower rhyolite on the north side in contact with a more recent rhyolite flow to the south. The displacement is probably a thousand feet or more. Above the Equity mine, just east of West Willow Creek, is another great fault which strikes a little west of north; it is marked by a small bench or sag along its line. East of it is the lower rhyolite and west of it is part of the same great rhyolite flow which lies south and southeast of the Equity mine.

On Mammoth Mountain several faults, probably of small throw, strike from south of east to east of south and bring into contact the two flows of the lower rhyolite.

About half a mile northeast of Sunnyside is a block of rhyolite, similar to the flow capping Bulldog Mountain, which is probably bounded by faults. It is rudely triangular in shape and is nearly a mile in length and about a quarter of a mile in width. Its longest side is on the south and runs a little south of east, its shortest or northwestern side running about northeast and its other side about northwest.

Other faults are mentioned in connection with the description of the mines.

## ORE DEPOSITS.

### PRINCIPAL GEOLOGIC FEATURES.

The ore deposits are silver-lead fissure veins in rhyolite and fractured zones of silver ore in shattered rhyolite. The total production, except a few thousand dollars, has been obtained from the silver-lead fissure veins. These are strong fault fissures and are extensive both vertically and along the strike. They include the Amethyst, Holy Moses, Solomon, Alpha, Mammoth, and several smaller lodes. All of these strike in the northwest quadrant, and the majority dip west or southwest.

Brecciation and faulting have taken place on a large scale, as is indicated by slickensided surfaces with abundant movement striæ and at some places by a lack of correspondence of the rocks on the two sides of a vein. Some of the veins fill fissures along normal faults and at some places in the hanging-wall blocks there are subordinate fissures which join the principal faults in depth. Such relations are thought to show that the hanging wall was shattered as it was drawn downward by gravity along the footwall.

Some of the veins have been opened by movement since the ore was deposited. The results of such movement in the Amethyst vein are very pronounced. The ore itself is crossed by striated slickensided planes and locally the vein quartz with associated sulphides forms a friction breccia. The ore minerals include zinc blende, auriferous galena, pyrite, chalcopyrite, and their alteration products. The gangue minerals include quartz, much of it amethystine, with chlorite, barite, and fluorite. The several veins show considerable differences mineralogically. Hydrothermal metamorphism is not pronounced a few yards away from the veins, but along the most productive portion of the Amethyst vein considerable alteration has taken place. It is attended by silicification and the development of adularia and some sericite. Ribbon quartz and banded crusts are common, indicating deposition in open spaces. At some places near the veins, however, the intensely altered replaced rhyolite constitutes good ore. For reasons which will be mentioned in a subsequent paper, it is thought that these veins have been deposited by ascending thermal waters. As they cut rocks that are probably of Miocene age, the deposits are Miocene or later.

In some of the deposits secondary enrichment is pronounced. The rich secondary ores extend downward to great depths, owing to the high relief of the area and consequent ample head of the solutions and the open character of the veins, all of which facilitate a rapid downward circulation.

The fractured zones of silver ore in shattered rhyolite include the deposits of the Mollie S. and Monte Carlo mines. The fractures and joint planes of the rhyolite are filled with thin veinlets of green chrysoprase and other green copper minerals and locally carry very high values in silver. Argentite, cerargyrite, and native silver are plastered on the walls of the thin, narrow cracks. Iron sulphides are not abundant. The rhyolite along the veinlets is apparently fresh and glassy and is not greatly affected by hydrothermal metamorphism. Deeper exploration has not exposed any body of sulphide ores, and it is possible that the rich ores of this class are genetically related to the present topographic surface.

## AMETHYST LODE.

### GENERAL FEATURES.

The Amethyst lode is the most important deposit of the Creede district. Its total production is estimated at about $35,000,000 in silver, lead, gold, and zinc. It is developed for about 9,500 feet along the strike, and for the greater portion of this distance it has been exploited to depths of 1,000 to 1,400 feet below the surface. Its strike is in general about N. 22° W. At the north end it strikes nearly north and at the south end it strikes about southeast. It dips southwest at 50° to 65°, or locally at greater angles.

The country rock is the lower rhyolite, which here and there is intruded by small bodies of porphyry. In most places but not everywhere the lower division of this rhyolite forms the footwall and the upper division forms the hanging wall. In the upper levels the character of the rhyolite which forms the hanging wall and of that which forms the footwall is noticeably different, especially in the Amethyst mine.

At several places along the strike the vein splits to inclose horses of the country rock, and a number of small veins make off in the hanging wall of the main fissure. These strike approximately but not exactly with the main vein. Some of them are nearly vertical or dip westward at angles which are higher than the dip of the vein; consequently they join it in depth. Others dip eastward and make angles of 30° to 60° with the main footwall fissure. These smaller veins are very numerous in the hanging wall but are comparatively rare in the footwall of the vein. As they do not cross the main fissure and are not crossed by it, it is concluded that all the fissures are of approximately contemporaneous age.

The subordinate fissures are especially well developed in the Last Chance mine. On level 6 a zone 100 feet wide includes six nearly parallel fissures, each from 6 inches to 4 feet wide. All of them dip westward, but the footwall has the lowest dip and the fissures projected join it below. Above this level the ground between the six fissures was highly altered and mineralized, and the ore body for a width of 100 feet was stoped and smelted. The position of this ore body is shown by figure 11, a cross section of the vein in the Last Chance and New York mines. In the Commodore mine, 275 feet north of Discovery shaft, on the first level below tunnel 1, six parallel veins are developed and four of these carry workable ore. As

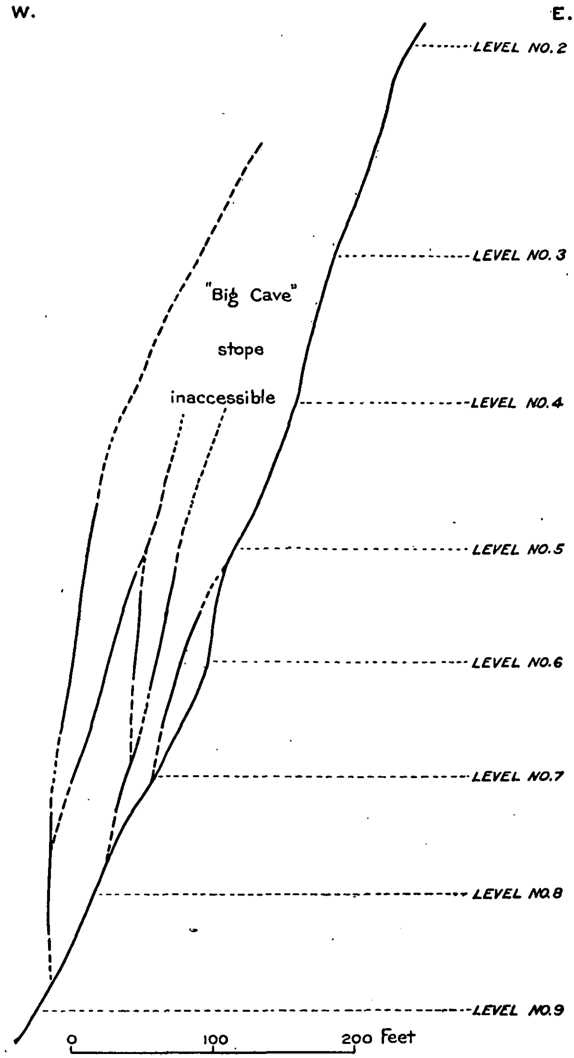



FIGURE 11.—Cross section of Amethyst vein in Last Chance and New York mines, Creede, Colo., showing the relation of the "Big Cave" stope to fractures of the hanging wall.

shown in the cross section, figure 12, these veins dip steeply into the footwall of the lode and join it about 100 feet below level 1. A large body of good ore was developed at the junction. In the Bachelor vein about 1,150 feet from the portal the vein is 16 feet wide, including a sheeted mineralized horse of country rock. The foot-wall dips about 70° S., and the wide body of ore extends downward 100 feet below level 4. Below this point the vein splits and both branches extend downward and carry ore. The vein is, as already stated, a normal fault, which implies a downthrow of the hanging wall. From the position of the minor fractures near the vein it is inferred that the hanging wall was extensively shattered as it moved downward.

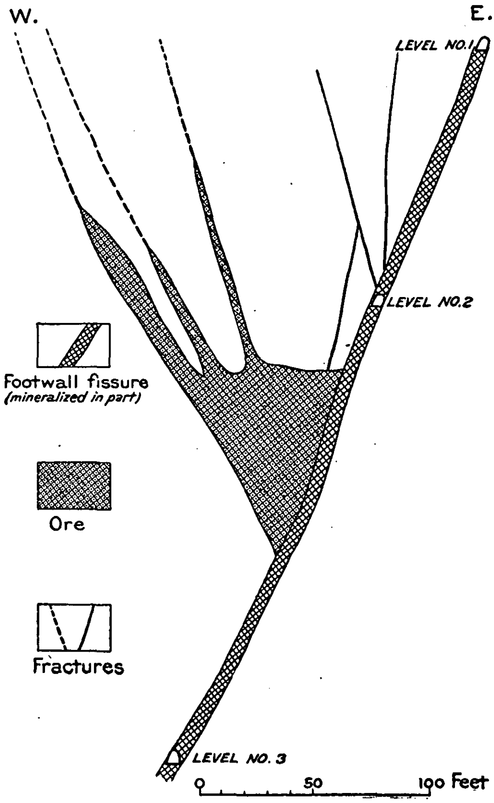



FIGURE 12.—Cross section on block 14, Commodore mine, Creede, Colo., showing fracturing in hanging-wall block.

Six mines on the Amethyst lode are credited with a production of $2,000,000 to $11,000,000 each. From south to north these are the Bachelor, Commodore, New York, Last Chance, Amethyst, and Happy Thought. North of the Happy Thought are the White Star and Park Regent, each of which has produced ore, but in much smaller quantities.

In the Wooster tunnel, which is the lowest and most extensive adit level, the lode is developed for a little less than 2 miles along its strike. At the face at the north end of the adit the vein is 3 or 4 feet wide and the ore is of comparatively low grade. The fissure is strongly developed, however, and shows no signs of playing out. On the surface about 1,000 feet above the north face of the main drainage adit the apex is concealed by débris. Some have maintained that the fault which the lode occupies passes northward approximately on its average strike to the Captive Inca mine, which is about 1½ miles north of the Park Regent, and thence to the Equity mine, which is about 1½ miles beyond the Captive Inca. The rhyolite flows are not sharply differentiated one from another, and in the absence of continuous exposures it is not possible with the data at present available to indicate the probable extension of the fault.

The apex of the lode is concealed also at its south end in the Bachelor mine. Near the point where encountered by the Wooster adit the lode makes a sharp turn and strikes about southeast. The face is not now exposed, but if the strike continues in the same direction its apex should be near the portal of the Wooster tunnel or a few paces north of it. Some shattered rhyolite is exposed at this point, but no strongly mineralized outcrop. Four hypotheses have been advanced respecting the southward extension of the lode. One is that it plays out in the Bachelor mine; a second that it continues southward to the Exchequer mine; a third that it continues southeast and joins the Mammoth vein; a fourth that it splits, one branch continuing to the Exchequer and another to the Mammoth.

The south face of the Amethyst vein is not accessible on the tunnel level. It is said that the vein is clearly defined at the face of the workings above the adit, where it carries some low-grade ore. The Exchequer tunnel is about half a mile south of this point. It passes through the lower division of the lower rhyolite. About 1,200 feet from the portal this tunnel encountered the upper division of the lower rhyolite, which is probably the hanging-wall rock, in the upper part of the Amethyst vein. The contact strikes about 20° east of north and dips 30° to 60° NW. There is much fracturing in the contact zone, but no clearly defined fault, and the two divisions are at some places tightly frozen to each other. In the upper division of the lower rhyolite there are three or four sheeted or fractured zones which strike northeast and dip northwest. These zones consist of broken rhyolite, cemented by barite but not highly altered by hydrothermal metamorphism. Here and there green copper stains impregnate the rock, and masses of quartz and galena carrying silver have been found. Much crosscutting and drifting has been done from the tunnel level, but thus far no body of workable ore has been encountered. Fragments of streaked purple rhyolite, like those which constitute the lower division, are found embedded in the upper division of the lower rhyolite and in the Exchequer mine appear to be confined to the horizon near the contact. These relations are interpreted to indicate that not much movement has taken place along the actual contact, though, as already stated, there is sheeting and brecciation in the upper division west of the contact.

The theory that the Amethyst vein and the Mammoth vein are on the same fissure is attractive to some, as the Mammoth vein would be near the line of the strike of the Amethyst vein if the latter were projected across the talus slopes in the canyons of East Willow and West Willow creeks from its face in the Bachelor mine. The Mammoth vein carries barite and a little amethystine quartz, with small amounts of silver, gold, and lead, and, like the Amethyst vein, it occupies a fault fissure. Both strike in the northwest quadrant and dip toward the southwest at about the same angle. Between the southeast end of the Amethyst vein and the northwest end of the Mammoth vein, a distance of about $1\frac{1}{8}$ miles, the country is almost completely covered with talus, which accumulates in great quantities on the lower slopes of the canyons of the two forks of Willow Creek. Just west of the East Fork of Willow Creek, about midway between the ends of the two veins, on the Jo Jo claim, a tunnel is driven westward on a slickensided plane of movement. It follows this plane for about 150 feet along its strike, which is S. 83° W. for 60 feet and N. 80° W. for 90 feet. Beyond that point the workings are caved. Near the portal the slickensided footwall shows prominent striæ, dipping 85° W. on the plane of the vein, or 5° west of the direction of the steepest dip. From 6 inches to 2 feet of crushed rock lies above the slickensided surface. Both walls of the Jo Jo fissure are of the lower division of the lower rhyolite. Some quartz that is said to carry small quantities of silver is mingled with the crushed gouge, but no ore has been stoped. The hypothesis has been advanced that the Jo Jo fissure is on the fault which has been developed in the Mammoth workings to the southeast, but no conclusive correlation can be made from the data now available.

### MINERALS OF THE LODE.

The minerals which constitute the unoxidized ore in the lower levels of the Amethyst vein include zinc blende, galena, pyrite, chalcopyrite, gold, barite, and amethystine and white quartz. In the country rock along the vein secondary quartz, chlorite, adularia, and some sericite are developed. A chlorite rich in iron appears to occur in the filled portion of the vein as well as in the country rock near it. At the outcrop, in the oxidized zone, and in the zone of partly oxidized sulphides numerous minerals have formed as a result of the weathering of the sulphide ores. These include limonite, hematite, pyrolusite, kaolin, jarosite, cerusite, smithsonite, anglesite, pyromorphite, cerargyrite, native silver, malachite, and jasper. Argentite has not been identified in the Amethyst ore but is present in other mines in the district and probably in the Amethyst ore also.

Barite is much more abundant in the upper levels and in the south end of the vein than in the lower levels at the north end. It is thus associated with the oxidized ore, although it may be residual in the oxidized zone. Fluorite was not identified in the ore of the Amethyst vein, though it was noted in ore from the Solomon vein.

### OUTCROP.

The outcrop of the Amethyst vein is notably inconspicuous. The sheeting and crushing which are everywhere apparent along the lode have probably favored its disintegration, and it does not form a ridge at any place. At the portal of No. 1 adit on the Bachelor claim the rhyolite is sheeted and barite stringers fill the cracks, but sulphides are very sparingly developed. Southwest of this exposure the apex of the vein, as indicated by the underground developments, is along a ravine which marks the base of a lofty, nearly vertical cliff of rhyolite. Just above the portal of tunnel 4 of the Bachelor and Commodore mines, about 650 feet below tunnel 1, the vein outcrops as a sheeted knob of iron-stained rhyolite, cut by stringers of barite. No exposures are known southwest of this point. A knob of rhyolite, somewhat fractured, is exposed between the portal of the Wooster tunnel and the portal of No. 5 tunnel of the Commodore. Whether this is on or near the apex of the vein has not been determined.

About 1,700 feet north of the portal of tunnel 1 of the Bachelor mine there is a cave on the Commodore claim where the workings extended nearly to the surface, but according to reports the ore did not outcrop at this place. Iron-stained sheeted rhyolite is exposed also just west of the Last Chance shaft near the apex of the vein. About 600 feet north of this point, between the Last Chance shaft and the Amethyst vein, there is considerable evidence of mineralization, and according to report some good ore was taken from the outcrop of the vein. Near the Amethyst shaft the stopes were raised to the very surface and are still open along the outcrop. North of this point the country is covered with glacial débris, and there are no outcrops of the vein.

None of the outcrops that have been mentioned, except the one between the Amethyst and Last Chance shafts, would perhaps be considered particularly promising. At this place only has the ore been worked at the surface, and at most places along the lode the stopes do not extend within 200 feet of the apex. In view of the persistence and the great regularity of the workable ore in the deeper levels these relations may reasonably be interpreted as indicating a leaching of the oxidized zone.

### ZONE OF RICH OXIDES.

The great bonanzas of the Amethyst vein were oxidized or partly oxidized ore. This ore consisted chiefly of lead carbonate with some lead sulphate, carrying high values in silver. The gangue of the ore is quartz and silicified rhyolite stained with iron and manganese oxides. Gold was of subordinate importance in the richer oxidized or partly oxidized ores, although some of this ore carried several hundred ounces of silver to the ton. Some of the silver is present as the chloride, cerargyrite, with which is associated the lead chlorphosphate, pyromorphite. Much native silver was present in the ore mined from the upper levels. It occurred as sheets and stringers in the oxidized ore and as little balls of silver wire nesting in open cavities. A common occurrence is a red jasper with flakes and sheets of the native metal. Some selected specimens of this jasper contain as much as 10 per cent of native silver. In cabinet specimens the sheets of silver exhibit a ribbon-like structure with combs of chalcedonic quartz and both are intergrown and contemporaneous. Under the microscope the jasper is seen to be made up of quartz and finely divided iron oxide. Native silver and jasper are confined to the oxidized ore and were not noted in the lowest levels of the mines.

### SULPHIDE ORES.

In the lower levels, in general about 500 to 800 feet below the apex of the vein, sulphides of zinc and lead become increasingly conspicuous. These are more abundant in ore found at higher elevations in the north end than in the south end of the lode. There is no sharp line of contact between the oxidized and sulphide zone, but along fractures the oxidation extends downward here and there to the adit level. Partly oxidized ore is found in several of the mines 1,000 to 1,400 feet below the surface.

In the lower levels of the Happy Thought and Amethyst mines the sulphide ore is cut in places by seams of black manganese oxide, and the amount of gold in parts of such ore is conspicuously greater. The minerals of the sulphide ore include pyrite, sphalerite, galena, and a little chalcopyrite; probably some argentite is present also. The sulphur compounds of arsenic and antimony have not been noted.

### SECONDARY ENRICHMENT.

In many deposits of copper, silver, and gold the ore near the surface is of relatively low grade and unworkable. At greater depths richer ore is encountered and at still greater depths such ore gives way to lower-grade sulphides. These relations are generally assumed to indicate that the metals have been dissolved out of the upper portion of the ore bodies and have been redeposited lower down. The leached portions of the deposits are in general highly oxidized. The richer portions are only partly oxidized, whereas the lower-grade ore in the deeper portions of the deposits shows comparatively little alteration. Briefly stated, many deposits may be divided into four zones—(1) an oxidized leached zone at or near the surface, (2) an oxidized or partly oxidized zone of richer ore below the leached zone, (3) a zone of rich sulphides below the rich oxidized ore, and (4) the lower-grade primary sulphide ore below the rich sulphides.[1]

These relations are indicated by the vertical distribution of the richer ore of the Amethyst vein. The horizon of the richest ore is in general from 200 to 800 feet below the surface, although such ore extended to the outcrop between the Amethyst and Last Chance shafts. The upper portion of the richer zone was highly oxidized, but a considerable number of nodules and masses of sulphide ore were present in the lower portion and the number of these increased in depth. The values in the oxidized ore are in silver, chiefly as the native metal and the chloride, and in lead, as the carbonate and sulphate. The proportion of gold to silver increased greatly below the thoroughly oxidized ore, suggesting a transfer of gold by descending waters. The lode is very strongly fractured and considerable oxidation has taken place along fractures and seams as deep as exploration has gone, or more than 1,200 feet below the surface. Limonite, set free by the oxidation of iron sulphides, and manganese oxide, liberated by the weathering of amethystine quartz, were deposited along some of these fractures. The great bulk of the ore in the lower levels carries from 6 to 20 ounces of silver to the ton, 5 to 15 per cent of lead, $1 to $2 to the ton in gold, and a variable percentage of zinc. Some of it is well within the limit of profitable exploitation, although it is considerably lower in grade than much of the more highly oxidized ore in the upper levels.

### EXTENSION IN DEPTH.

As bearing on the possibility of profitable developments below the adit level, inquiry may be made respecting the position of this level in the zone of secondary enrichment. If the adit is below the bottom of the altered zone any ore bodies that may be encountered below the adit will be primary. If the adit is above the bottom of the zone of alteration, bodies of enriched ore may be expected. One would be bold indeed to prophesy in advance of development that such ore bodies will or will not be found, yet there is some evidence that bears directly on this point.

With respect to the distribution of silver it may be stated frankly that no bonanzas comparable to those which were worked in the upper levels of the mines have been developed within 100 feet of the adit level. Stopes have been raised at many places from the adit, but they are small compared with those higher in the vein and as already stated the ore in them is generally of lower grade. The evi-

[1] Emmons, S. F., Trans. Am. Inst. Min. Eng., vol. 30, 1900, p. 177.

dence of values alone, however, does not warrant the conclusion that the bottom of the zone of possible enrichment has been reached. The state of the ore with respect to alteration processes is important in this connection. At the southeast portion of the vein, in the Bachelor and Commodore mines, comparatively thorough oxidation extends to greater depths than in the mines on the lode farther north. At some places a considerable amount of oxidation has taken place in the Bachelor mine within 100 feet of the adit, and on the Commodore claim, which lies just north of the Bachelor, a stope called the Wire Silver stope was raised from level E, which is just above the Commodore tunnel. The bottom of this stope is about 225 feet above the Nelson drainage adit and about 1,200 feet below the surface. Although this stope was not accessible to the writers, the presence of wire silver in the ore is regarded as an indication of secondary alteration. A winze that was sunk below the adit in the Bachelor mine is now filled with water, but according to report some sulphide ore of shipping grade was developed.

The fracturing of the lode is very great and the secondary fracturing is complicated, the ore being much more permeable at some places than at others. On the whole, however, the circulation of water from the surface is exceptionally vigorous, owing to the highly fractured condition of the ore. These observations lead to the conclusion, therefore, that the adit level in the Bachelor and Commodore mines is probably not below the bottom of the zone which is marked by partial secondary alteration of the ore. Whether processes of enrichment have gone far enough to make exploration of this part of the lode profitable is a question which can not now be answered.

The northwest end of the lode, as already stated, is not so thoroughly oxidized in the lower levels as the southeast end. Nevertheless the sulphide ore in the lower levels of the Last Chance, Amethyst, and Happy Thought is crossed by numerous fractures in and along which limonite and manganese oxide have formed. Some of the ore which is cut by stringers of these oxides is low-grade concentrating ore. Locally, however, this ore carries considerable values, the increase being mainly gold. On level 12 in the Amethyst mine the ore 350 to 600 feet north of the shaft is composed of galena, zinc blende, pyrite, chalcopyrite, and other minerals and is said to carry about 11 per cent of lead, 6 to 8 ounces to the ton in silver, and about $1.20 to $3 to the ton in gold. In another stope about 800 feet north of the shaft and just below level 12 similar ore containing conspicuous veinlets of manganese oxide carries from $5 to $15 to the ton in gold. In the Happy Thought mine, 370 feet north of the bottom of the shaft, the sulphide ore only 20 feet above the adit level is cut by veinlets of manganese oxide. This ore is said to carry 8 per cent of lead, about $1.80 to the ton in gold, and a little silver.

There is not much doubt that the gold of this ore has been increased somewhat by secondary processes, for the association of gold with manganese dioxide is significant of such processes.[1] For example, in the Happy Thought mine on the Amethyst vein between levels 7 and 8 a body of partly oxidized ore composed of galena, zinc blende, copper carbonates, cerusite, and anglesite carries a conspicuous amount of manganese dioxide, which coats the older sulphides and occurs in fractures cutting the partly oxidized ore. A considerable tonnage of this ore concentrated in the Humphrey mill yielded $20 in gold to the ton, and some of it ran as high as $100 to the ton. This figure is of significant magnitude, for the average content of gold in the Happy Thought ore is about $2 to the ton.

In reviewing these facts it is pertinent to inquire whether they warrant the expectation of any enrichment of gold below the adit level in the north end of the Amethyst vein. It has been shown that gold in these relations is found in stopes just above the adit level, but so far as is now known the enrichment of gold due to secondary deposition at this level is not great. The present methods of concentration, however, permit the recovery of lead, silver, zinc, and gold, and in much of the ore the gold values are rather subordinate. Silver is comparatively low in these levels, but so far as is indicated by the data available there is no reason to suppose that lead and zinc will be less abundant in the zone 200 feet below the adit than in the zone 200 feet above it, provided, of course, that the ore of the vein maintains an equal width.

In connection with the possibilities of profitable development below the adit level certain considerations other than the changes in the character of the ore in depth merit attention. The amount of water which issues from the portal of the adit is very great, and most of it is collected in that part of the adit which is driven on or near the vein. No notable quantity of water is added in the portion of the adit that crosscuts the country rock. In sinking a deep winze that was put down in the footwall in the Commodore mine pumping charges were high, and they would doubtless have been higher if the crosscuts had been run to the vein. Owing to the highly fractured condition of the vein, any project which contemplates deep exploration should provide for handling a considerable proportion of the water now draining from the adit. Some of this drainage could probably be kept out of lower workings, but extensive stoping below the adit would surely increase the flow.

The possibilities of tunnels below the Nelson adit have, of course, been considered. A crosscut driven north for 5,500 feet from a point near the mouth of Windy Gulch should encounter the lode at a depth

[1] Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Trans. Am. Inst. Min. Eng., 1910, p. 767.

between 250 and 300 feet below the Nelson adit. This would not provide for dumping, however, and would necessitate a long extension of the track for disposal of waste. The expense of such an undertaking could be decreased by the development of cheap electric power, but the writers do not profess to know whether the possibilities of finding profitable ore below the adit level would warrant the necessary outlay of capital.

### SOLOMON AND RIDGE GROUP OF MINES.

The Solomon and Ridge group of mines is on the west side of East Willow Creek canyon, about 2 miles north of Creede. The claims located on this group include the Holy Moses, Ridge, Ethel, Mexico, and Solomon. All these deposits are in the two divisions of the lower rhyolite. The principal deposit is an anastamosing fissure vein which strikes about N. 7° W. and dips 55° to 85° W.

Underground developments are almost continuous for about 3,300 feet along the strike of the lode. The most extensive developments are on the level of the Solomon tunnel, which is driven westward from the canyon of East Willow Creek at an elevation of about 9,300 feet. This level encounters the vein about 420 feet from the portal, and from the point of intersection a short drift is driven toward the south. About 75 feet to the north the vein splits, inclosing a narrow block of rhyolite. The two branches diverge along their strike and at a point 800 feet from the intersection they are 300 feet apart. The east branch is termed the Ethel vein and the west branch the Solomon vein. In the Ridge tunnel, which is about 90 feet above the Solomon adit, the east vein is termed the Ridge and the west vein the Mexico. The two branches probably join toward the north, but the point of intersection is not shown in the underground developments of the Solomon and Ridge mines. This point, estimated by projecting the two branches in the workings of the Ridge adit, is probably about 1,950 feet north of the south intersection. If this estimate is correct the horse of rhyolite inclosed between the Solomon vein and the Ethel branch is 1,950 feet long and has a maximum width of about 300 feet. Both veins dip as a rule from 55° to 75° W. but at some places are vertical or dip steeply to the east. North of the point which is assumed to be the north intersection the Solomon vein is developed for about 1,000 feet along the strike. At the north face this vein strikes north and dips 75° W. Above this point, at an elevation about 1,100 feet higher, the Holy Moses vein is developed from No. 1 adit level, where it strikes north and dips 56° to 66° W. Although the underground workings are not connected, it is thought that the Solomon and the Holy Moses veins are on the same lode. If this conclusion is correct the lode is approximately a mile long.

On the surface the Solomon and Ethel veins are exposed at several points on the Ridge ground. Brecciation and slickensiding of the walls are evidence of movement, but so far as may be judged from exposures the faulting has involved but one formation. The ores carry some sulphides at the outcrop. Owing to the low content of gold and silver in these veins, however, very little secondary concentration is apparent at or near the surface.

The ore of the Solomon and Ethel veins is composed of galena, blende, pyrite, and a little chalcopyrite in a gangue of green chlorite, talc, and quartz. A little fluorite is present in some of the ore. It carries a small amount of gold, but its silver content is very low. In some of the ore gold and silver together are below $1 a ton, the lead running as high as 35 per cent. Barite is not abundant in the ore of the vein now exposed, although a little was found in the Holy Moses workings, which are probably on the same vein. Amethystine quartz was not noted, nor is quartz conspicuous in any of the ore. Extensive crushing has taken place since the ore was formed; indeed, both the Solomon and Ethel veins at most places are zones of green gouge with abundant crystals of galena and zinc blende mixed with considerable crushed country rock. At some places the sulphides are powdered and mixed with a green mud resembling putty. There is probably considerable microscopic silica, but very little is visible in much of the ore.

The veins vary in width from 1 or 2 feet up to 15 feet. In the Ridge mine, about 250 feet north of the blind shaft on the lower tunnel level, 150 feet up in the stopes, the vein is 10 or 15 feet wide. It dips 72° W. and a smooth slickensided surface is near the footwall. This surface is polished and grooved by movement, and the grooves are inclined in the plane of the vein, dipping about 15° to the south of the line of steepest dip. The vein here consists of white and green mud, carrying many fragments of rhyolite, not highly altered. Here and there streaks of nearly pure zinc blende and galena are included in the crushed mass, and crystals or lumps of the powdered sulphides impregnate the mass. Locally seams of limonite cross the ore and some portions of the vein are oxidized. The sulphides predominate, however, although the ore is within 150 feet of the surface at this point. About 250 feet north of this point, on the adit level, 400 feet below the surface, oxidized ore was found at the north end of the workings.

Where exposed in the Solomon workings the vein is a great crushed zone, and a slickensided fissure runs nearly the whole distance through which the vein is developed. This fissure is in general on the hanging wall of the vein. About 2,000 feet from the portal of the Solomon adit a shaft has been put down about 400 feet. North of the shaft and about 3,150 feet from the portal of the adit, in a raise 70 feet above the tunnel level, 9 feet of concentrating ore is exposed. This consists of zinc blende, galena, some pyrite, and a little limonite and manganese dioxide. The gangue is crushed rhyolite and green chloritic gouge, much like that in parts of the Amethyst vein. The ore carries 30 per cent of zinc and lead, with 1 to 3 ounces of silver and \$1 to \$2 in gold to the ton.

About 80 feet above tunnel level and 1,100 feet below the surface the sulphides change abruptly to oxides. The ore there consists of cerusite, limonite, manganese dioxide, a little galena and zinc blende, and considerable pyrite. This ore carries about \$2.50 to the ton in gold. Two feet above the partly oxidized ore no unaltered sulphides were noted. The occurrence of oxides along fissures and fractures far below the zone of complete oxidation is conspicuous, as it is also in the Amethyst vein.

### ALPHA LODE.

The Corsair and Alpha mines are at Sunnyside, near the point of the ridge between Miners and Rat creeks, about 2 miles west of Creede. They are on the same lode and together have yielded about \$600,000 in silver. Three adits are driven in the lode at different elevations on the southwest point of McKenzie Mountain. About 900 feet from the portal of the Corsair adit a winze equipped with steam haulage has been sunk to a depth reported to be about 155 feet. This is now submerged. On the surface a number of shallow inclines and pits are sunk on the outcrop, a few of them showing sheeted siliceous rhyolite stained with iron oxides. The vein, striking a little west of north, extends nearly along the crest of the ridge for about 600 feet to a point where it bends northwestward and strikes approximately parallel to Miners Creek. On the surface the dip is 50° to 65° NE.

The deposits are mainly in the lower rhyolite, which is intruded by dikes and irregular masses of quartz monzonite porphyry. The lode occupies a fault fissure, which may be followed along the southwest slope of McKenzie Mountain for 4,000 feet along the strike.

In the upper tunnel on the Alpha claim the vein is encountered about 100 feet from the portal. From that point it is followed northward in a drift 700 feet along the strike. It is a wide faulted zone, sheeted and highly crushed. For the greater part of this distance rhyolite forms the footwall and porphyry the hanging wall. At a point about 550 feet from the portal both walls are porphyry. Near this point the vein splits, and the zone of sheeting and crushing is about 75 feet wide. At the end of the upper tunnel short stopes from 1 to 5 feet wide have been raised on three veins which occupy the sheeted zones.

The workings on the upper tunnel of the Alpha are holed with the workings of the Corsair tunnel, which is driven on the vein at a level

75 feet lower. In the Corsair ground near the boundary between the two properties the vein is greatly fractured. The most persistent fissure strikes north for about 150 feet, then bends, and is followed northwest for 450 feet. For the greater part of this distance a warped slickenslided plane dipping about 53° NE. separates the rhyolite of the footwall from the porphyry of the hanging wall. The ore where stoped was nearly everywhere in the footwall of the fault and showed a preference for rhyolite rather than for porphyry.

The deposit where exposed is a replacement vein. Crustified structures such as are characteristically developed in simple fissure fillings are not conspicuous but were noted at some places. The ore contains much finely divided pyrite and nearly everywhere is heavily stained with iron oxide and a blue sulphate. According to report the values are mainly silver chloride. Barite is present but is not so abundant as on the Amethyst vein. Amethystine quartz is not abundant, but most of the quartz is a chertlike variety, probably a replacement of rhyolite. Argentite, stephanite, and stibnite have been reported from the lower levels, which are now inaccessible. None of the ore is suitable for concentration, and all has been shipped to smelters. That carrying below 30 ounces of silver to the ton is not profitable under present conditions. According to report the bulk of shipments carried between 40 and 70 ounces of silver to the ton, but some selected ore is reported to have carried over 1,100 ounces.

### OTHER MINES AND PROSPECTS.

Besides the mines on the Amethyst, Alpha, Solomon-Ridge, and Mammoth lodes there are several other mines and prospects in the district, some of which have produced a few carloads of ore. Space does not permit more than brief mention of them in this preliminary paper.

Considerable development work has been done in the Monon mine, at Sunnyside, and in the Kreutzer Sonata, Paris, and Diamond King properties, on Miners Creek. Between Sunnyside and Bachelor are the Bethel, Little Gold Dust, Conejos, North Star, and Jack Pot lodes. North of the Park Regent mine are the Dolgooth, the Captive Inca, and the Equity. The Oxide claims are southeast of the Mammoth claim, probably on the extension of the Mammoth vein. The Jo Jo, between the Bachelor and the Mammoth veins, has already been mentioned. Several claims are located in the steep cliffs which form the west slopes of Mammoth Mountain. Of these the Mollie S., Eunice, and Homestake have produced some ore. The Monte Carlo mine is across the canyon of East Willow Creek, opposite the Mollie S., and the ore of the two mines has many features in common. Two or three prospects located near the head of West Willow Creek have not yet been visited.

# A PRELIMINARY ACCOUNT OF THE ORE DEPOSITS OF THE LOON CREEK DISTRICT, IDAHO.

By Joseph B. Umpleby.

## SITUATION AND HISTORY.

The Loon Creek district comprises an unorganized area of perhaps 75 square miles situated in the northwestern part of Custer County, Idaho. It is drained by the headwaters of Loon Creek, a tributary to the Middle Fork of Salmon River. The Parker Mountain district lies to the northeast, Sheep Mountain to the west, and the Yankee Fork district to the southeast. Mackay, Idaho, situated 110 miles southeast of Ivers, the principal local settlement, is the supply point for the region.

Placers which are variously estimated to have produced from $500,000 to $2,000,000 in gold were worked actively on Loon Creek during the decade closing with 1879. Most of the white men in the camp, attracted by other placer excitements, left the creek in the middle seventies, but 30 or 40 Chinamen remained. In 1879 all of these were massacred save one, who escaped on snowshoes At that time it was commonly supposed that Indians committed the deed, but now it is the prevalent opinion that white men were guilty. Since then comparatively little mining has been done on the creek, though all the promising ground is held as placer claims.

The principal property in the district at present is the Lost Packer mine, located by Clarence E. Eddie, a prospector, in July, 1902. Soon thereafter it was purchased by Ivers & Finlan, of Salt Lake, who began to develop it in the spring of 1904. A 100-ton smelter was completed in 1905, and although it has been necessary to haul coke 110 miles, development has been carried on with the returns from three short smelter runs—one in 1907, one in 1908, and one in 1911. Several other properties are situated in the district, but they are little developed and most of them have changed hands several times, successive holders becoming discouraged because of the difficulties of transportation. As a whole, the district is inadequately prospected and mining is in an initial state. Among the lode deposits those of gold-copper and silver-lead are most promising.

## CONDITIONS AFFECTING MINING.

The district is a well-timbered and well-watered area of bold topographic forms. Sites suitable for the development of water power are numerous, though only Canyon Creek, a comparatively small stream, is now being utilized. The bold relief makes it possible to obtain a depth of 1,000 to 2,000 feet on most of the deposits without resorting to shafts. Suitable fluxes for local smelting are abundant in the district. Indeed, the only handicap to successful and economical mining operations is the expense of freighting supplies and especially coke from the Oregon Short Line terminus at Mackay, 110 miles distant. The route is difficult because of two high summits which must be crossed in addition to the 3-mile climb from Loon Creek to Ivers. The cost of haulage is 2½ cents a pound per round trip. When a load can be taken each way this is split into 1½ cents in and 1 cent out. The cost of coke is therefore the prime problem in local smelting, its average price laid down at Ivers being $46 a ton.

The various expenses charged against a ton of ore delivered as matte, f. o. b. Mackay, aggregate $20 to $22. It is this high cost which is serving as a damper on development in the Loon Creek and adjoining districts; the need of the region is railroad transportation. Only ores running $60 to $80 a ton have been smelted, but for every ton of this grade which has been developed there are estimated to be 2½ tons which will average $25.

## GEOLOGY.

*Physiography.*—The Loon Creek district is a mountainous area varying in elevation from 5,000 to more than 9,500 feet. Loon Creek, a rapid stream averaging perhaps 30 feet in width, flows north through the area. Its most important tributaries are Mayfield and Cottonwood creeks from the east and Trail, Canyon, and Grouse creeks from the west. The area is a part of that broad region known as the Salmon River Mountains and preserves upon its highest parts the Eocene erosion surface from which those mountains were carved. These remnants constitute the most significant geologic datum plane in the region.

*Sedimentary rocks.*—The oldest rocks recognized in the district are mica schists and quartzites of Algonkian age, which outcrop over an irregular area of about 2 square miles in the central part of the district. In most directions they are cut off by late Cretaceous or early Eocene quartz diorite, but to the north they disappear beneath a capping of quartz latite. Throughout these ancient sediments few bedding planes are discernible, a strong schistosity striking west of north and dipping southwest being the dominant structural feature.

Overlying the Algonkian rocks in the south-central part of the area are beds of Paleozoic age. Although these beds are presumably separated from the underlying rocks by a pronounced structural unconformity, this relation was not observed in any of the exposures visited. As a rule areas of intrusive rock separate the two sedimentary terranes, but near the Lost Eagle mine they are in juxtaposition. This contact, however, is probably due to faulting. The Paleozoic series includes fine-grained quartzites and massive blue dolomitic limestones, both apparently nonfossiliferous. Nevertheless the similarity of the rocks to those at Gilmore, Lemhi County,[1] suggests that the quartzite is of Cambrian age, and that the massive blue dolomitic limestone is Ordovician. Their thicknesses were not determined. Higher beds of the Paleozoic probably outcrop in the extreme south-central part of the district, but this area was not visited.

*Igneous rocks.*—Igneous rocks of diversified types are widely distributed in the Loon Creek district. The oldest of these is a great batholithic mass of quartz diorite that extends into the district from the west. Outliers from it appear at several places east of the area of Algonkian schists, and about 3 miles farther east another broad area of the batholith, which is thought to underlie the entire district, is uncovered. The rock has a dark-gray color, due to the conspicuous amounts of biotite scattered through it. The feldspars are of medium size and about the composition of oligoclase. Orthoclase, though commonly present, is not an essential constituent. Quartz occurs as irregular grains and small interstitial fillings. Hornblende, nowhere abundant, and titanite and apatite are commonly present. This rock is thought to be a special phase of the great granitic intrusion which occupies an area of more than 20,000 square miles in central Idaho. This intrusion has been assigned, on what seems to be sound evidence, to the late Cretaceous or early Eocene.

Closely related to the quartz diorite are dikes of granite that is notably poor in ferromagnesian minerals. These are excellently shown in the Lost Packer mine, where they vary from narrow stringers to dikes 30 feet or more in width and usually follow the schistosity of the Algonkian rocks. Locally, however, they follow the vein fissure, which strikes west of north but at a much lower angle than the schistosity of the inclosing formation. It is thought that this rock is younger than the quartz diorite intrusion and that it is a differentiation from that mass. It is older than the ore deposits. When examined microscopically the granite dikes are seen to be made up of microcline, orthoclase, quartz, muscovite, a little plagioclase, and subordinate amounts of biotite. Apatite and zircon are the principal accessory minerals. Secondary pyrite is developed locally.

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: Bull. U. S. Geol. Survey No. 528 (in press).

Subsequent in age to both the granite dikes and the veins are dikes and sills of granite porphyry and diorite porphyry. The relative age of these rocks has not been satisfactorily determined, although there is some evidence for thinking that the diorite is the older. Both rocks traverse the ore in several places and on the No. 3 level of the Lost Packer mine the two intersect, but the fine grained and extremely altered condition of the specimens from this point make it impossible to determine whether the older one should be correlated with the diorite porphyry or with the granite porphyry. Near the portal of No. 6 tunnel, however, the diorite porphyry presents a marginal facies similar to the older dike in No. 3 tunnel and from this it is thought that the granite porphyry is the younger. In the larger masses a phenocrystic development of quartz characterizes the granite porphyry, but this is lacking in the narrower dikes.

Eruptive quartz latites, probably still younger than the dikes and sills described above and certainly more recent than the veins, cap the summit above the Lost Packer mine. They are gray in color and are made up of phenocrysts of oligoclase, quartz, and biotite set in a microcrystalline groundmass which constitutes perhaps 60 per cent of the rock. Partial chemical analysis reveals 3.26 per cent of potassium oxide, which makes it necessary to class them as quartz latites instead of dacites as suggested by the microscopic description. It is thought that they are younger than the Eocene erosion surface.

*Glaciation.*—During the Pleistocene epoch alpine glaciers extended down the larger valleys to points about 7,000 feet above the sea—locally perhaps to 6,000 feet. Canyon Creek, which supplies water and hydroelectric power to Ivers, heads in three little lakes situated in the floor of a broad cirque in the north slope of Pinon Mountain and illustrates well the habits and limits of the local glaciation.

## ORE DEPOSITS.

### GENERAL FEATURES.

The Loon Creek district is noteworthy at present because of its gold deposits. These include lodes in which chalcopyrite and siderite carry most of the gold and placers along the streams in favorable places below them. From the lodes $350,000 has been derived, and from the placers possibly $1,000,000. The lode deposits have yielded $150,000 in copper along with the gold. Lodes of lead-silver have also been recognized in the district, but are inadequately developed. The ore found in them, however, is of excellent grade, being in many places clean galena carrying from 60 to 100 ounces of silver to the ton.

Excellent iron and lime fluxes are abundant along the contact between the Paleozoic limestone and the quartz diorite south of Ivers. These contain about 60 cents in gold and 1 ounce in silver to the ton—almost sufficient to pay for handling them. Whether or not they are contact-metamorphic deposits has not been established.

### GOLD-PLACER DEPOSITS.

The Loon Creek Hydraulic Placer Co. owns six claims—in all, 470 acres—which extend from a point near the mouth of Canyon Creek to the Loon Creek Narrows, 4½ miles north. The average width is approximately 1,000 feet. A strip about 75 feet wide and 1 mile long, comprising the upper part of the central channel, was worked during the early seventies and is said to have produced a large amount of gold, occasional pans containing as much as $300. The gravels here were from 2 to 6 feet thick, but back of them are gravel terraces which were not explored during the early days. The present owners prospected these terraces during two seasons, making an average saving of 25 cents a cubic yard. A flume capable of delivering 80 second-feet of water to any point on the ground is partially completed and is part of a matured plan for hydraulicking the entire deposit. Heretofore water has been derived from two small streams—Grouse Creek and White Creek—but the present plans include the diversion of Loon Creek at a point well above the placers.

The auriferous gravels rest upon a floor of schist which as now explored presents a comparatively even surface. The gravel beds are rarely more than 15 or 20 feet thick, although locally attaining a depth of 30 or 40 feet. The individual pebbles are usually less than 6 inches in diameter, but locally bowlders up to 3 feet and rarely 6 feet in diameter are found at various distances from the base of the deposit. Being loosely cemented, the gravels fall apart readily when undermined by the giant. The gold is near bedrock, commonly in joints and shallow depressions in it, and as a rule is coarse, nuggets weighing more than an ounce being not uncommon and perhaps 50 per cent of the product averaging 25 cents a color or more. Its market value is $18 an ounce.

### GOLD-COPPER DEPOSITS.

A description of the Lost Packer vein constitutes essentially a description of the known gold-copper deposits of the district. Other veins are recognized, but they are little developed and have produced only returns from test samples. Promising among these is the Effa ledge, which outcrops a few hundred feet west of the Lost Packer vein. The Sunset and South Packer groups also present some encouragement to the holders, although the small amount of development on them has not revealed commercial deposits.

The Lost Packer vein is a fissure filling inclosed in mica schist throughout most of its extent, though in places it traverses granite dikes. Later than the vein are a number of flat-lying dikes of granite porphyry and diorite porphyry, which vary in width from 5 to 80 feet, those about 30 feet across being most common. Ten of these dikes have been encountered and each one traverses the vein. The ore adjacent to them is usually crushed, and in places is separated from the intrusion by a gougelike layer as much as 3 inches thick. The most important effect of the dikes on the ore body, however, consists of offsets. In places there is a small lateral displacement of the vein as if the dike had entered along a fault plane, but usually the intrusion has acted simply as a wedge, prying apart portions of the vein formerly contiguous and leaving them opposite each other along a course at right angles to its surfaces. As the dikes roughly parallel the ore body in strike but dip westward at a much lower angle than it, there is a series of offsets to the east with increasing depth on the vein. (See fig. 13.)

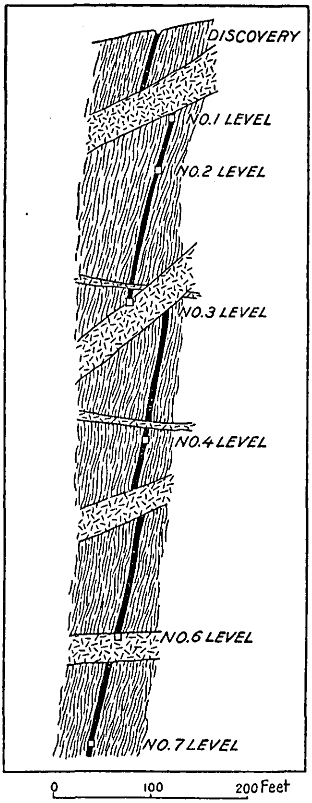



FIGURE 13.—Transverse section through Lost Packer vein, Loon Creek district, Idaho, looking north. Illustrates offsets in the vein caused by the intrusion of dikes.

The Lost Packer group of six claims and two fractions covers the known extent of the Lost Packer vein, which begins at Ivers and extends northward, successive portals being near the bed of the steep gulch which it approximately follows. The vein strikes north and south and dips 75° W. The development consists of 10 tunnels aggregating about 10,000 feet in length, which explore the deposit to a level 1,000 feet below its highest outcrop.

The vein varies in width from a fraction of an inch to 4 or 5 feet, averaging perhaps 20 inches. In most places it lies between well-defined walls which stand about 5 feet apart, the intervening material being gouge, sheeted schist, or ore. In many places all three appear in the same cross section, but even there the ore is usually a separate band, next to either the hanging wall or the footwall, more commonly the latter. In a few places small lenses of ore occur in the schist as far as 20 feet from the vein, but this is exceptional; usually the mineralization is confined to the fissure.

Three ore shoots, locally designated the north, south, and middle shoots, are recognized in the vein. These are connected on some levels by stringers, but as they are not of the same degree of importance and as they present somewhat different types of mineralization, they will be discussed separately. The north shoot is reached only by No. 4 and No. 3 tunnels. On the former it is 120 feet and on the latter 250 feet in length. Its average width is about 2 feet. The ore consists of coarse-textured milky to bluish-white quartz, with chalcopyrite and a little pyrrhotite and pyrite irregularly scattered through it, the chalcopyrite in places inclosing small crystals of the other minerals. On No. 3 level siderite is rare, but on the next level below it is equally abundant with chalcopyrite and presents a similarly irregular distribution. This ore body is comparatively lean, roughly sorted material running about $20 a ton—half an ounce of gold, 2 ounces of silver, and 3.5 per cent of copper.

The middle shoot is by far the most important in the mine. It lies 200 feet south of the north shoot and is developed from the seventh level to the quartz latite capping, 700 feet above. Like the two others, it has a general pitch to the south. The southern limit of ore is a fairly regular line, but the north boundary is not parallel to it. Thus the shoot is about 500 feet long on No. 2 level but narrows both above and below, so that its average length is about 300 feet.

In places this ore body stands in slight relief at the surface as a honeycombed quartz heavily stained by iron, together with a little manganese oxide and copper carbonate. Usually, however, it has little or no surface expression. Oxidation is unimportant in the deposit, primary ore predominating at a depth of 30 or 40 feet and being exclusively present below 70 or 80 feet. The ore averages about 20 inches in width, but locally is as much as 4 or 5 feet, wedging out on the ends of the shoot. This wedging out of the shoot seems to bear a definite relation to the tenor of the ore, for it has been commonly found that as the ore body narrows its assay value diminishes. Thus the ends of stopes temporarily abandoned are usually in ore running about $25 a ton, whereas the portion removed varies between $60 and $80 a ton. On No. 4 level the middle shoot is shorter than anywhere else in the mine and here also it contains a minimum amount of gold. Ore from levels both above and below ran 2 to 3 ounces of gold to the ton, but here less than 1 ounce was present.

The ore consists essentially of chalcopyrite distributed as bunches, small patches, irregular grains, and interstitial fillings in a gangue of coarse white quartz. The copper mineral constitutes about one-third of the total material mined. Siderite is present in small amounts but is not an important constituent. The chalcopyrite and quartz carry each about 3 ounces in gold to the ton, but less than half an ounce is present in the siderite.

The south shoot of ore differs markedly from the other two in the high percentage of siderite which it contains. It lies 500 feet south of the middle shoot and is developed from No. 10 level to its outcrop near the portal of No. 6 tunnel. This ore body varies in length from 75 to 150 feet and is about 20 inches wide. It consists of siderite and chalcopyrite in a gangue of coarsely crystallized quartz, in such proportions that the ore runs 26 per cent of iron and 4.5 per cent of copper. Gold and silver, averaging half an ounce and 3 ounces, respectively, are present. This shoot of ore is a valuable asset to the mine because it combines a fair amount of the precious metals and copper with an excess of iron, an element which must be added in the smelting of ores from the other shoots.

The three ore shoots worked in the Lost Packer mine have been described as separate units and as such they are mined, but in reality they are not distinct. All occur on the same fissure and on most levels stringers of low-grade ore connect them.

Considerable ore is blocked out in the mine and this will probably be materially increased during the present year. Returns from the last smelter run will be used to extend No. 7 tunnel beneath the north shoot and No. 10 tunnel beneath the middle shoot.

## SILVER-LEAD DEPOSITS.

Silver-lead deposits have been found near the limestone area south of Ivers. The Lost Eagle claim and the Metcalf group are the principal properties, but neither is sufficiently developed to afford a satisfactory idea of the nature or extent of the ore bodies. Their occurrence, however, is thought to be of special significance and in order to emphasize this they will be described briefly. The Lost Eagle is situated on the divide between Canyon and Deer Creek cirques, at an elevation of 8,800 feet above the sea. It is inclosed in Algonkian schist though removed but a few hundred feet from an area of Paleozoic dolomitic limestone. The development consists of a shaft 50 feet deep and a short drift from it. The vein, which strikes N. 5° W. and dips 85° SW., is about 6 feet wide and is bordered by well-defined walls. Between them is crushed wall rock inclosing bands and interstitial areas of argentiferous galena, pyrite, and a little chalcopyrite in a quartz-siderite gangue.

The Metcalf property, situated about 1,000 feet northeast of the Lost Eagle shaft, contains an irregular vein partly developed for about 100 feet along its outcrop. The deposit is a fissure filling inclosed in granite near its contact with Paleozoic dolomitic limestone. The ore consists of argentiferous galena which fills the fissure almost exclusively and varies from a narrow stringer in most places to a body 3½ feet wide locally. The galena contains about 1 ounce of silver to the unit of lead.

In both of these deposits the amount of ore actually found is not of so much significance as its mode of occurrence. Both deposits are inclosed in rocks which are not nearly as favorable to the deposition of lead ore as limestone, even where that is impure; hence, in the opinion of the writer, the area of dolomitic limestone adjacent to them should be encouraging territory for the prospector. In the few places where time permitted an examination of the dolomitic limestone it was found to be rather intensely mineralized. The three iron mines which supply flux to the Ivers smelter illustrate this point. Each is a deposit of pyrite, now oxidized, which has replaced the dolomitic limestone.

## SUMMARY OF CONCLUSIONS.

The more important points brought out in this preliminary report may be summarized as follows:

1. The Loon Creek district is a poorly prospected area of more than ordinary promise.
2. It is held back primarily by inadequate transportation, the nearest railroad point being 110 miles distant.
3. There are noteworthy gold placers in the area.
4. The principal gold-copper deposit has been explored to a depth of 1,000 feet, and throughout this extent the ore has ranged in value from $25 to $90 a ton, giving no evidence of impoverishment with increasing depth.
5. The area of dolomitic limestone near the head of Deer Creek is thought to be a promising field in which to prospect for lead-silver deposits.

# GEOLOGY OF THE ST. JOE-CLEARWATER REGION, IDAHO.

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

## INTRODUCTION.

The classification of lands of the Northern Pacific Railway Co.'s grant in the upper St. Joe and Clearwater basins, in northern Idaho, was commenced in the field season of 1910 by three parties of the Geological Survey. Owing to the shortness of the season and the difficulties encountered in this region, the classification was not completed in 1910. In 1911 the area remaining to be classified was examined by F. C. Calkins, with E. L. Jones, jr., as assistant, and was topographically mapped by J. E. Blackburn. The results of the geologic work performed in 1910 have been published in a paper by J. T. Pardee,[1] and the present report is intended to supplement that paper.

The tract examined in 1911, a map of which forms Plate II, has an area of about 250 square miles. It lies north of the forty-seventh parallel, in the northern part of Idaho and near its eastern boundary, which is formed by the watershed of the Bitterroot Mountains. The Cœur d'Alene lead-mining district is 20 or 30 miles away in a northwesterly direction.

## GEOGRAPHY.

*Relief.*—The region is mostly occupied by flat-topped or gently sloping ridges, the remnants of what has been described[2] as representing an old erosion surface of low relief, into which the intricate drainage systems of St. Joe and Clearwater rivers have been entrenched. Some peaks attain elevations several hundred feet above the ridges on which they are situated, and among these the group known as the Three Sisters, on the divide between the forks of

[1] Geology and mineralization of the upper St. Joe River basin, Idaho: Bull. U. S. Geol. Survey No. 470, 1910, pp. 39-61.

[2] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 59. 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, p. 75.

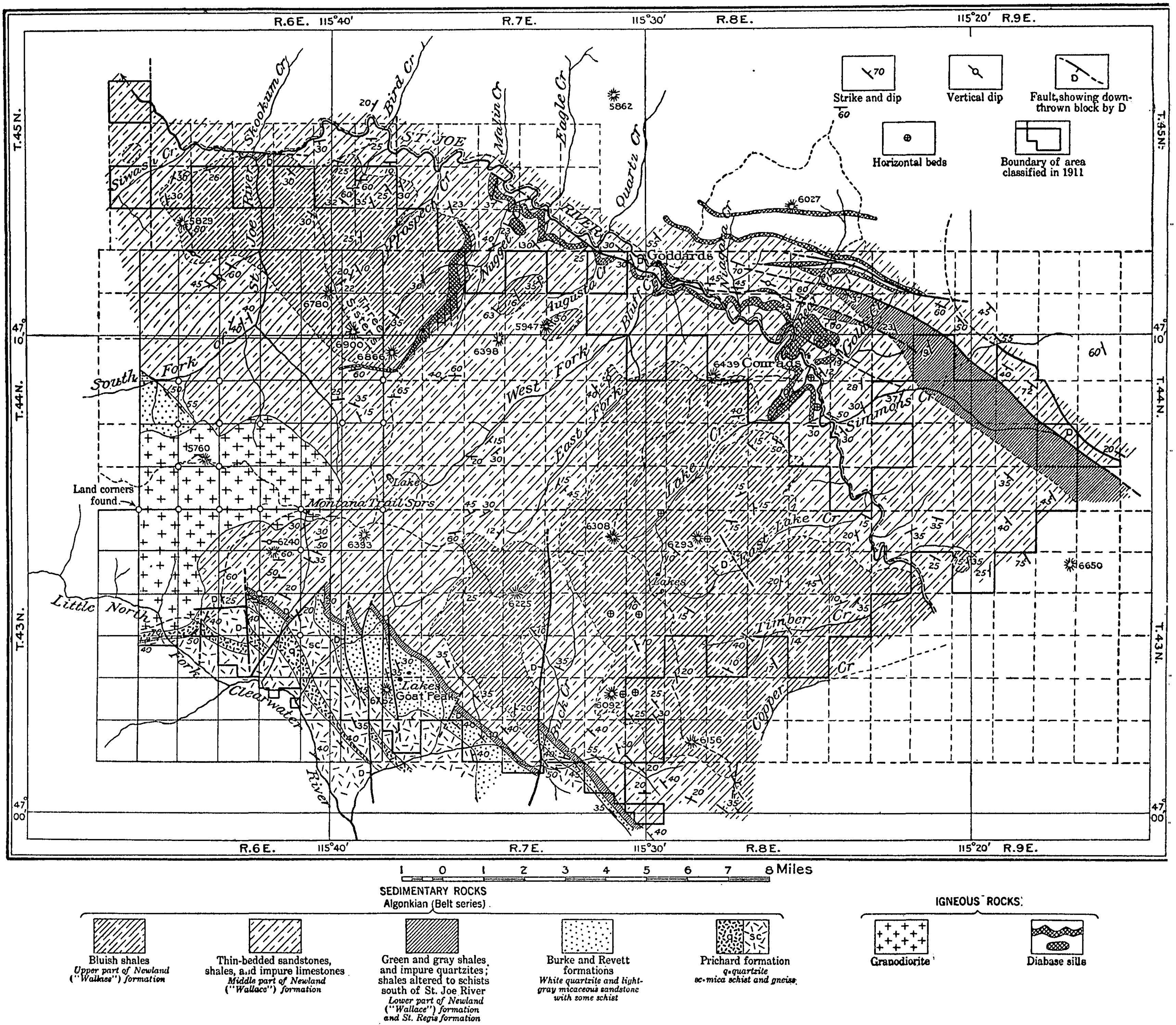
St. Joe River and Goat Peak, on an outlying ridge near the southern boundary of the area, is the most prominent. The Three Sisters are approximately 6,900 feet and Goat Peak is 6,760 feet in elevation. Average elevations on the main divide are about 6,000 feet; elevations on St. Joe River are 2,700 feet at the mouth of Skookum Creek and 3,300 feet at Conrads.

*Drainage.*—St. Joe River, with its principal tributaries, South Fork and Bluff, Lake, Simmons, Gold, and Bear creeks, drains two-thirds of the area under examination. The remaining southwestern part is drained by the headwaters of the Little North Fork of Clearwater River. The heavy vegetation, combined with abundant precipitation, conserves the water supply, so that all the streams maintain a large volume of water throughout the year.

*Vegetation.*—With the exception of steep southern slopes most of this region previous to the forest fires of 1910 was covered with a dense growth of coniferous trees and underbrush; but now nearly the whole area drained by St. Joe River south of the East Fork of Bluff Creek and by the Little North Fork of Clearwater River south and east of a stream flowing west from Goat Peak is burned over. The northwestern part of the area also suffered heavily from the fires of 1910. Many evidences of ancient fires and various stages of reforestation were noted in this region. Stumps of trees several feet in diameter were found standing in a forest of trees uniformly about a foot in diameter. Other areas are covered by a growth of trees but a few feet in height. The south and west slopes of the St. Joe-Clearwater divide, as well as the divide separating St. Joe River from the South Fork, are less susceptible to reforestation than the northern slopes, but they support a luxuriant growth of grass in many places, as well as numerous patches of huckleberry bushes and other shrubs.

The dense vegetation in large part conceals the rock outcrops and has greatly hindered the thorough prospecting of this region.

*Trails.*—A few trails suitable for pack animals are the only means of access to this region. It is usually entered by way of the trail leading up the St. Joe from Avery to Conrads. From Conrads a good trail leads northward to De Borgia, Mont., distant about 20 miles. The most frequently traveled route across the area south of the river runs in a general southwesterly direction from Conrads and ultimately reaches Clarkia. It joins others leading westward and southeastward along the St. Joe-Clearwater divide and northward over the Three Sisters to the St. Joe. The trails within the limits of the area mapped are in general fairly good, but the one that follows the divide west of the Montana Trail Springs is badly clogged with fallen timber, and the trail from the river to the Three Sisters is in places very steep.




GEOLOGIC MAP OF ST. JOE-CLEARWATER REGION, IDAHO.

# GEOLOGY.

## SEDIMENTARY ROCKS.

### BELT SERIES (ALGONKIAN).

#### GENERAL STRATIGRAPHY.

The greater part of the area is occupied by Algonkian sedimentary rocks which represent formations exposed in the Cœur d'Alene mining district. In the 30 miles, more or less, that intervene between that district and the area examined in 1911 the lithologic features of the series are sufficiently constant to make general correlation possible. Detailed correlation, however, is made difficult by the fact that certain formations vary greatly in thickness within this distance and some exhibit variations in lithologic character which are accentuated by metamorphism.

The general character of the rocks, as well as of their variations, is shown in the following sections. In each column the descriptions of beds supposed to be equivalent are placed in the same horizontal position, and horizontal lines mark the limits of cartographic units.

*Sections of Algonkian rocks (Belt series) in Idaho.*

| Cœur d'Alene district. | Vicinity of St. Joe River. | Vicinity of Clearwater River. |
|---|---|---|
| *Striped Peak formation:* Red and green shales and sandstones. | Removed by erosion............ | Removed by erosion. |
| *Newland ("Wallace") formation* (total thickness 4,000 feet):[a]<br>Bluish and greenish shales, partly calcareous. | Blue shales, mostly free from lime, partly altered to schists and hornstones. Thickness, 2,500 feet. Top removed by erosion. | Mica schists with garnet, cyanite, and scapolite. Top removed by erosion. |
| Interbedded calcareous shale, sandstone, and impure limestone. | Interbedded calcareous shale and sandstone; the shales partly altered to hornstone. Thickness, 2,000 feet. | Schist and hornstone containing scapolite interbedded with calcareous sandstone and quartzite. Thickness, 2,000 feet. |
| Green shales, calcareous in part.. | Green shales, calcareous in part; locally altered to green hornstone containing scapolite. Thickness, 1,500 feet. | Mica schist, locally scapolite bearing, with some interbedded quartzite. Thickness, about 500 feet. Not readily separated from overlying beds. |
| Ravalli group:<br>*St. Regis formation:* Purple and green shales and sandstones. Thickness, 1,000 feet. | Gray sandstones with interbedded shales. Little or no carbonate. Thickness, 1,000 feet. Base not exposed. Possibly includes part of Revett quartzite. | |
| *Revett quartzite:* White thick-bedded quartzite. Thickness, 1,000 feet. | .................................... | White thick-bedded quartzite. Thickness, 1,500± feet. |
| *Burke formation:* Pale-tinted siliceous shale and flaggy quartzites. Thickness, 2,000 feet. | .................................... | Flaggy sandstone and quartzite interbedded with mica schist. Thickness, 1,000± feet. |
| *Prichard formation:* Blue shale or slate with subordinate interbedded gray sandstone. Thickness, 8,000 feet. Base not exposed. | .................................... | Mica schist, with subordinate quartzite. Thickness, 2,000± feet.<br>Quartzite with subordinate schist. Thickness, 1,500 feet.<br>Schist. Thickness, 2,000± feet. Base not exposed. Intruded by granodiorite gneiss. |

[a] "Wallace" is the name originally applied to the formation in the Cœur d'Alene district. (See Prof. Paper U. S. Geol. Survey No. 62, 1908.)

### LITHOLOGY AND VARIATIONS.

The rocks referred to the Prichard formation of the Cœur d'Alene district are exposed only in the vicinity of Clearwater River, where they have been subjected to intense metamorphism. They consist of mica schist and pure-white quartzite, with rocks of intermediate composition, comprising micaceous quartzites and siliceous schists. Garnet is commonly present in the schists and some of the less pure quartzites.

This assemblage of strata differs strikingly from the typical Prichard formation, inasmuch as it includes a thick and well-defined quartzitic member. This difference in the lowest part of the stratigraphic column is explainable according to one of two hypotheses, choice between which is not determined by the facts in hand. The quartzite member may be older than any beds exposed in the Cœur d'Alene district; in this case the Prichard must thin out toward the south. The alternative hypothesis is that some of the sandstones comprised in the Prichard of the type section may pass horizontally into quartzites that are much more purely siliceous.

Above the schists correlated with the Prichard and likewise exposed in the Clearwater basin are quartzitic rocks which correspond closely in character to the Burke and Revett formations but whose total thickness is somewhat less. These are mapped as a unit, but they comprise an upper and a lower division that are fairly distinct in good exposures. The upper division consists mostly of vitreous quartzite; the lower division consists chiefly of a peculiar soft-weathering light-gray micaceous sandstone, with which some flaggy quartzite and schist is interbedded.

Some of the most serious difficulties in the way of exact correlation pertain to the beds at the horizon, approximately, of the St. Regis formation. North of St. Joe River rocks are exposed which correspond closely to those of the typical St. Regis in most respects; they consist partly of light-gray impure quartzite, in beds a foot or less in thickness, in which ripple marks and other features indicating deposition in shallow water are conspicuous, and partly of greenish-gray shale. The sole respect in which these rocks differ from those of the St. Regis of the type localities is in the absence of the purple color which, in the Cœur d'Alene district, was regarded as the diagnostic feature of the formation. It is possible that the destruction of this color has been one of the effects of the slight igneous metamorphism that prevails where these rocks are exposed. Owing to the absence of this distinctive feature, the rocks in question can not readily be separated from the overlying beds, which constitute the lower part of the Newland ("Wallace") formation, for they grade into these and do not essentially differ from them except in being more sandy. For this reason the beds representing the lower part of the Newland are mapped with those representing the St. Regis north of St. Joe River.

The lower part of the Newland formation, as exposed in the basin of Simmons Creek, presents much the same appearance that it has in the Cœur d'Alene district. It consists chiefly of gray-green fine-grained argillite but includes a little greenish-white sandstone in thin beds. Metamorphism of rather slight intensity has given the argillite a perceptibly crystalline appearance and has caused the formation of round whitish grains of scapolite, which are somewhat less abundant and conspicuous than in the overlying portion of the Newland formation.

In the Clearwater basin the division corresponding to the Revett and the lower part of the Newland ("Wallace") is so thin and ill defined that it would hardly deserve to rank as a stratigraphic unit if that area were considered by itself; but it is distinguished on the map for the sake of consistency. The beds that here intervene between those that correspond in lithologic character to the Revett and the middle part of the Newland, respectively, are only about 500 feet in thickness, compared with 2,500 feet north of St. Joe River. They consist in general of gray or brown, rather siliceous mica schist and micaceous quartzite. A little scapolite which occurs in certain beds of schist indicates the presence of a small amount of lime. If the purplish and greenish tints that distinguish equivalents of these beds in the Cœur d'Alene district were originally present here, they have been obliterated by metamorphism, so that these rocks present no marked contrast to those that overlie them.

The beds representing the middle part of the Newland ("Wallace") formation maintain, apart from the effects of metamorphism, a fairly uniform character throughout the region. They are not exposed in a wholly unmetamorphosed condition in any part of the area classified in 1911, but they are little altered in some parts of the area examined that lie a short distance north of the river. They consist essentially of alternating thin beds of calcareous argillite and sandstone. The argillite is mostly dark blue, but that in the lower part of this stratigraphic division is greenish; the sandstone is gray or white, and, although most of it is calcareous, it comprises some quartzite free from lime and similar to the Revett quartzite. The rocks in part of the stratigraphic series differ from their equivalents in the Cœur d'Alene district chiefly in being somewhat less limy and in containing a larger proportion of sandy beds.

The effect of metamorphism is clearly manifested, in nearly the whole of the area mapped, by the argillaceous layers. These become altered, for the most part, to chocolate-colored biotitic hornstones of fine texture, in which roundish grains of scapolite whose average diameter is about that of buckshot are abundant. On weathered surfaces the scapolite grains are white, in strong contrast with their dark matrix, from which they project in relief.

In general these rocks are easily weathered and not well exposed, except on the steep slopes of cirques or canyons.

One of the most striking differences between the stratigraphy of the Cœur d'Alene district and that of the area here described consists in the great development in the latter area of the rocks representing the upper part of the Newland ("Wallace") formation, which are apparently several times thicker than in the Cœur d'Alene district and constitute a well-defined stratigraphic unit. Locally, indeed, a thin conglomerate with sandstone pebbles is found near their base, which makes it appear possible that their great variation in thickness is due to unconformity and overlap.

This division is remarkably homogeneous and consists almost wholly of material that in an unaltered state is a regularly banded shale in which dark-blue layers about half an inch thick alternate with thinner light-green layers. These beds, in contrast to those of the middle part of the Newland, are almost free from lime and are comparatively resistant to erosion, so that good exposures of them are common.

Metamorphism, where of slight extent, gives these rocks a brownish cast owing to the development of biotite. Where the metamorphism is more advanced it results in the formation of garnetiferous schists, which form the country rock of the Three Sisters. Over extensive areas metamorphism is still more strongly manifested by the development of brown staurolite crystals, largely in the form of cross twins, which attain lengths of 2 or 3 inches, and of pale-blue cyanite crystals whose maximum length is still greater. These minerals are conspicuous along the St. Joe-Clearwater divide. Where the metamorphism is extreme the schists take on a coarse crinkly texture and resemble those of the strata correlated with the Prichard.

## IGNEOUS ROCKS.

### KINDS AND SEQUENCE.

The Algonkian sediments have been invaded by the following intrusive rocks, named in order of age: Diabase (partly altered to amphibolite), granodiorite (altered to gneiss), pegmatite, a second granodiorite with apophyses of granodiorite porphyry, quartz porphyry, and diabase porphyry. In addition to these there are dioritic dikes whose relation to the other intrusives is not known, and a breccia, possibly of volcanic origin, which occurs in small quantity.

### CHARACTER AND OCCURRENCE.

Diabase sills of remarkable persistence occur at several horizons within this region. The principal one, named by Pardee the "Wishards sill," is intruded in the quartzites of the middle division of the Newland formation. This sill has been traced by Pardee along the Bitterroot divide for a distance of 15 miles. In the vicinity of Wishards Peak it leaves the divide and, through a series of faults, is finally thrown south of St. Joe River, where for many miles it forms a prominent bluff.

Another sill of some importance occurs near the base of the upper division of the Newland. It is best exposed on Nugget Creek, where the outcrop forms a striking bench. This sill is very persistent, although its thickness is much less in other areas. Occurrences of metamorphosed diabase stratigraphically lower than those previously noted consist of amphibolite found in the quartzites on Goat Peak and also near the Little North Fork of Clearwater River in close proximity to the granite gneiss.

The diabase is greenish black in color, spotted with white feldspar laths. The texture varies from fine grained to coarsely granitoid. The principal original constituents are labradorite, augite that is purplish in thin section, interstitial quartz and alkali feldspar, and numerous grains of ilmenite.

Metamorphism of the diabase has altered most of the augite to hornblende, has formed in places large garnet crystals, and in the intrusions intercalated with the Prichard formation has produced a decided schistose structure.

Granite gneiss is found in the southwestern part of the area intercalated with mica schists, amphibolites, and quartzites of the Prichard formation. The gneiss is a gray medium-grained rock, in which biotite, hornblende, feldspar, and quartz can be recognized. The chief feldspar is oligoclase. The gneiss is much older than the granodiorite, as the latter is intruded into the former and has suffered but little deformation.

Pegmatite intrusions, presumably related to the gneiss, are numerous within this region, especially in the southwestern part, where they form conspicuous dikes and sheets, commonly 5 or 10 feet thick, in the older metamorphosed rocks. Gradations were noted from coarse-grained pegmatites consisting of feldspar, mica, and quartz to those consisting essentially of quartz.

The unsheared granodiorite occurs on either side of the St. Joe-Clearwater divide in the western part of this area and is a continuation of that in T. 43 N., R. 5 E., mapped by Mr. Calkins in 1910. The rock is of medium-granular texture and consists of the same minerals that were noted in the gneiss. This rock resembles that of the great batholith[1] of central Idaho, which, however, is described as quartz monzonite. In the rock of the St. Joe region plagioclase is so abundant as to make granodiorite seem the more appropriate name.

Apophyses of granodiorite porphyry are abundant on the borders of the granodiorite batholith. In the vicinity of the forks of the South Fork of St. Joe River a great number of these dikes are intruded between steeply dipping beds of the Newland formation; in other localities they occupy fissures and have also been noted cutting across diabase sills.

Porphyritic, nearly white dike rocks, in which phenocrysts of glassy quartz are prominent, are closely related to the granodiorite porphyry dikes and are similar in distribution but are less abundant.

Narrow dikes of a fine-grained rock consisting chiefly of needles of hornblende and plagioclase feldspars are of sparse distribution. They closely resemble the dike rocks found in the Cœur d'Alene district.

A fine-grained black diabase porphyry containing large glassy feldspar phenocrysts occurs in the Clearwater region. Dikes of this character probably represent the latest stage of igneous activity.

The breccia possibly of volcanic origin occurs in a few very small areas north and south of the river near Conrads, apparently overlying slates of the upper Newland ("Wallace") and diabase. It consists chiefly of fragments of a gray porphyritic rock, with phenocrysts of plagioclase, quartz, and biotite in a fine-grained gray groundmass.

## METAMORPHISM.

Metamorphism of the sediments is apparent everywhere, but it is much more intense in some parts of the region than in others. It is least toward the northwest but is gradually more and more marked toward the southwest, where it reaches its extreme stage. The change brought about in the sediments is so great that were it not that gradual transitions can be observed in traversing from the northeast to the southwest and that the stratigraphic sequence can be held fairly well in hand, the determination of formations would be difficult.

The metamorphism is due in part to the nearness of the great Idaho batholith and in part to dynamic stresses acting under a heavy load of sediments. Minor metamorphic effects are displayed in the vicinity of the diabase sills and on the borders of the granodiorite mass, but such effects are largely overshadowed by those due to the agencies just mentioned.

One of the most noteworthy metamorphic effects has been the widespread formation of scapolite in the calcareous rocks of the middle

[1] Lindgren, Waldemar, op. cit., p. 63.

division of the Newland ("Wallace"). The chlorine which this mineral contains was probably given off by the metamorphosing magma, for scapolite is wholly absent from the contact zones of other instrusions that cut the Newland formation in the Cœur d'Alene district and near St. Joe River.

## STRUCTURE.

### FOLDS.

The principal structural feature of this region is a broad synclinal fold which extends roughly from the northwestern part to the southeastern part. At the northwestern part, as indicated by the plotted dips and strikes on the accompanying map (Pl. II), the syncline ends in a canoe-shaped form opposite the Packsaddle syncline,[1] on the north side of St. Joe River. The axes of these two major folds are approximately parallel and strike west-northwest. In general the strikes of the rocks are northwest and southeast, but variations are numerous, especially within the synclinal trough; the numerous variations in strike indicate a series of minor folds as well as dislocations of the strata.

The major fold controls in large part the distribution of the rocks in this region. Upper Newland ("Wallace") rocks lie within the trough of this fold. Southwest from the central part of the syncline older formations follow in succession to the Prichard, and to the northwest the area of Newland rocks is greatly increased by the occurrence of several faults and the lower formations are not exposed.

### FAULTS.

Numerous faults complicate the structure of this region. They are most numerous in the southwestern part of the area and along St. Joe River. Although no definite rule as to direction of strike or throw of the faults can be given, yet those in the southwestern part generally strike north and south, with downthrow on the west, and those along the river strike west-northwest, with downthrow on the north. Most of the faults have steep dips which make it probable that they are normal, although this has not been proved for many of them. The two series of parallel faults correspond closely in direction with two systems of the Cœur d'Alene district.[2]

The west-northwest faults, as previously stated, have greatly increased the areal distribution of the Newland rocks north of St. Joe River. A prominent fault of this series extends from a point near the mouth of Bluff Creek to a point opposite the mouth of Malin Creek. In a number of places this fault cuts off large blocks of the prominent diabase sill on the south side of the river.

[1] Pardee, J. T., op. cit., p. 40.

[2] Ransome, F. L., and Calkins, F. C., op. cit., p. 62.

The principal development of north-south faults occurs near Goat Peak, where they have greatly broadened the outcrop of the quartzite from which the peak has been formed. The diabase sill on Nugget Creek is broken into numerous blocks by a series of northward-trending faults.

The displacements of these faults are difficult to estimate, but probably the one having the greatest amount is that near the mouth of Buck Creek, where rocks of the upper Newland are brought adjacent to quartzites of the Ravalli group. The throw here is at least 2,500 feet. Probably the majority of the faults mapped represents displacements of 1,000 feet or more. Numerous faults of small displacement and others of greater throw doubtless exist, but except where condition are favorable for their detection they are overlooked.

## MINERALIZATION.

### DISSEMINATED MINERALS.

The minerals associated with ores in the Cœur d'Alene district[1] are widely distributed in this region. Siderite, or more generally its oxidation product, limonite, commonly occurs in the sandy quartzites of the middle Newland ("Wallace") and in the greenish shales of the lower Newland and the St. Regis. Magnetite and pyrite occur sparingly in the shales of the lower Newland and the St. Regis.

### VEINS.

#### CHARACTER AND DISTRIBUTION.

The veins of the region may roughly be classed as follows:

1. Veins consisting almost wholly of quartz but locally containing a little feldspar and mica.
2. Veins consisting chiefly of quartz but containing much chlorite and more or less calcite.
3. Veins composed of carbonates and quartz in nearly equal quantity.

In general, these veins are of small size—rarely more than a foot or two in thickness—and their prevailing strike is more nearly east-west than north-south.

The veins of the first class are the most numerous and widely distributed; they occur in all parts of the region but are more abundant in the southern than in the northern part. They are present in all formations but are apparently most abundant in the rocks of the upper part of the Newland formation. The chloritic veins are occasionally found in the upper Newland south of St. Joe River, but they are most abundant in the Newland and the St. Regis formation north

[1] Ransome, F. L., and Calkins, F. C., op. cit., pp. 95, 97, 138.

of the river, and were most frequently noted about Simmons Creek basin. The veins containing carbonate are comparatively scarce and were found only in the middle Newland north of the river.

Numerous assays on veins of all these classes showed small amounts of gold and traces of silver. A few assays for copper gave negative results.

#### ORIGIN.

The necessarily superficial nature of the present study of these veins could hardly afford a secure basis for speculation as to their origin. The most interesting problem, perhaps, that arises in this connection concerns the relation of mineralization to intrusion. That this relation, in some places at least, is a close one is suggested by the fact that small quantities of gold are found in quartz that appears to be a part of highly siliceous pegmatite, or so intimately associated with pegmatite that it seems likely to have a close genetic relationship with that rock. It is certain, at least, that all gradations may be found between typical pegmatites and quartz veins containing little or no feldspar, and some of the facts indicate that the pegmatite quartz is locally auriferous.

There is nothing to suggest at first sight a magmatic origin for the chloritic veins or those rich in carbonates. These contain no feldspar and occur at relatively great distances from large intrusions. On the other hand, it is not improbable that they are more or less remotely related to the intrusions which have almost everywhere metamorphosed the country rock.

### DEVELOPMENT.

The region has been very little prospected, the small amount of development noted being confined largely to the more accessible localities. The prospects along St. Joe River in the vicinity of Goddards, Conrads, and the mouth of Bird Creek have been described by Pardee [1] in the previous report on this region. South of the St. Joe to the Clearwater divide but one prospect of any importance is known to exist.

Conrad's mine is located on the St. Joe-Clearwater divide several miles southeast of the limits of the area under classification. No work has apparently been done there within recent years. Copper is said to occur in this mine.

On the ridge a short distance northwest of the Three Sisters Mr. Stevens, a prospector, has uncovered narrow iron-stained quartz veins in two shallow pits. An assay of the quartz gives values of $11 in gold and 2 ounces of silver to the ton.

---

[1] Pardee, J. T., op. cit., p. 48.

Placer mining was attempted at one time on a rather extensive scale within this region, but evidently no work of this character has been done for many years. Old placer workings were noted on Gold and Simmons creeks. At the former locality old blazed trees evidently mark the corners of claims, and piles of bowlders along the creek indicate former work. The stream has been dammed by beavers in the sluiced creek bed and a willow swamp now occupies the site of former placer mining. An old trail leads from the Bitterroot divide to the headwaters of Simmons Creek, on which old cabins, forges, and large piles of washed bowlders furnish ample evidence of former work.

It is said that colors of gold can be obtained along St. Joe River as far down as the mouth of Bird Creek. Rumors of the occurrence of gold on the headwaters of the Little North Fork of Clearwater River and streams flowing northward to the St. Joe are apparently verified by the results obtained from the quartz-vein assays. On the headwaters of Bluff Creek old blazes and squared posts may mark the position of old placer locations.

## NOTES ON THE ANTELOPE DISTRICT, NEVADA.

By F. C. SCHRADER.

### LOCATION.

The Antelope district is in Nye County, south-central Nevada, about 30 miles east-southeast of Goldfield, the nearest supply point, on the Las Vegas & Tonopah Railroad, with which it is connected by a good wagon and automobile road, and 25 miles from Ralston siding, the road to which is nearly all gently down grade or level. The nearest mining camps,[1] all of which are small, are Wellington and Jamestown, about 6 miles distant on the southwest; Wilson's on the southeast; Trappmans, 2 miles south of Wilson's; Cactus Springs, 9 miles to the northwest; and Gold Crater, 11 miles to the southwest. (See Pl. III.)

### HISTORY AND PRESENT CONDITIONS.

The district is named from a group of springs, which have long been marked on Government maps. The largest of the springs flows about 500 gallons of cool palatable water daily, and, together with two wells recently sunk on the downstream side, furnishes the main supply of water for the camp. Ample water for milling can probably be obtained at very reasonable depths.

Several isolated prospects within a few miles of the springs have been intermittently developed in the last decade, almost from the time the region was visited by the wave of prospectors that followed in the wake of the Tonopah boom.

Gold was first discovered here in 1903 by the Bailey Brothers, of Cactus Spring, on the Antelope ground, which they still hold and develop, about a mile southwest of the main spring. In 1906 the Jordan brothers made locations about the same distance to the south, including the ground of the recent strike, and they too have annually done considerably more than the required development work. The strike of high-grade ore which recently attracted attention to the district and gave the camp its present impetus was made

[1] Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, Pl. I.

by Jordan & Reilly on the Antelope View ground early in November, 1911, and soon afterwards there were 150 men in camp prospecting and making locations. By the close of the year a $15,000 five-day option had been taken on the Antelope View claim by George Wingfield, of the Goldfield Consolidated Mines Co., who prosecuted the work of sinking a shaft continuously with good results, but as he wished a brief extension of time, which it is said the owners would grant only at a very large price, he relinquished the option.

The present paper is based on a two days' visit to the camp by the writer early in January, 1912, when about 100 men were at work on nearly as many prospects developing their own ground. To these men and to James H. Parks, of Goldfield, the writer is indebted for information and assistance in making his examination.

At this time the district had been organized and named, two town sites were being developed, half a dozen frame buildings had been erected, and supplies and machinery were being freighted in and some ore hauled out. A stage-line service with Goldfield every other day was in operation and teams and automobiles were coming and going daily. The welfare of the camp was being cared for by committees appointed by miners' meetings.

The Antelope View ground and the Western Union claim adjoining it on the south had been nearly all leased in small blocks 100 by 600 feet extending across the claim and vein, with the perhaps oversanguine expectation that the rich ore of the Discovery shaft would be found extending continuously throughout the length of the claims. On each of these blocks the lessees were sinking in quest of rich ore, mostly on the main vein, and some of them were obtaining encouraging results.

Including the earlier work several tunnels and incline shafts about 150 feet in extent and many prospect pits had been opened in the camp, but the development was still in the oxidized zone, so that only ores oxidized by surface waters had been encountered.

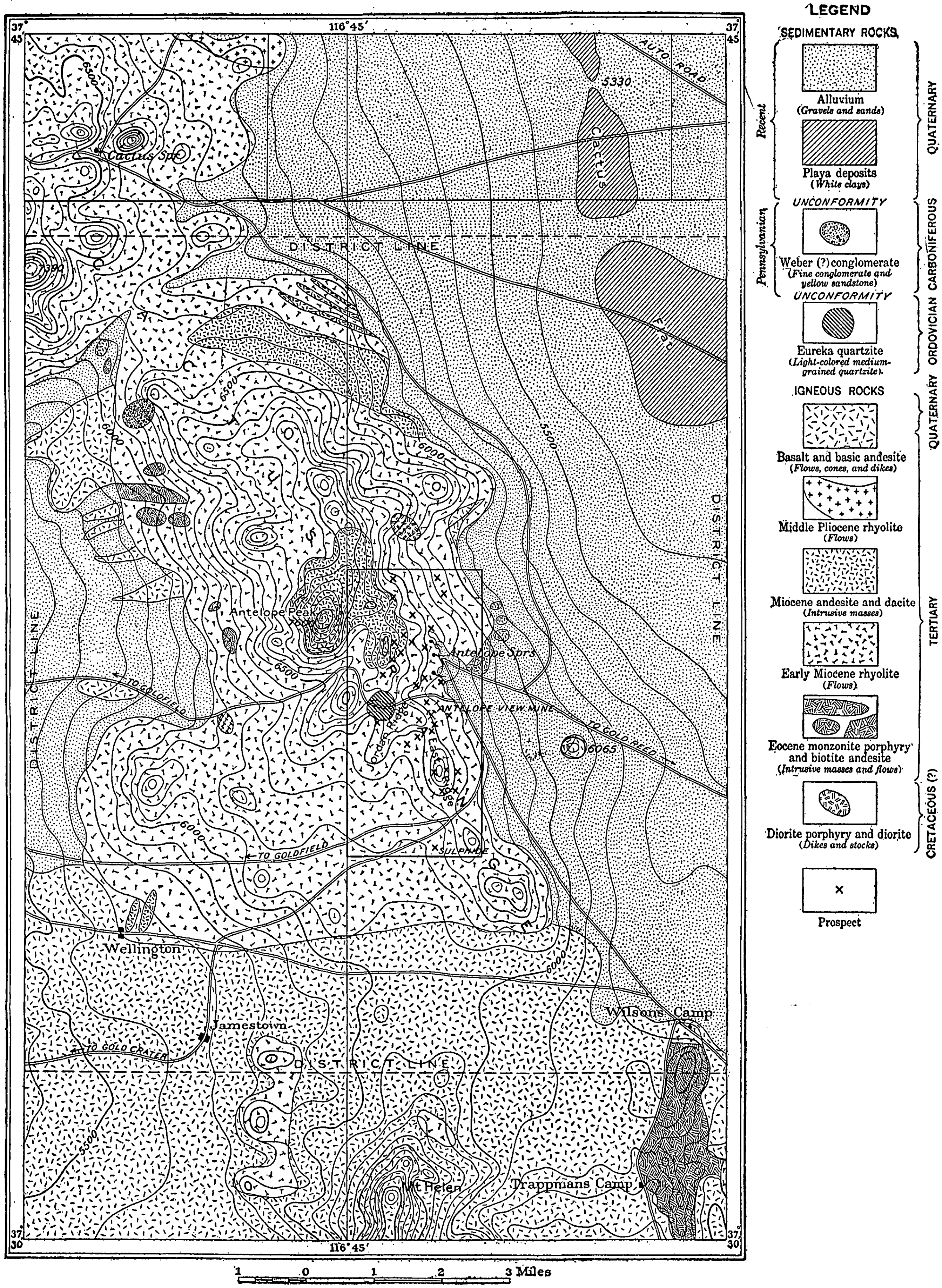
According to latest accounts received early in April the outlook for the camp is encouraging. Good ore has been found at several places and the installation of a mill is contemplated.

## TOPOGRAPHY.

The relief of the region is characteristic of the Great Basin province, which comprises nearly all of Nevada and portions of adjacent States. The dominant features of this province, as shown by earlier publications,[1] are parallel north-south minor mountain ranges—the "desert ranges"—separated by detritus-filled valleys.

The district is situated in the southern part of one of these ranges, the Cactus Range, which trends northwesterly, and has a length of

[1] U. S. Geol. Expl. 40th Par.; Bull. U. S. Geol. Survey No. 208, Pl. I; No. 303, Pl. I; No. 308, Pl. I.




GEOLOGIC RECONNAISSANCE MAP OF ANTELOPE DISTRICT, NEVADA.

about 20 miles, a width of about 10 miles, and an average height of crest of about 7,000 feet. The range rises about 1,500 feet above Cactus Valley on the east, 2,000 feet above Stonewall Valley on the west, and culminates at 7,600 feet in Antelope Peak on the south.

The prospects to which attention was chiefly directed at the time of visit were contained essentially in a north-south rectangular area about 4 miles long and 2 miles wide, near the center of the region shown on the map (Pl. III). It is with this area that this paper chiefly deals, and for convenience it will in a general way be referred to as the district or camp. The "official" district, as laid out at a miners' meeting January 3, 1912, and named the Antelope Springs mining district, is a much larger area, and contains about 120 square miles. It extends from the main spring 6 miles north, 6 miles south, 4 miles east, and 6 miles west. Its boundaries on the east and on the west coincide respectively with those on figure 1, where also its south limits are marked by the east-west broken line passing about a mile south of Wilsons and its north limits by a similar line about a mile south of Cactus Spring.

The area here treated lies mainly on the easterly slope of the range, and extends from 6,000 to 7,000 feet in elevation. The topography is in part rough but not rugged. Its general character is fairly well expressed on the Survey map of the Kawich quadrangle, from which figure 14 is adapted, and also on Plate I of Bulletins 303 and 308. The principal features are several north-south monoclinal or hog-back ridges, of which East Ridge and Jordan Ridge (see Pl. III and fig. 14), situated diagonally to the axis of the range, are examples, and their intervening small valleys or open gulches. The collected drainage issues mainly by means of a broad, open wash through a long, gentle débris-covered slope eastward into Cactus Valley.

## GEOLOGY.

Most of the older rocks in the desert ranges are faulted Paleozoic and Mesozoic sediments cut by many intrusive dikes and bodies of porphyry and flooded by lavas.[1] According to Ball,[2] who has written the best report on the general geology of the southwestern part of Nevada, the succession of formations exposed in the Cactus Range from the base up is as follows: "Pogonip limestone, Eureka quartzite, Weber conglomerate, granite, diorite porphyry, hornblende-biotite latite, earlier rhyolite, biotite andesite, augite andesite, later tuffs (?), later rhyolite (?), and basalt."

The range, however, is composed of predominantly Tertiary volcanic rocks, and the covering or country rock as shown on Ball's

[1] U. S. Geol. Expl. 40th Par.; Bull. U. S. Geol. Survey No. 208, Pl. I; No. 303, Pl. I; No. 308, Pl. I.

[2] Ball, S. H., A geological reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 89.

map, from which the geology of Plate III is adapted,[1] is almost wholly rhyolite, regarded as of early Miocene age. This rock contains the ore deposits of the camp.

The rhyolite forms almost all of the higher part of the range, occupying a belt 5½ miles wide. On the south, in the latitude of Wellington, it is abruptly terminated by a large area of early Quaternary and late Tertiary flows of basalt and basic andesite, small bodies of which also flank the rhyolite in other parts of the range.

Locally capping the rhyolite unconformably as flows and likewise intruding it are andesite and dacite, which occur also in the northwestern part of the district and near by form the upper part of Antelope Peak. They too are referred to early or middle Miocene age.[2]

In the western part of the district, where the rhyolite is bared by erosion, occurs a small area of quartzite, regarded by Ball as the Eureka quartzite of Ordovician age. "This is a fine to medium

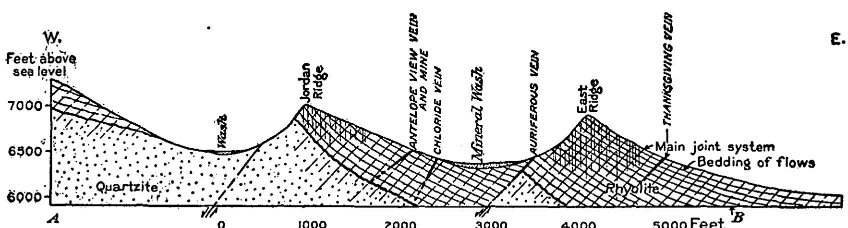



FIGURE 14.—Section through Jordan Ridge and East Ridge, Antelope district, Nevada, showing rock structure and some of the principal mineral veins along line *A-B*, figure 15.

grained quartzite of white, yellow, or red color, and is cut by small stringers of white quartz. It lies unconformably below the surrounding rhyolite."[3] Its presence in the Antelope camp is of importance only in indicating in a general way the probable thickness of the overlying rhyolite in which the mineral deposits occur.

The rhyolite is a porphyritic lava or igneous rock with a glassy base and has about the same chemical composition as granite. It occurs mostly in heavy flows which have been domed and transversely faulted into the series of monoclinal ridges above described. The flows dip mainly 20°–60° E., and the fault scarps formed by their broken upturned edges face to the west. (See fig. 14.) The flows are crosscut by a prominent system of sheeting which dips 30°–60° W., about parallel with the fault planes. This sheeting is probably contemporaneous in origin with the faults and was induced by the same forces. It is important in that its fissures and cracks contain or are associated with the mineral deposits. Locally, as in

[1] At the time of visit the writer did not know that the district was covered by this map.

[2] Ball, S. H., op. cit., p. 94.

[3] Idem, p. 90.

Jordan Ridge, the cracks contain also many small nonworkable veins or ledges and stringers of quartz. The rocks, in places at least, as best shown in East Ridge, are also thinly sliced by a close vertical sheeting amounting almost to cleavage, and in places dikes or bodies of younger but similar rhyolite seem to be intruded along the faults.

The rhyolite is mostly light greenish gray or white, but varies from flow to flow and locally is red, purple, dark brown, or blackish. It is considerably altered, especially near the veins. Much of it is heavily stained with iron and manganese and some contains disseminated pyrite scarcely visible to the naked eye. Some of this pyrite is probably cupriferous and is the source of the copper stain found in part of the ore.

The rock is normally medium grained, with moderate-sized or small phenocrysts of orthoclase and quartz freely disseminated through the lithoidal groundmass, and much of it shows banding or fluxion structure. Some portions, however, are silicified, dense, and flinty, and others are kaolinized and altered to a white chalklike mass. As pointed out by Ball,[1] it is chiefly in association with these silicified and kaolinized areas that mineralization has taken place.

Microscopically the rhyolite is seen to be composed essentially of a turbid brownish glassy groundmass which has flow structure, which varies from cryptocrystalline to microcrystalline in texture, and in which are phenocrysts (or their casts) of orthoclase, quartz, biotite, plagioclase, and hornblende. The phenocrysts are medium or small in size and are usually abundant and uniformly distributed. Some of them are fractured by flow.

Hematite as black phenocrysts and as ferriferous grains and dust-clouded areas in the groundmass is present and is probably secondary. Apatite is sparingly present as an accessory.

The rock as a whole is highly altered. The groundmass is in part devitrified and silicified or replaced by secondary quartz and orthoclase, mostly fine but varying greatly in size of grain, containing quartz blebs. Alunite in grains and aggregates is scattered through the groundmass.

The phenocrysts are mostly changed to or replaced by secondary products, the orthoclase to kaolin, chalcedonic quartz, secondary orthoclase, sericite, and alunite; the biotite to green chlorite and muscovite. Much of the quartz is deeply embayed by magmatic corrosion and some is slightly smoky or has a pale wine-red color. Veinlets of fine-grained chalcedonic silica and secondary orthoclase fill cracks in both the groundmass and the phenocrysts.

Alunite occurs chiefly as a replacement of orthoclase in a variable zone on the surface of the phenocrysts and along the fracture walls,

[1] Ball, S. H., op. cit., p. 43.

while here and there secondary quartz and orthoclase replace the remainder of the crystal. Some crystals are traversed by a reticulating network of fractures. The alunite occurs also in veins traversing the phenocrysts and in grains and elongated forms in the groundmass. Calcite is sparingly present in most slides, and with acid the rock in general gives a slight lime reaction.

Exceptions to the above general descriptions are (*a*) the purple cap rock in the crest of East Ridge, which is relatively fresh, profusely banded, and probably younger than the flows containing the deposits; (*b*) a pale-greenish flow underlying the cap rock of East Ridge, which contains very little quartz and which seems to stand close to trachyte; and (*c*) the purple rock occupying most of the west slope of this ridge, which, though rich in quartz, contains relatively considerable acidic plagioclase (oligoclase near oligoclase-andesine), whence the rock is close to dacite. Dacite is also reported to be the country rock in the northeastern part of the district, on the Spendel claim group, where it is probably an outlier of the Antelope Peak area.

## ORE DEPOSITS.

The deposits of the camp are veins containing ores of silver and gold. Their occurrence is in a general way similar to that of like deposits in the Tertiary volcanic rocks of the West. They are found in or associated with veins and fissures contained in the rhyolite which has been described. The veins are about 20 in number. The relative position of the principal veins is shown in figure 15 and the distribution of the principal prospects in Plate III. They occur mostly at elevations of about 6,500 feet. The general strike of the veins is N. 12° E., about parallel with the principal jointing system above described, but some of them depart from this direction, both to the east and especially to the west. The dip is about 40° W., into the range, but varies from 30° to 60°. Of the steeper dips the Chloride vein (fig. 14) is an example. In several places the dip was observed to flatten in depth, and the tendency to flatten seems to be general. The veins are fairly persistent, several having a known extent of 2,000 feet or more, while for some a much greater length is claimed. Branching and intersection seem to be common.

The veins are exposed principally in the southern and northern parts of the district. If present through the considerable stretch of intervening ground, they are mostly covered by alluvial wash and débris from the mountains.

The veins vary from 1 to 20 feet or more in width, 8 feet being perhaps a fair average. As for the most part they weather evenly with the country rock, the croppings are generally not prominent.

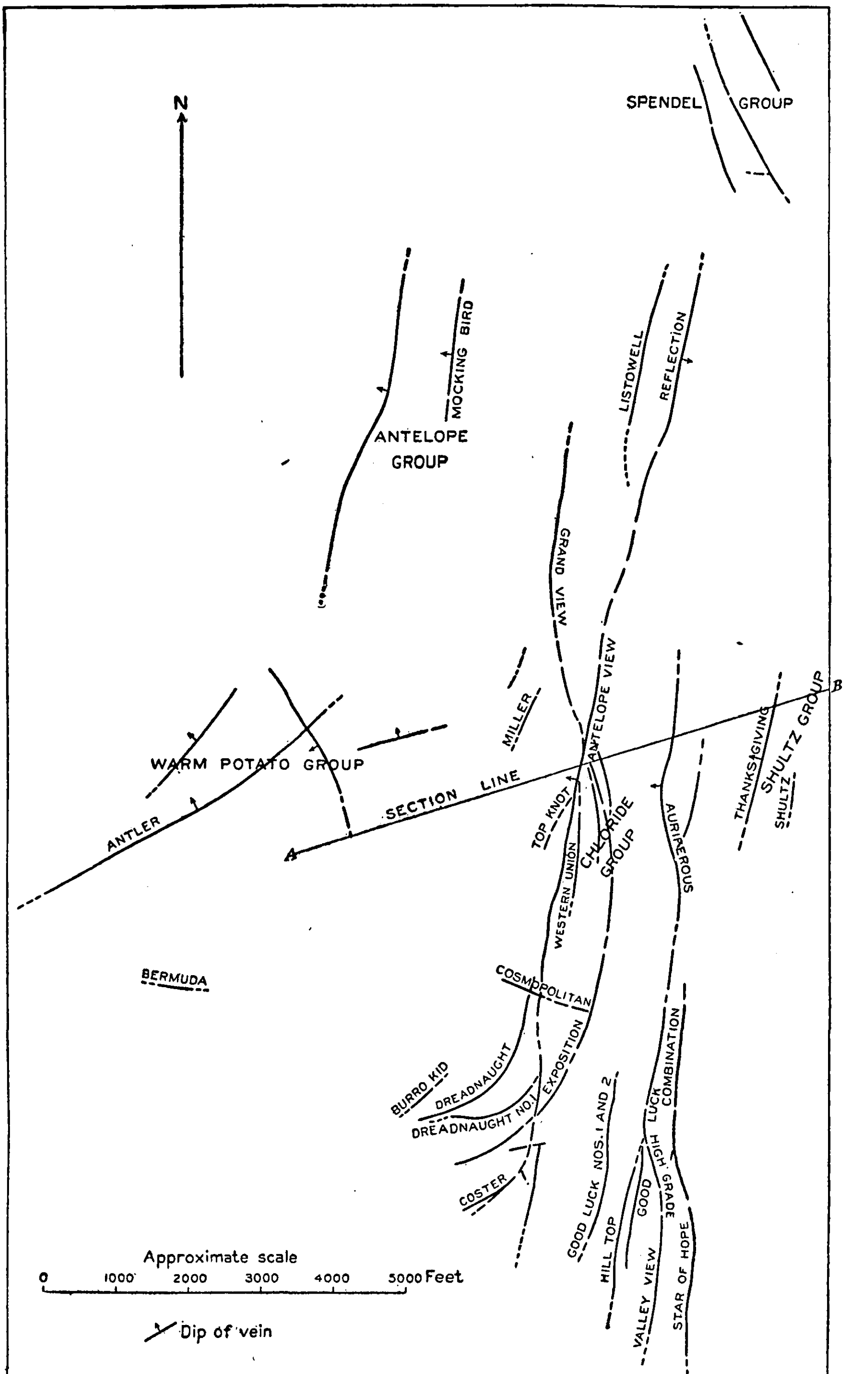



FIGURE 15.—Sketch showing principal veins of Antelope district, Nev. *A–B*, Line of section in figure 14.

However, there are some good-looking croppings, consisting chiefly of iron and manganese stained quartz and silicified rhyolite, in the southern part of the district on the Chloride and Auriferous groups, in the western part on the Antelope group, and to the north on the Reflection and Listowell claims.

The Auriferous croppings have considerable gossan that pans well in gold. Quartz samples from the Exposition shaft show hematite with specularite and some pyrolusite, and quartz ore from the Chloride shaft, near the southwest corner of the Antelope View, contains considerable chrysocolla.

The gangue is quartz and faulted, crushed, and altered rhyolite. The rhyolite is in part silicified, in part completely kaolinized to a white chalklike mass of so-called talc, and in part affected by all stages of alteration between these extremes. The chalklike material is largely kaolin, with some alunite. The portions most resembling talc in the hand specimen are found under the microscope to consist principally of sericite, a filmy white or colorless mica derived by alteration from the orthoclase. Even the portion of the gangue which at first appears to be normal vein quartz is found on examination to be mainly altered and silicified rhyolite replaced by quartz. Some of it has a finely honeycombed or porous texture, which seems in part due to cavities of disseminated pyrite dissolved out of the rhyolite. The quartz is also drusy, with small, very irregular cavities, containing acute solid angles and jagged walls studded with pyramidal quartz crystals and filmed with hyalite. Adularia is sparingly associated with the quartz as a gangue mineral.

In the northwestern part of the district, on the Antelope group, was observed some platy quartz, pseudomorphic after calcite or other spar, indicating that the present gangue has in part replaced an earlier gangue mineral, but this phase of replacement seems to be very subordinate.

In general, much of the gangue is more or less heavily stained with iron and manganese, and, as shown by slickensides and displacements, there has also been considerable postvein movement.

The valuable ore minerals are chiefly the silver chloride, cerargyrite or horn silver, and the sulphide, argentite. They occur mainly in the form of dark-green or gray-green specks, bodies, and films widely distributed through the gangue, and with them and the iron oxide is associated the gold. Some of the bodies are cuboidal and apparently fill casts of dissolved pyrite crystals. The film form is best developed on slickensides in the chalky kaolinized masses.

About four-fifths of the valuable content of the ore is in silver and one-fifth in gold. In places occur bodies several inches in diameter of yellowish and gray-green horn silver that are very rich. Macroscopic free gold is not common, especially in the main vein, but in a cellular quartz specimen collected at about 60 feet down the hill slope from the Antelope View mine the pocket lens shows the dark silver ore bodies to be peppered with small beads and specks of gold. The light color of much of this gold denotes that it is in alloy with native silver.

Associated with the ore in many places is considerable iron oxide, mostly limonite, which so permeates and stains large bodies several feet in diameter that the mass resembles partly decomposed iron ore. Much of the ore of this type, as well as of the porous honeycombed siliceous ore, pans well in gold.

In places the ore minerals, by metasomatic replacement, impregnate to a considerable degree the surrounding altered wall rock, which is locally kaolinized or silicified for distances of 60 feet or more back from the vein. In contracted parts of fissures and in small fissures and joint cracks showing little or no distinct vein the ores appear along the planes of division.

## MINES AND PROSPECTS.

### ANTELOPE VIEW MINE.

The Antelope View mine, where the recent strike was made, is near the south-central part of the district, about a mile south of the spring, in the east base of Jordan Ridge. (See Pl. III, figs. 14 and 15.) At the time of visit it was opened by a 150-foot crosscut tunnel and a 23-foot inclined shaft sunk on the vein. The shaft was sunk mainly under the Wingfield option, already described.

The vein strikes N. 12° E. and dips 35° W. into the hill. The country rock is the rhyolite which has been described. Locally the hanging wall only is known as rhyolite, the footwall, because of its numerous kaolinized feldspar phenocrysts, being called "birdseye porphyry." The supposed difference is due to weathering, however, for the microscope shows the rock in the two walls to be the same.

The shaft is about 50 feet above the edge of Mineral Wash on the east and 35 feet above the tunnel. The vein here has a width of about 10 feet. It is opened in one of the best-mineralized spots of the camp and near by seems to be joined by one or more spurs or feeders coming in from the Chloride group on the southeast (fig. 15). As exposed in the shaft, it consists principally of crushed and blocky silicified and kaolinized rhyolite, partly iron stained, with quartz in irregular bodies, bands, stringers, and veinlets.

Practically all the material excavated from the shaft (about 30 tons) is ore. It is reported to average about $200 to the ton, and contains some rich bunches. At the time of visit 2 tons of the ore had been shipped, 14 tons was sacked ready for shipment, and about an equal amount lay on the dump.

The bottom of the shaft at this time contained several angular blocks of relatively little altered rhyolite which seemed in part to displace or crowd out the vein. Later reports,[1] however, state that at the depth of 50 feet the vein was widening and the ore had improved in grade.

Early in April the shaft had attained a reported depth of 85 feet. At that depth the vein is about 3 feet wide, and some samples taken across its width assayed $600.

The tunnel, which also has produced some ore, is driven on the footwall side in crushed and partly altered rhyolite. Its dump material is more or less iron stained and much of the rock has a parallel elongated or semirodded structure, the rods consisting mainly of chalk kaolinization products, apparently derived from the feldspars.

On several of the leases to the north and the south, on the Western Union claim, and on the Hilltop, adjoining the Western Union on the west, where the vein is split or is represented by three veins, some shallow openings show good-looking prospects that yield fair assays of ore minerals, principally horn silver, but not yet in workable amount. In fact, the lease openings, some of them 20 feet or more deep, seem to indicate that the rich ore found in the Discovery shaft does not extend continuously along the vein, as was expected.

## CHLORIDE GROUP.

Six hundred feet south-southeast of the Antelope View mine, near the southwest corner of the Chloride claim, a vein which seems to be a spur or feeder to the Antelope View vein, is opened by a 40-foot 60° inclined shaft. The dump shows the vein material to be principally crushed quartz, and it is reported to carry only low values.

On the Clifford lease, about 100 feet to the east of the above-mentioned shaft, in the west edge of Mineral Wash, is another ledge which at the time of visit was being opened with good results, its material panning well in gold. A few hundred feet north of this locality a 3-foot hole that was being sunk, apparently on the same deposit, exposed a 10-foot vein, which, together with its iron and manganese stained croppings, ranks among the best indications seen in the camp.

## AURIFEROUS GROUP.

Easterly across Mineral Wash about 1,300 feet from the Antelope View mine is the Auriferous vein, on the claim group of this name, shown in figure 15. It is opened by a 30-foot inclined shaft. The croppings here show a vein width of about 12 feet. The vein is reported to have a known extent of about 2,000 feet and to contain

[1] Jordan, P. T., letter of Feb. 22, 1912.

considerable $14 ore, and it pans well in gold. About one-fourth mile south of the shaft the vein is opened by a 120-foot crosscut tunnel.

### GOOD LUCK GROUP.

South of the Auriferous group, on the Good Luck group, two claim lengths in extent, is a vein reported to be opened by a 65-foot shaft and a 45-foot tunnel. The vein is said to be 4 feet in width and yields assays of $18 to $75 to the ton in silver and gold.

### STAR OF HOPE GROUP.

East of the Good Luck group, with the High Grade claim intervening, is the Star of Hope vein, about two claim lengths in extent, opened principally by a 150-foot tunnel. This vein has a reported width of about 4 feet and considerable portions of it carry ore containing about $6 in gold and $9 in silver to the ton.

### ANTELOPE GROUP.

On the Antelope group, owned by the Bailey Brothers, in the northwestern part of the district, the principal upper or western vein lies at about 6,800 to 6,900 feet elevation, being about 100 feet higher on the north than on the south. It is situated similarly to the Antelope View vein, shown in figure 15, but on a steeper upper slope. It also is in rhyolite, which is pale greenish and is possibly a dike, and it seems to be associated with the contact of this rock with the "intrusive" andesite-dacite area of Antelope Peak on the west. It is opened at eight or ten points by a series of pits and inclined shafts, mostly earlier work, extending through a distance of about half a mile.

On the south, where opened by a 40-foot 40° inclined shaft, the vein has a width of about 14 feet and contains some greenish quartz which traverses the rhyolite in stringers and veinlets, locally forming a sort of stockwork.

Toward the north end of the vein the principal opening is a 150-foot 35° inclined shaft, which is in iron-stained crushed and in part altered and silicified rhyolite, some of which is also brecciated and cemented with infiltrated quartz.

The eastern or Mocking Bird vein, situated about 100 feet lower than the upper vein, is opened principally by a 120-foot 30° inclined shaft. The walls consist of rhyolite that is less crushed and more massive, coarse, and blocky than that on the upper vein. They are also in part silicified. The dump contains a little ore, but so far as learned there has been no production.

### REFLECTION GROUP.

The vein on the Reflection group, in the northern part of the district, extends about 2,000 feet northward from the vicinity of the spring, which seems to be connected with it in origin. It is about

12 feet in width and apparently forms an exception to the general westerly dip of the veins in that it seems to dip 40° E., but the openings on it are too shallow to determine this point conclusively. Portions of the vein look well, as do also portions of the Listowell vein, nearly paralleling it about 500 feet distant on the west. In places the croppings on the Listowell are prominent and are pitted with cavities representing dissolved-out pyrite.

### SULPHIDE PROSPECT.

The prospect commonly known as the Sulphide, or Trappmans new camp, which represents earlier work than that of the recent strike, is located at the south border of the district, on the upper west slope of the range. It is opened principally by a 120-foot shaft, the lower part of which is in the sulphide zone. A gasoline hoist used in sinking the shaft has been removed, it is said, on account of the large amount of water in the shaft and the relatively low grade of the ore.

## CONCLUSIONS AND SUGGESTIONS FOR PROSPECTING.

Although no deep sinking has yet been done in this camp, present developments and the geologic and mineralogic conditions indicate that the region probably contains a reasonable amount of fair-grade ore. From the general nature of the deposits, the relatively unfavorable character of the underlying rock, and the tendency of the veins to flatten in dip as they go down and to follow the bedding of the flows, it is inferred that the deposits are practically confined to the rhyolite covering and as a rule do not penetrate the underlying quartzite. The thickness of the rhyolite probably nowhere much exceeds 500 or 600 feet and in most places it is considerably less.

The view held by many that rhyolite is a particularly unfavorable formation for the occurrence of mineral is without good foundation. This is shown by the Jarbidge, De Lamar, and other camps. Besides, the rhyolite of this district is known to be among the productive rocks of the Southwest.[1]

In prospecting, as pointed out by Ball, attention should be given to the quartz veins and fissures in the kaolinized and silicified areas of the rhyolite, to the contact of the rhyolite with the underlying intruded rock, especially if it is limestone, and also especially to the contact of the rhyolite with the younger intrusive andesite and dacite, as in the Antelope Peak area on the northwest, and to the andesite and dacite themselves.

[1] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 49.

# NOTES ON THE NORTHERN LA SAL MOUNTAINS, GRAND COUNTY, UTAH.

By JAMES M. HILL.

## FIELD WORK AND ACKNOWLEDGMENTS.

This report is based on a reconnaissance of the north end of the northern group of the La Sal Mountains, Utah, including the Miners Basin and Wilson Mesa districts. The field work was undertaken in the middle of June, 1911. A later date would have been preferable, as these mountains are from 11,000 to 12,500 feet above sea level and the snow lies in drifts from 10 to 20 feet deep in the more sheltered places until the beginning of July, blocking the trails and mine workings. Few of the prospects could be entered. So far as could be learned the miners at the basins (numbering about 20 to 30 men) depart with the approach of winter and rarely return before the first of July.

The writer is indebted to the few men who were in the mountains at the time of his visit for numerous courtesies, and in particular to Mr. M. I. Fowler, of Basin and Salt Lake, who gave generously of his time and by his knowledge of the region aided the field work materially. Mr. L. M. Prindle, of this Survey, who has visited these mountains, has generously supplied much information from his notes and made many helpful suggestions during the preparation of this report.

## LOCATION.

The La Sal Mountains are shown on the La Sal topographic sheet of the United States Geological Survey at about latitude 38° 30′ north, longitude 109° 15′ west. The northern group of these mountains is in the extreme southeast corner of Grand County, near the Colorado line. The region is most easily reached from Cisco, on the main line of the Rio Grande Western Railway. A daily stage runs from Cisco to Castleton, a distance of 38 miles. The latter town lies in Castle Valley, at the northwest base of the mountains, and roads of varying degrees of poorness radiate from it to the lower parts of the basins and to Wilson Mesa and Moab. Moab, the county seat, is about 14 miles west-southwest of Castleton in an air line, but the road between the two towns is over 20 miles long. A daily stage runs between Moab and Thompsons, on the Rio Grande Western, about 30 miles north-northwest of Moab.

## PREVIOUS WORK.

The first known mention of the Sierra La Sal is in the report, published in 1876, of the exploring expedition headed by Capt. J. N. Macomb, of the United States Engineers, in 1859, from Santa Fe to the junction of Grand and Green rivers. Macomb's party visited the Sierra Abajo, or Blue Mountains, south of the La Sal Mountains, studied their character, and from long-range observations concluded that the two ranges were of similar character, being formed by eruptive trachyte which has domed the sedimentary beds.

In 1875 Peale and Holmes[1] studied the Sierra La Sal, making a topographic map and drawing several sections across the mountains. Peale describes the mountains as consisting of three groups of eruptive trachyte porphyry with low sedimentary saddles between. The northern group shows beds of red sandstones, slates, and shales of Cretaceous and Triassic age, dipping away from the mass in all directions, steeply near the mountains and at low angles a short distance from them. The eruptive rock is described as a light-gray feldspathic trachyte with crystals of feldspar and hornblende, giving it a porphyritic appearance. The specimens were lost, but were said to be similar to the rock of Mount Marcellina, in Colorado. Peale places the age of the eruption as post-Cretaceous and preglacial. The present form of the mountains he ascribes to extensive erosion, in part glacial. This erosion has removed the sedimentary beds, which may have at one time completely covered the group, except on some peaks on the north and northeast flanks of the mountains.

Endlich,[2] in reviewing the "acidic volcanic eruptives" of Colorado, summarizes Peale's report and classes the rock of the La Sal Mountains as porphyritic trachyte, a group of eruptive rocks which he describes as including those that are isolated in their topographic character and geognostic position and show all the typical characteristics of trachyte.

Peale[3] in 1877 reviews the work of the Hayden Survey since 1873, and concludes that many mountain masses in Colorado and Utah show the same general characteristics, namely, they are isolated, they are of eruptive origin, they show general resemblance in their rocks, and they occur in areas of sedimentary rocks. He notes that in all of them the igneous material came up through fissures in the lower sedimentary strata with or without tilting the beds until it reached the Cretaceous shales, where the magma spread out in dikes and

[1] Peale, A. C., On the Grand River district: Ninth Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1875, 1877, pp. 59-62, 80-92, 95-98.

[2] Endlich, F. M., On the erupted rocks of Colorado: Tenth Ann. Rept. U. S. Geol. and Geog. Survey Terr., for 1876, 1878, pp. 232, 239.

[3] Peale, A. C., On a peculiar type of eruptive mountains in Colorado: Bull. U. S. Geol. and Geog. Survey Terr., vol. 3, 1877, pp. 551-564.

sheets, in some places doming the superimposed beds. He states that there is considerable difference between individual rock specimens but concludes that they all belong to one class of acidic feldspathic rocks.

In 1880 Gilbert[1] published his report on the Henry Mountains of Utah, which is a classic for the laccolithic type of which the Sierra La Sal is an example. This report is exhaustive and can not well be summarized in a short paper like the present one. C. E. Dutton examined his specimens microscopically, and classes them as porphyritic trachyte. He notes large crystals of feldspar and hornblende in a "compact uniform paste through which hornblende is disseminated."

In 1894 Cross[2] summarized the available knowledge of laccolithic mountains, giving brief descriptions of the principal groups and discussing the chemical and mineralogic character of the rocks, which he considered derivatives of a similar magma. He describes the rocks as typical porphyries. The phenocrysts were formed in the magma before eruption, but probably continued to grow afterward. The most typical phenocryst is plagioclase with hornblende and biotite subordinate. Hypersthene and augite are present in some types. The ferromagnesian minerals vary in amounts rather than in kind in the various specimens. The groundmass is generally gray, with few ferromagnesian minerals, but consists essentially of feldspar (usually orthoclase) and quartz.

The rock of Mount Marcellina, in Colorado, with which Peale correlates the La Sal Mountain eruptive, Cross calls a porphyritic diorite, "consisting essentially of plagioclase, orthoclase, hornblende, biotite, and quartz." It is a fine-grained grayish rock in which the dark minerals are subordinate and the phenocrysts small, ranging from 1 to 3 millimeters in diameter.

Several of the typical rocks of the La Sal Mountains, collected by L. M. Prindle in 1901, have been analyzed by the survey and brief descriptions of them published,[3] as follows:

*Analyses of rocks from the La Sal Mountains.*

Petrographic descriptions by L. M. Prindle. Analyses by W. F. Hillebrand, record No. 2032.

A. Monzonite porphyry, 2 miles west of Mount Peale. *Akerose.* Contains phenocrysts of plagioclase, partly resorbed hornblende, and pyroxene in a groundmass of partly striated feldspar. It may contain also orthoclase and quartz. P. R. C. 1306.

B. Ægirite granite porphyry, about 1.5 miles south of Mount Waas. *Omeose-liparose.* Contains quartz, feldspar, pyroxene, and iron ore. The pyroxene is probably for the most part ægirite. P. R. C. 1304.

---

[1] Gilbert, G. K., Geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[2] Cross, Whitman, The laccolithic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 165–241.

[3] Clarke, F. W., Analyses of rocks and minerals: Bull. U. S. Geol. Survey No. 419, 1910, pp. 120–121.

C. Syenite-aplite porphyry resembling grorudite. About 2 miles south of Mount Waas. *Liparose.* Contains potash and soda-lime feldspars, quartz, pyroxene, titanite, and iron ore. In the groundmass are needles which are probably ægirite. P. R. C. 1301.

D. Syenite porphyry resembling sölvsbergite. About 1 mile northwest of Mount Waas. *Phlegrose near nordmarkose.* Contains potash and soda-lime feldspars, quartz, pyroxene, and iron ore. Needles of ægirite (?) in the groundmass. P. R. C. 1303.

E. Pulaskite, 1 mile west of Mount Waas. *Nordmarkose.* Contains potash feldspar, pyroxene, biotite, apatite, titanite, and iron ore. P. R. C. 1305.

F. Noselite syenite porphyry, dike on northwest shoulder of Mount Waas. *Miaskose.* Contains feldspar, pyroxene, sodalite or noselite, apatite, titanite, and iron ore. The pyroxene appears to be mostly ægirine-augite and the feldspar mainly potash feldspar. P. R. C. 1302.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $SiO_2$ | 61.21 | 73.27 | 70.02 | 68.96 | 62.64 | 58.99 |
| $Al_2O_3$ | 17.10 | 13.29 | 14.38 | 15.42 | 17.36 | 19.01 |
| $Fe_2O_3$ | 2.72 | 1.16 | 1.17 | 1.99 | 2.79 | 1.74 |
| FeO | 1.88 | .13 | .13 | .16 | .63 | .59 |
| MgO | 1.47 | .07 | .61 | .22 | .53 | .27 |
| CaO | 4.83 | .21 | .66 | .25 | 1.70 | 2.02 |
| $Na_2O$ | 5.66 | 3.44 | 5.48 | 6.59 | 7.00 | 9.11 |
| $K_2O$ | 3.00 | 7.53 | 5.87 | 5.48 | 4.97 | 5.07 |
| $H_2O$ at 105° | .34 | .23 | .27 | .22 | .43 | .38 |
| $H_2O$ above 105° | .68 | .43 | .44 | .30 | .53 | 1.24 |
| $TiO_2$ | .51 | .10 | .10 | .12 | .43 | .21 |
| $ZrO_2$ | .02 | .02 | .01 | .04 | .02 | .07 |
| $CO_2$ | None. | .02 | .38 | .13 | .54 | None. |
| $P_2O_5$ | .24 | Trace. | Trace. | Trace. | .12 | .04 |
| $SO_3$ | None. | .07 | .19 | None. | .06 | .96 |
| Cl | .04 | .01 | .03 | .01 | .03 | .15 |
| MnO | .15 | .03 | .02 | .07 | .04 | .08 |
| BaO | .13 | .10 | .13 | Trace. | .10 | .02 |
| SrO | .07 | None? | .06 | None. | .07 | .02 |
| $Li_2O$ | Trace? | Trace? | Trace. | Trace. | None. | Trace. |
| | 100.05 | 100.11 | 99.95 | 99.96 | 99.99 | 99.97 |

S absent from all.

In 1904 Boutwell[1] visited the vanadium deposits in the vicinity of Richardson, near the north end of the La Sal Mountains. His description of the sedimentary beds is fairly complete, but he made no attempt at correlation with similar formations elsewhere. As these deposits were not accessible in 1911 a brief summary of his observations is given for the benefit of those who have not seen his report.

A zone of deformation enters the Richardson amphitheater near the mouth of Fisher Creek and crosses it in a southwesterly direction. Along this zone the sedimentary beds are upturned, brecciated, and probably faulted. Mineralization has occurred through the replacement of crushed sandstone for a distance not greater than 4 feet from the main fracture. The yellow, green, and blue vanadium minerals are usually found in "thin patches 1 to 10 inches in diameter upon the walls of sandstone blocks," being more abundant near the main fissure. Small oval masses of yellow earthy carnotite up to 1 inch in diameter are also found in certain beds of gray sandstone, particularly on the hanging wall. The vanadium minerals are the more abundant and important.

[1] Boutwell, J. M., Vanadium and uranium in Utah: Bull. U. S. Geol. Survey No. 260, 1904, pp. 200-210.

In 1905 Cross and Howe[1] published a paper correlating the subdivisions of the "Red Beds" of Colorado and suggesting their continuance farther west. During the summer of 1905 Cross studied in greater detail the stratigraphy of southeastern Utah. His report[2] not only gives his own results but reviews and correlates all the previous work in this region and includes a very complete bibliography on this problem. The formations discussed by him are shown in the subjoined table, together with their chief characteristics and their distribution in the Grand River region.

*Sedimentary formations exposed in Grand River region.*

[After Whitman Cross.]

| | Powell. | Peale. | Holmes. | San Juan folios, United States Geological Survey. | | Character in Grand River region. |
|---|---|---|---|---|---|---|
| Cretaceous. | | | | Mancos. | | Dark shales; very small exposures left. |
| Cretaceous. | Henry's Fork. | Dakota or Upper Dakota. | Upper Dakota. | Dakota. | | Light-colored sandstones and shales, thin bedded. Partly eroded, leaving uncertain thickness. |
| Jurassic. | Flaming Gorge. | Lower Dakota. | Lower Dakota. | Gunnison. | McElmo. | Soft variegated, light-colored sandstone with much green, red, and white shale and marl. Probably thin in the vicinity of Mesa. |
| Jurassic. | Flaming Gorge. | Jurassic. | Lower Dakota. | Gunnison. | La Plata. | Light-pink, orange, or reddish sandstones showing marked cross-bedding. Two massive beds separated by thin-bedded sandstones. The total thickness at good exposures is about 625 feet. |
| Jurassic. | White Cliff. | Triassic. | Triassic. | Gunnison. | La Plata. | |
| Triassic. | Vermilion Cliff. | Triassic. | Triassic. | Dolores. | | Massive dark-red sandstone, cliff-making above, 100 to 200 feet of thin-bedded sandstones and shales below, with beds of limestone conglomerate containing saurian fossils. |
| Carboniferous. | Shinarump group. (All assigned to Triassic.) | Permian, Permo-Carboniferous, or Upper Carboniferous. | | Permian? | Cutler. | Red, purple, and green thin-bedded arenaceous shales, locally gypsiferous. From 600 to 800 feet thick as exposed along Grand River between Moab and Castle Valley, but estimated to be between 1,500 and 2,000 feet in maximum thickness. |
| Carboniferous. | Aubrey. | Middle Upper Carboniferous. | | Pennsylvanian. | Hermosa. | Blue fossiliferous limestone and thin light-colored sandstones. At Moab about 475 feet thick. |

## TOPOGRAPHY.

The La Sal Mountains are in the Colorado Plateau region, which is marked by long mesas cut by abrupt canyons from 2,000 to 2,500 feet in depth with steep cliffs 500 to 600 feet high. Above this relatively level plateau, which has a general elevation of 8,000 feet, the northern

[1] Cross, Whitman, and Howe, Ernest, Red Beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, pp. 447–498.

[2] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, 1907, pp. 634–679.

group of the mountains rises abruptly to an extreme height of 12,586 feet at Mount Waas. The group trends north-northwest and south-southeast and is about 8 miles long by 5 miles across. Rising as it does some 4,000 feet in 2½ miles, the slopes are necessarily steep, in places precipitous.

The mesas from a distance give the impression of having a very gradual, even slope away from the mountains. In detail they are more like broad, uneven steps. The horizontal portions are separated by wavy cliffs or by steep talus slopes with low cliffs at the top. The rises are not everywhere the same, but vary from a few feet to a hundred feet in height. The mesas are usually narrower near the mountains and broaden as they approach the rivers. This is particularly noticeable of Wilson Mesa. The long, narrow, flat-topped ridge between Castle Valley and Rock Creek shows the reverse condition.

The main drainage from the mountains is radial, and the permanent streams are in the bottoms of deep canyons. On the east and northeast sides the streams flow into Dolores River, which joins the Grand about 20 miles north of Mount Waas. On the other sides the drainage is directly into Grand River by way of Fisher Valley at the north, Castle Valley in the center, and Mill Creek at the south.

There are no permanent streams on the mesas, but broad, shallow drainage lines with flat gradients parallel to the longer dimensions of the mesas are prevalent. The grade is so small that in several places dams 2 to 4 feet high pond water over several acres. The water on Wilson Mesa is taken from Mill Creek, though melting snows and infrequent showers account for at least a part of that stored in the reservoirs.

## GEOLOGY.

### SEDIMENTARY ROCKS.

The sedimentary series, outlined in the table on page 103, in the region of Castle Valley and Wilson Mesa, is as follows: The floor of the west end of Castle Valley is cut into the red shales and sandstones of the Permian. Some gypsiferous sandstones occurring at the top of the series can be clearly seen in the low hogbacks at the north side of the valley. Between these beds and the massive red sandstone (Vermilion Cliff) which forms the "Castle" at the lower end of the valley there is a series of alternating shale, sandstones, and conglomerate of red color about 550 feet thick, which probably represents the basal portion of the Dolores formation. The Vermilion Cliff sandstone, the equivalent of the upper part of the Dolores formation, is the rim rock of the west end of the valley and underlies the lowest western part of the Wilson Mesa. The middle mesa, extending westward from Mesa post office about 1 mile, is underlain by light-reddish sandstones which are probably referable to the White Cliff sandstone, regarded as the appropriate equivalent of the La Plata sandstone. The upper mesa, extending eastward from the ridge east of Mesa post office to the mountains, consists of thin-bedded light-colored sandstones mapped by Hayden[1] as upper Dakota, and in Cross's correlation called Dakota. At the base of the sandstones exposed in a creek bed southeast of Mesa post office there are some soft green and white shales that may represent the McElmo formation. The Mancos shale is exposed close to the mountains about 4 miles west of Mesa post office.

The correlation given above is based on the similarity of the sedimentary series exposed here to the formations as described in the published reports on the "Red Beds." The writer did not have the opportunity to study the section described by Cross or to correlate the series from any known point to the immediate vicinity of Wilson Mesa.

## DETRITAL MATERIAL.

In some localities on Wilson Mesa there are deposits of unconsolidated auriferous gravels for whose character and distribution it is rather difficult to account. These gravels will be discussed under the heading "Economic geology." Extending eastward from the intrusive dome in the center of Castle Valley to the base of the mountains there is a ridge separating the valley into two parts. This ridge consists of relatively fine material near the dome showing some rough stratification, but of coarse, unstratified cobbles and sands near the mountains. It is cemented by a white calcareous material at the east end and contains some gypsum cement in some places near the center. The cobbles were derived in part from the sandstones, but by far the most abundant fragments are similar to the rocks of the laccolithic mountains. In appearance this conglomerate somewhat resembles the Gila conglomerate of the desert country of southwestern Arizona.

In the heads of the basins in the high mountains there are small glacial moraines. These are very short and low, but they have typical moraine topography. Few of them extend below 10,000 feet and none reach the lower parts of the basins. The best example is in Miners Basin, where the town of Basin is built on a small flat just above the terminal.

Rock streams or rock glaciers are developed in most of the cirques. Three small examples are to be seen in Miners Basin, two in Bachelor Basin, and two in Beaver Basin. Those in the last two localities were partly covered by snow in June, 1911. On the south side of Miners Basin, about a quarter of a mile southeast of Basin post

[1] Hayden, F. V., U. S. Geog. and Geol. Survey Terr., Atlas Sheet XIV.

office, is what at first glance appears to be a talus slide. However, it has rude concentric ridges at the lower end, which rises at a steep angle about 50 feet above the valley floor and appears to be advancing into a grove of pine trees. Its sides in the lower part are marked by steep V-shaped depressions between the rock glacier and the talus slopes of the valley. The heads are clearly talus slopes. Time was not available for detailed study of these glacier-like slides. The theory advanced by Capps [1] that such forms are actually moving, owing to the movement of interstitial ice filling, seems to the writer not to fit the conditions in the La Sal Mountains as well as the landslide theory which Howe [2] applied to apparently similar forms in the San Juan Mountains.

The most recent formation is the relatively insignificant deposit of fine gravels along the streams, in the mountains, and on the mesas. The west-central part of Castle Valley is covered by gravel, apparently of the same origin as the conglomerate ridge, and silts from the wash of the present stream. The gravels cover the broad, flat bottom to considerable depths. At least 20 feet is shown in stream cuts, and it is reported that wells 100 to 150 feet in depth penetrate no other formation. The silts are relatively thin and patchy in distribution.

## INTRUSIVE ROCKS.

The core of this group of the La Sal Mountains is composed of a series of rocks probably all derived from the same magma. The earliest and by far the most widely distributed rock is a light-gray, fine to medium grained porphyry, with distinct phenocrysts of plagioclase and hornblende, and smaller ones of pale-green augite. Normally this rock shows no quartz, but here and there blebs are noted up to one-eighth inch in diameter. Orthoclase feldspar phenocrysts are seen in some specimens, but this mineral is usually more abundant in the groundmass, a large proportion of which is made up of finely granular plagioclase. The normal rock is a monzonite porphyry, but with more abundant quartz it approaches quartz monzonite porphyry. The monzonite porphyry forms the main intrusive mass indicated on the map (fig. 16) and also the knob northwest of Castleton.

Cutting the monzonite porphyry are at least two, and possibly three, sets of dikes, whose general direction is about north-northeast to south-southwest. They vary from a few feet to 100 feet in width, but are relatively short.

The most common of these dikes is a rock with a fine-grained gray feldspathic groundmass containing conspicuous tabular phenocrysts

[1] Capps, S. R., Rock glaciers in Alaska: Jour. Geology, vol. 18, 1910, pp. 359–375.

[2] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.

of plagioclase and orthoclase up to half an inch or more in diameter. The proportion of ferromagnesian minerals is small. This rock has been classed by Prindle as syenite porphyry. It weathers gray to yellow and is, as a rule, not iron stained except near veins.

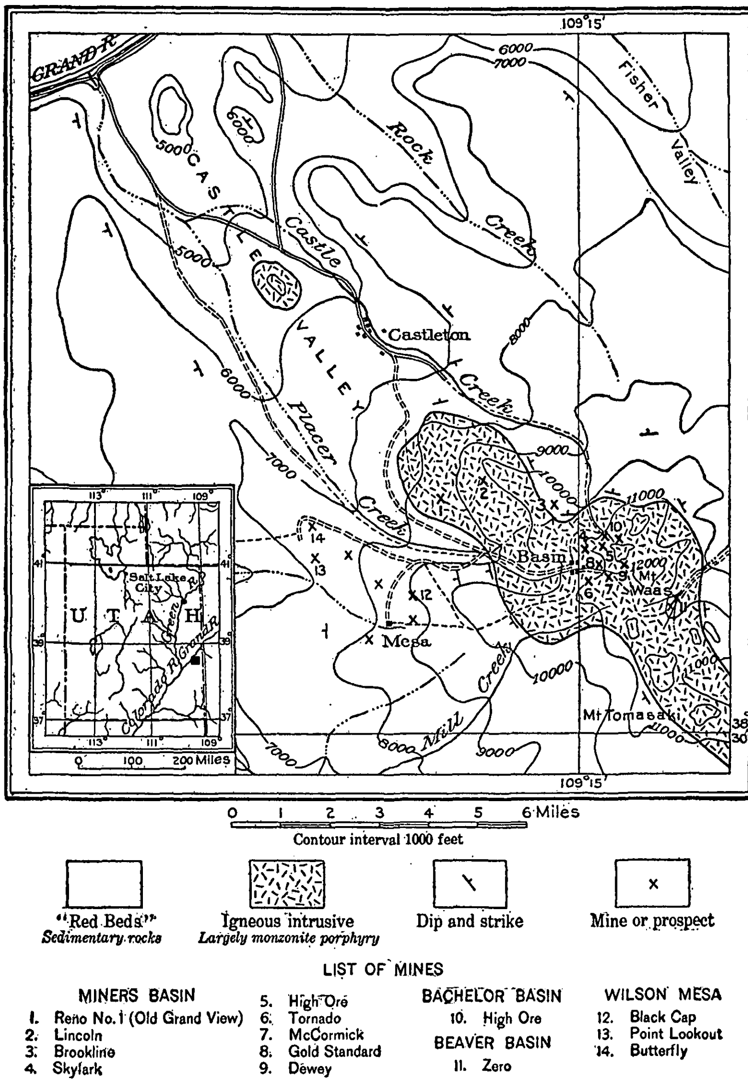



FIGURE 16.—Sketch map of the northern group of the La Sal Mountains, Grand County, Utah. Adapted from La Sal topographic sheet, U. S. Geol. Survey. Black square on index map indicates location of area.

A second type of porphyry dike rock Prindle has called noselite syenite porphyry. It occurs in a few dikes up to 20 feet in thickness in the monzonite porphyry and the syenite porphyry. It is composed of very large zonally banded orthoclase crystals up to $1\frac{1}{2}$ inches across set in a medium-grained porphyritic groundmass. The groundmass constitutes less than one-third of the rock and contains megascopic crystals of orthoclase, pyroxene (ægirite-augite and ægirite), and noselite in a feltlike mass composed of orthoclase without crystal outlines and ægirite needles. The orthoclase crystals are rounded and in places weather out of the groundmass as nearly perfect crystals. The groundmass becomes pitted and of a brownish-yellow color upon weathering.

The third dike rock, quartz monzonite porphyry, was found at only one locality, about half a mile west of Basin post office, and the croppings were largely covered by slide rock. The material is all intensely altered, leaving a yellowish-white pitted groundmass showing scattered plagioclase feldspars with abundant quartz blebs and prismatic crystals of altered white orthoclase from one-eighth to three-fourths of an inch in longest dimension. It may be that this is simply a very siliceous phase of the monzonite porphyry, though its high orthoclase content makes it appear to be a distinct type.

So far as noted, the sedimentary beds adjacent to the intrusive rocks contain no contact-metamorphic minerals, and in the descriptions of these mountains cited above no mention is made of contact metamorphism. Cross[1] makes the following statement in this regard:

> One interesting difference between these magmas [the laccolithic] and the closely allied ones of the Elk Mountain diorites has already been alluded to. Not only are the sediments adjoining the laccolithic masses unattacked by heat, but they seldom exhibit any development of secondary minerals as contact phenomena.

The age of the formation of the laccolith can not be given definitely. The Mancos shale is involved in the doming, so the intrusion is at least later than Upper Cretaceous. Cross in the paper above cited places the age as Tertiary. This estimate is based on the hypothesis that a load of probably several thousand feet of sediments, above those now exposed, was present at the time of the intrusion. This great thickness is thought essential to account for the uniform conditions of cooling through a great vertical range shown by the porphyries of the several laccolithic groups.

## STRUCTURE.

The "Red Beds" at first sight appear to be in an absolutely horizontal position along Grand River but on closer inspection are seen to lie in broad, flat anticlines, with a few faults of small displacement.

A pronounced anticlinal axis with a northwest-southeast trend runs through Salt Wash, northwest of Grand River and south of Thompsons, on the Rio Grande Western Railway, continuing through Castle Valley, and apparently is again seen southeast of the La Sal

[1] Cross, Whitman, The laccolithic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 230.

Mountains in the Paradox Valley, Colorado. Salt Wash is a broad, flat valley surrounded by low hogbacks which approach one another at each end, the beds dipping northeast on the north side and southwest at the south. It is an excellent example of a broad, low dome.

Castle Valley has an average width of 2 miles and is 9 miles long from Grand River to the base of the La Sal Mountains. It has a flat floor, except for a round porphyry butte near the center and the conglomerate ridge already mentioned joining it to the mountains and dividing the valley into two parts. The sides are nearly vertical cliffs about 1,500 feet high. They are composed of "Red Beds" strata and dip away from the axis of the valley at angles of 5°. To the northwest they converge and just east of Grand River a fault of about 100 feet displacement is clearly shown in the butte which stands in the center of the valley. The broader southeast end of the valley is blocked by the intrusive mass of the La Sal Mountains. The sedimentary beds on the north side are bent toward the intrusive mass about three-fourths of a mile from it, then are sharply upturned over the porphyry core. Castle Creek follows this sharp syncline. On the south wall of the valley the sedimentary rocks dip southwest at very steep angles for one-fourth of a mile or less from the intrusive and at that distance flatten out rather abruptly to the general level of the beds underlying Wilson Mesa.

On the north side of the mountains the sedimentary beds come up to an elevation of 10,750 feet, overlying a ridge of porphyry that runs northwest from the central core. East of Beaver Basin the beds dip about 45° E. and form the east wall of the basin.

## ECONOMIC GEOLOGY.

Two classes of deposits are worked in the vicinity of Basin and Mesa. In the mountains there are several quartz mining prospects and at least one locality where placer gold has been recovered. On Wilson Mesa there has been recently some little excitement over the discovery of gold-bearing gravels.

### HISTORY.

So far as can be learned, the earliest discoveries of minerals in this area were made about 1886, the first location being made in 1888 on the ridge between Bachelor and Miners basins, on what is now the High Ore claim. Practically no mining was done in these mountains until 1896, when a party of prospectors did some work that resulted in the discovery of the Tornado deposit in 1897. The district has never attracted much attention, on account of its distance from the railroad and the inclement winters. Shortly after the discovery of the Tornado, a small stamp mill was installed in Miners Basin. It has five 600-pound stamps, driven by a Pelton wheel, generating

6 horsepower. A 5 by 9 foot copper amalgamation plate and two Frue vanners were used for saving the gold. After about 100 tons of ore had been run through the mill it was closed and has not been operated since.

In 1907 it was first noted that the gravels on Wilson Mesa carried gold. For two years these gravels were washed by crude methods, and in 1910 a little excitement was created in Salt Lake and Grand Junction over the richness of the deposits. That their nature was not understood is clearly shown by placer and lode locations which cover the same ground.

There has been practically no production from the quartz mines, and it is probable that $5,000 would cover the entire output from both quartz and placer mining in the region.

## QUARTZ PROSPECTS.

### GENERAL FEATURES.

There has been very little work done on the mineral deposits of the La Sal Mountains. The greatest depth reached is perhaps 150 feet below the surface, and 95 per cent of the shafts and tunnels are not more than 50 feet below the grass roots. The general procedure seems to have been to locate a mineralized zone on the hill slope and then go into the valley bottom and start a long crosscut to reach it in depth. As yet few of these crosscuts have reached the desired goal. It is evident that from the exposures available under these conditions only a superficial knowledge of the nature and character of the deposits is possible.

The general direction of the lodes seems to be northwest and southeast to east and west, with one or two east-northeast fractures. The northwest-southeast trend corresponds in a general way to the longer axis of the intrusive mass, as is shown in figure 16.

There are two rather distinct types of deposits—one characterized by glassy quartz with copper, silver, and gold, and the other with apparently the same kind of quartz, but containing largely gold in a pyritic carrier. The deposits of the former type are usually simple, relatively narrow quartz veins that have affected the walls to a much less degree than the second type. The gold-pyrite deposits appear to be stockworks or zones of minute branching, interlacing quartz-filled fissures. In the deposits of this type the wall rock is altered and impregnated with pyrite, forming masses of low-grade ore as much as 20 feet across. These two types, though more or less distinct, merge into each other and in places the gold-pyrite deposits show copper minerals. Veins characterized by carbonate gangue were seen in two places and carry both pyrite and chalcopyrite.

The ores so far developed are largely oxidized, but remnants of chalcopyrite and pyrite are found surrounded and cut by masses of limonite, malachite, and chrysocolla. These three oxides are more or less mixed, the iron being much more abundant than the copper minerals, forming a low-grade copper-pitch ore. Very minor amounts of bornite and chalcocite occur in Beaver Basin, but were not noted elsewhere. Azurite is rather uncommon. Glassy, coarsely crystalline quartz is by far the most abundant gangue mineral. It is usually rather smoky but may be clear. Calcite and siderite are seen in some veins, and associated with them in one place is a very minor amount of fluorite. Barite with limonite was noted in one deposit in sandstone near the monzonite porphyry. The association of glassy quartz with much copper-bearing limonite in small stringers is commonly seen in the brownish float of the mountains.

The lodes are later than all the porphyries except possibly the very siliceous quartz monzonite mass half a mile west of Basin. It seems possible that they may be the final product of the intrusion. The interpretation of the origin of these deposits, however, can be attempted only after much more development has uncovered the primary ores of the region, so that more detailed study of them is possible.

### MINERS BASIN.

The Reno claim (No. 1, fig. 16) crosses a high ridge overlooking the southern part of Castle Valley. A shear zone about 6 to 8 feet in width cuts this point, bearing N. 60° W. and standing almost vertical. The development consists of several pits and caved tunnels on both sides of the ridge. The country rock is monzonite porphyry and the ore seen on the dumps is largely the same rock cut by stringers of quartz with abundant limonite and some malachite and chrysocolla, surrounding kernels of chalcopyrite. The principal body of ore is on the east side of the ridge, and has an elliptical cross section. All the ore is oxidized with the exception of the kernels of chalcopyrite noted.

The Lincoln prospect (No. 2, fig. 16) is on a 12-foot zone of somewhat silicified monzonite porphyry, showing on joints and narrow fractures a coating of calcite and siderite. The monzonite contains a little disseminated pyrite, largely altered to limonite. The short tunnel does not extend below the zone of oxidation.

The Brookline prospect (No. 3, fig. 16) is in a saddle of the ridge called Horse Mountain, north of Pinhook Gulch. This ridge is capped by white sandstones dipping north at steep angles. Monzonite porphyry outcrops about 400 feet below it in Pinhook Gulch and about one-fourth of a mile east and west on the top of the ridge A 50-foot shaft sunk in apparently unaltered sandstone disclosed a small body of iron-stained barite and a little limonite deposited along an open watercourse running N. 30° W. A minor amount of limonite (?) is seen coating fragments of sandstone.

On the Skylark claim (No. 4, fig. 16) there are two tunnels, the lower about 205 feet and the upper about 35 feet long. They expose a vein varying from knife-blade thickness to 2 feet. This vein cuts both monzonite porphyry and a dike of syenite porphyry. It strikes N. 52° E. and stands nearly vertical. In its wider portions there is an abundance of glassy dark quartz with drusy cavities. Some of these druses are coated with greenish-blue chrysocolla, much of it dull and earthy. Masses of limonite, usually copper bearing, which are probably the alteration products of cupriferous pyrite or chalcopyrite, occur in the quartz. Narrow quartz stringers make off into the porphyry, which contains some disseminated pyrite near them.

The upper workings of the High Ore claim (No. 5, fig. 16) are located on the divide between Miners and Bachelor basins. They consist of shallow shafts in a body of very siliceous oxidized copper ore said to have carried about $157 to the ton in copper, gold, and silver.

The Tornado property (No. 6, fig. 16) has been worked to more advantage than any of the other properties in the basin. Two zones of fracturing intersect near the main workings; one, the Tornado vein, strikes N. 80° E., and the other, the Indiana, strikes N. 40° E. Along these zones there are numerous branching fractures filled with dark glassy drusy quartz up to three-fourths of an inch in width. Near the junction of the two systems the interlacing seams are more abundant. Pyrite has been deposited both with the quartz and disseminated in the altered monzonite porphyry wall rock. The Indiana zone averages about 10 feet in width and the Tornado from 15 to 20 feet. The former is opened by two short tunnels and the latter near its junction with the Indiana by a tunnel and a 50-foot shaft. A crosscut tunnel, now 270 feet long, has been started for the intersection but has not yet reached it. All the altered pyrite-impregnated monzonite porphyry cut by quartz stringers is classed as ore, with a reported average value of $15 to $20 a ton in gold. It is all oxidized, and only a few pyrite crystals remain unchanged to limonite. The material pans well, but it is said that the iron concentrates, made at the mill, ran $28 to the ton in gold.

The McCormick prospects (No. 7, fig. 16) are only slightly developed. The Gold Coin No. 1 is on a 10 to 15 foot zone of altered monzonite cut by interlacing quartz stringers and containing some disseminated pyrite, now altered to limonite. Copper carbonates are seen in some joints and a little chalcopyrite in process of alteration is noted. One other prospect is on a vein at the contact of syenite and coarse noselite syenite. This vein is not very well defined and is nowhere over 21 inches wide. The vein material is calcite, siderite, and a little fine quartz, partly filling the fracture, which in a few places shows stains of copper carbonate.

The Gold Standard tunnel (No. 8, fig. 16) is about one-eighth of a mile east of Basin post office. It is a crosscut tunnel and could not be entered. On the dump some serpentine was noted on what appeared to be a fault. Pyrite-impregnated monzonite cut by quartz stringers, similar to the Tornado ore, was also seen, as well as calcite-siderite vein matter like that of the McCormick vein. A small amount of very black compact earthy material on the dump contains manganese and iron with some copper. It is probably a mixture of limonite and pyrolusite.

The Dewey group of claims (No. 9, fig. 16) is located at the extreme east end of Miners Basin, just under Green Mountain. The monzonite porphyry is cut by a series of nearly parallel fractures bearing N. 45° W. A 225-foot crosscut tunnel exposed near its face an open fracture in which drusy quartz crystals are coated with chrysocolla. Fifty feet farther out toward the mouth a 12 to 18 inch vein of glassy quartz shows some limonite and copper carbonates with a little calcite. This material is said to average about $20 to the ton in gold, silver, and copper from assays. On the surface this vein is largely calcite with some fluorite and minor quartz and siderite. The tunnel does not reach the sulphides, though in some of the limonite ore there were kernels of pyrite and chalcopyrite.

There are several other small prospects in Miners Basin, most of them on zones of pyrite-impregnated monzonite porphyry similar to the Tornado ore.

## BACHELOR BASIN.

Only one mine in Bachelor Basin could be visited, as snow covered all the prospects. The High Ore tunnel (No. 10, fig. 16) cuts two veins. One striking east and west is cut about 50 feet from the mouth of the tunnel. It is distinctly a vertical fissure filling from 6 to 18 inches wide, consisting partly of glassy quartz with many drusy cavities. Chalcopyrite, largely altered to copper-pitch ore, was deposited with the quartz, and copper carbonates are prevalent as coatings in the druses. A little earthy fluorite of a light lilac color is found in some specimens. The other vein strikes about N. 32° E. It is followed for about 100 feet, the drift then running north of it for about 250 feet, to a point where a crosscut has been turned south, intersecting the vein at 50 feet. This vein is very narrow and consists of sugary quartz in altered monzonite porphyry. The mineralization seems to be largely pyritic, though some copper stains were noted near the junction with the other vein. It is oxidized throughout. Seven tons of the ore from the siliceous north vein was shipped and is said to have brought $54 a ton in copper, silver, and gold.

### BEAVER BASIN.

In Beaver Basin the workings were entirely covered by a snowslide, except for one end of the dump of a crosscut tunnel of the Zero group (No. 11, fig. 16). The material on this dump is largely monzonite porphyry, showing some serpentine developed along shear planes. A small quantity of ore on the dump consists of glassy quartz with minor amounts of bornite, chalcocite, limonite, and malachite. It is said that the tunnel runs southeastward along a zone of altered porphyry, about 12 feet wide, containing many joints coated with serpentine, and that the ore occurs in small seams between this altered zone and unaltered monzonite. The values are said to be largely in copper and silver, with very little gold.

## PLACER MINES.

### WILSON MESA.

*Geology and mining conditions.*—The flat mesas south of Castle Valley are covered by a coating of gold-bearing gravel. This deposit is usually very thin, being indicated by scattered bowlders and pebbles or by small flattened mounds of like material here and there on the sandstone bedrock. In a few places it attains greater thicknesses. Some of the larger deposits stand as low rounded knobs, but most of them seem to occupy reentrants in cliffs. The latter was apparently the position at the Point Lookout placer. A combination of the two forms is seen at the Black Cap workings. A third and much rarer occurrence is along what appears to be an old channel which runs northwestward from the Black Cap.

The gravels are the same throughout, consisting of subangular cobbles of igneous material similar to that seen in the La Sal Mountains to the east, with a relatively small proportion of sandstone fragments. They range in size from one-fourth of an inch to 2½ feet, with an average size of about 10 to 12 inches. Fragments of monzonite porphyry cut by quartz stringers are fairly abundant and magnetite cobbles up to 4 or 5 inches in diameter are not at all rare. There seems to be a slight decrease in size of the bowlders at the western edge of the deposits, but it is not everywhere the same and is rather doubtful. There is practically no stratification of these gravels except along the present drainage lines in reworked material.

The gold, said to be worth from $19 to $20 an ounce, occurs in small wires or flakes, and none of that seen appeared to be much waterworn. It is distributed throughout the thickness of the deposits, which are said to be of about the same grade from the surface to bedrock. Besides the gold that can be recovered by washing, it has been found that the "ribbon rock" (the monzonite porphyry cut by quartz stringers) contains a fairly large portion of the gold value of the gravels. Some of the miners assert that for every ounce saved by sluicing 10 ounces is lost in the ribbon rock which goes over the dump.

There is no natural water supply on Wilson Mesa. A ditch originally built for irrigation is said to supply about 12 cubic feet a second from the beginning of the thaw in April to the last of July, when the greater part of the snow has disappeared from the mountains. From then until October the supply is about 8 cubic feet a second, and it is further diminished during the winter. The water is all taken from Mill Creek, and considerable trouble has been experienced in obtaining enough for sluicing, as the town of Moab also takes its supply from this source and has a prior right to the water.

*Prospects.*—The Black Cap placer (No. 12, fig. 16) is located in the cliff between the middle and upper mesas. The gravels here form a low knoll, and are also found below the general rim-rock level in what appears to be a cleft or reentrant from the face of the cliff. The maximum thickness above the true rim rock is about 50 feet, with possibly as much more below at one place.

Hydraulicking into sluice boxes located in the reentrant has opened a pear-shaped cut about 40 feet in maximum width by 60 feet long, with a face 40 feet high. The location is ideal for this sort of work, as there is plenty of ground for a dump much below the level of the gravels. It is said that some difficulty was experienced with the larger bowlders and that considerable gold was lost in the ribbon rock.

At the Point Lookout placer (No. 13, fig. 16) the gravels clearly occur in a reentrant at the rim of a canyon leading into Mill Creek. This locality is also in the rim of the middle mesa, just above the lower mesa. A very thin veneer of gravels covers an area of 2 or 3 acres, with one deeper deposit just at the rim.

A shaft sunk in the deep deposit has gone down about 20 feet through gravel that contains a large amount of magnetite, usually as small pebbles, though some cobbles as large as 8 inches in diameter were noted. Very little water can be had here. The surface has been partly sluiced into a vibrating screen which allows only the finest material to pass. The fines were put through riffles and finally over a small amalgamation plate. Practically all the free gold was saved, but it was found that the tailings carried gold in the quartz ribbon rock.

At the Butterfly placer (No. 14, fig. 16) a low ridge running from the middle to the lower mesa is covered with gravel to varying depths, a knoll at the lower west end showing the greatest thickness. The main irrigating ditch referred to above passes this place and the gravels were handled by road scrapers, being carried upon a platform through which they fell into sluice boxes. The method was very cheap and it is said that with a team and scraper two men could make $16 a day.

Figure 16 shows prospects just northwest of No. 12 and east of No. 13. At the latter locality two shafts about 100 feet apart have been sunk; one to a depth of 40 feet is all in gravel, and the other, 10 feet deep, entirely in sandstone bedrock. This is on the relatively flat middle mesa, but in a depression that at present is a watercourse and seems to have been a channel at the time of the deposition of the gravels. Little work has been done on the prospect nearer No. 12, a low gravel knoll. The prospect southwest of Mesa post office is also a low knoll of gravel with bedrock outcropping just east of it. This is apparently a remnant behind a ledge of sandstone. The prospect just east of Mesa is a continuation of the Black Cap deposit. It is a relatively thin layer of gravels except in a few shallow reentrants.

*Origin of the gravel.*—The material composing the gravels of Wilson Mesa is at least nine-tenths igneous. It occurs on flat-lying undisturbed sandstones which nowhere show any igneous rock in place. All the porphyry types represented in the main laccolithic mass of the La Sal Mountains are represented by pebbles or bowlders in these gravels. Pebbles of monzonite porphyry cut by stringers of glassy quartz containing limonite, which resemble the ore of the Tornado and other places, are frequently seen. These, owing no doubt to their original altered condition, are softer and more weathered than the previously unaltered rocks. It can hardly be questioned that the gravels were very largely derived from the La Sal Mountains. Their present distribution is probably due largely to erosion since their deposition. In sheltered places such as reentrants the gravels have not been removed, but they have been largely eroded from the flat-topped mesas except for the remnants left in old channels or between the present drainage lines.

The method of deposition of the gravel on this mesa is open to question. That its deposition is not related to the most recent glaciation is clearly shown by the fact that the last glaciers were very small, rarely reaching below an elevation of 10,000 feet and never issuing beyond the high mountain valley. The material is subangular, no rounded pebbles being noted; it is fairly coarse for the most part, with only a little sand; and it is so far as seen unstratified. Two hypotheses are suggested by its character. Both torrential floods and glaciers form such deposits. That one or the other of these agencies brought the material to its present resting place is fairly sure. In either event it is quite certain that the gravels were deposited at a time when the La Sal Mountains were higher than they now are, and either explanation presupposes a very much greater precipitation than there is at present in this region. It seems probable that the gravels were deposited prior to the establishment of the present drainage system, for deposits of this class are found only on flat-topped mesas, and if ever present have been entirely removed from the places now occupied by canyons. Similar gravels that were not visited are reported on the mesas north of the mountains.

If these gravels are glacier-borne deposits they must surely afford some evidence of this mode of transportation. The writer at the time of his visit did not fully realize the difficulty of proving this point, so did not spend sufficient time to collect conclusive evidence. One bowlder of sandstone 10 feet in diameter on the upper mesa about half a mile east of Mesa post office showed marks that were thought to be striæ.

Wallace W. Atwood, of the United States Geological Survey, who is making a study of the somewhat similarly disposed gravels in the San Juan region, has come to the conclusion that they are the result of glaciation very much older than that which produced any of the Pleistocene drift heretofore found in the Rocky Mountains, and from his description of these deposits at the meeting of the American Association for the Advancement of Science held in Washington in December, 1911, the writer is inclined to attribute to a similar agency the deposition of the gravels of Wilson Mesa.

The question is, however, still far from solution, and more detailed study of the mesa will be necessary before a final statement can be made as to what brought the gravels to their present position.

## MINERS BASIN.

The town of Basin is located on a flat just above a very small, indistinct terminal moraine of the last glacial epoch. This moraine is composed entirely of angular igneous material, none of which has traveled over a mile and much of it a very inconsiderable distance. The moraine lies on the top of a débris-filled V-shaped valley. Both the glacial material and the débris contain a little fine free gold. The amount of material is, however, very small and hard to handle on account of the large angular talus blocks included in it.

## OTHER MINERAL RESOURCES.

About a mile north of Mesa post office a tunnel starts in at the base of the cliffs to the upper mesa. On the dump there is some manganese ore which is a replacement of slightly calcareous sandstone. Pyrolusite has replaced the lime and coated the quartz grains. Some of the ore is nearly pure manganese oxide. The tunnel is caved, but it is said that there is 10 feet of material similar to that seen on the dump.

The vanadium prospect near Richardson, just beyond the northwest corner of the area shown on figure 16, was not being worked. Boutwell's description of this prospect is summarized on page 102.

About 9 miles east of Dewey, the halfway station on the Cisco-Castleton road at Grand River, a copper-silver mine entirely in sandstone, with no igneous rock in the vicinity, is said to be producing some ore. The property was not visited, but the writer had an opportunity to see some of the ore. It consists of chalcocite deposited in small seams cutting white sandstone and also disseminated in the adjacent walls. Along the borders of these seams a thin zone of malachite is usually present, and this mineral, together with azurite, stains the sandstone near the fissure. The mine is now being worked for its silver, which occurs in native form and as silver chloride. The development is rather shallow. The vein is said to strike a few degrees north of west and to be traceable for more than a mile.

Emmons [1] has described an apparently similar deposit on the east side of the La Sal Mountains in Montrose County, Colo.

In June, 1911, several oil men were prospecting in Fisher Valley, where there are said to be some oil seeps. The east end of this valley is at the extreme northeast corner of the area represented on figure 16.

## FUTURE OF THE DISTRICT.

The quartz prospects in the northern La Sal Mountains do not at present give much hope for a large mining camp. They are few in number and the values are low even at the surface, where many gold-bearing deposits are enriched. The veins, so far as could be seen, are very small and contain much barren quartz. The high freight charges to the railroad at Cisco ($25 a ton in and $12 to $15 out) are an additional handicap.

The Wilson Mesa placers apparently are of minor extent. There is not a large amount of gravel and all the values in it can not be saved by sluicing. As has been said, part of the values are carried in the tailings. These values are in free gold carried in the quartz stringers in fragments of monzonite porphyry. To save all the gold will require some sort of crushing of these bowlders. There is so much material that surely carries nothing of value that it would hardly seem advisable to install expensive crushing and amalgamating machinery unless it were found practical to sort the ore from the waste by hand. There is a very meager and uncertain supply of water available for placer operations. Unless some company controls practically all the gravel deposits on the mesa and is assured of a certain permanent supply of water such operations would hardly be a profitable venture. There is, however, a fair amount of free gold that might be procured at a profit if the deposits are worked in a small way.

[1] Emmons, W. H., The Cashin mine, Montrose County, Colo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 125-128.

# 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 520, the annual report on the progress of the Survey's investigations in Alaska for 1911.

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.

Arnold, Ralph, Gold placers of the coast of Washington: Bull. 260, 1905, pp. 154–157. 40c.

Bain, H. F., Reported gold deposits of the Wichita Mountains [Okla.]: Bull. 225, 1904, pp. 120–122. 35c.

Ball, S. H., Notes on the ore deposits of southwestern Nevada and eastern California: Bull. 285, 1906, pp. 53–73. Exhausted. See also Bull. 308, 1907, 218 pp.

Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

Barrell, Joseph, Geology of the Marysville mining district, Montana: Prof. Paper 57, 1907, 178 pp. 50c.

Becker, G. F., Geology of the Comstock lode and the Washoe district, with atlas: Mon., vol. 3, 1882, 422 pp. $11.

——— Gold fields of the southern Appalachians: Sixteenth Ann. Rept., pt. 3, 1895, pp. 251–331.

——— Witwatersrand banket, with notes on other gold-bearing pudding stones: Eighteenth Ann. Rept., pt. 5, 1897, pp. 153–184.

——— Brief memorandum on the geology of the Philippine Islands: Twentieth Ann. Rept., pt. 2, 1900, pp. 3–7.

Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper 38, 1905, pp. 73–385.

——— Progress report on Park City mining district, Utah: Bull. 213, 1903, pp. 31–40 (25c.); 225, 1904, pp. 141–150 (35c.); 260, 1905, pp. 150–153 (40c.).

Boutwell, J. M., Geology and ore deposits of the Park City district, Utah, with contributions by L. H. Woolsey: Prof. Paper 77, 1912, 231 pp.

Calkins, F. C., and MacDonald, D. F., A geologic reconnaissance in northern Idaho and northwestern Montana: Bull. 384, 1909, 112 pp.

Collier, A. J., Gold-bearing river sands of northeastern Washington: Bull. 315, 1907, pp. 56–70.

Cross, Whitman, General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept., pt. 2, 1895, pp. 13–109. $1.25.

——— Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept., pt. 2, 1896, pp. 269–403. $2.35.

Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colorado: Twenty-first Ann. Rept., pt. 2, 1900, pp. 15–165.

Curtis, J. S., Silver-lead deposits of Eureka, Nev.: Mon., vol. 7, 1884, 200 pp. $1.20.

Diller, J. S., The Bohemia mining region of western Oregon, with notes on the Blue River mining region: Twentieth Ann. Rept., pt. 3, 1900, pp. 7–36. $1.50.

——— Mineral resources of the Indian Valley region, California: Bull. 260, 1905, pp. 45–49. 40c.

——— Geology of the Taylorsville region, California: Bull. 353, 1908, 128 pp.

——— The auriferous gravels of the Trinity River basin, California: Bull. 470, 1911, pp. 11–29.

Diller, J. S., and Kay, G. F., Mines of the Riddles quadrangle, Oregon: Bull. 340, 1908, pp. 134–151. 30c.

——— Mineral resources of the Grants Pass quadrangle and bordering districts, Oregon: Bull. 380, 1909, pp. 48–79.

Eckel, E. C., Gold and pyrite deposits of the Dahlonega district, Georgia: Bull. 213, 1903, pp. 57–63. 25c.

Emmons, S. F., Geology and mining industry of Leadville, Colo., with atlas: Mon.; vol. 12, 1886, 870 pp. Exhausted.

——— Progress of the precious-metal industry in the United States since 1880: Mineral Resources U. S. for 1891, 1892, pp. 46–94. 50c.

——— Economic geology of the Mercur mining district, Utah: Sixteenth Ann. Rept., pt. 2, 1895, pp. 349–369. $1.25.

——— The mines of Custer County, Colo.: Seventeenth Ann. Rept., pt. 2, 1896, pp. 411–472. $2.35.

Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: Bull. 320, 1907, 72 pp.

Emmons, W. H., The Neglected mine and near-by properties, Colorado: Bull. 260, 1905, pp. 121–127. 40c.

——— Ore deposits of Bear Creek, near Silverton, Colo.: Bull. 285, 1906, pp. 25–27. Exhausted.

——— The Granite-Bimetallic and Cable mines, Philipsburg quadrangle, Montana: Bull. 315, 1907, pp. 31–55.

——— Gold deposits of the Little Rocky Mountains, Montana: Bull. 340, 1908, pp. 96–116. 30c.

——— Reconnaissance of some mining camps in Elko, Lander, and Eureka counties, Nev.: Bull. 408, 1910, 126 pp.

Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Montana: Prof. Paper 78 (in press).

Emmons, W. H., and Garrey, G. H., Notes on the Manhattan district, Nevada: Bull. 303, 1907, pp. 84–93. 15c.

Gale, H. S., The Hahns Peak gold field: Bull. 285, 1906, pp. 28–34. Exhausted.

——— Gold placer deposits near Lay, Routt County, Colo.: Bull. 340, 1908, pp. 84–95. 30c.

GRATON, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians, with notes on the Dahlonega mines, by Waldemar Lindgren: Bull. 293, 1906, 134 pp.

HAGUE, ARNOLD, Geology of the Eureka district, Nevada: Mon., vol. 20, 1892, 419 pp. $5.25.

HAHN, O. H., The smelting of argentiferous lead ores in the Far West: Mineral Resources U. S. for 1882, 1883, pp. 324–345. 50c.

HESS, F. L., Gold mining in the Randsburg quadrangle, California: Bull. 430, 1910, pp. 23–47.

HILL, J. M., Notes on the economic geology of southeastern Gunnison County, Colo.: Bull. 380, 1909, pp. 21–40.

——— Notes on the placer deposits of Greaterville, Ariz.: Bull. 430, 1910, pp. 11–22.

——— Notes on the economic geology of the Ramsey, Talapoosa, and White Horse mining districts, in Lyon and Washoe counties, Nev.: Bull. 470, 1911, pp. 99–108.

——— Mining districts of the western United States: Bull. 507, 1912, 309 pp.

IRVING, J. D., Ore deposits of the northern Black Hills: Bull. 225, 1904, pp. 123–140. 35c.

——— Ore deposits of the Ouray district, Colorado: Bull. 260, 1905, pp. 50–77. 40c.

——— Ore deposits in the vicinity of Lake City, Colo.: Bull. 260, 1905, pp. 78–84. 40c.

IRVING, J. D., and BANCROFT, HOWLAND, Geology and ore deposits near Lake City, Colo.: Bull. 478, 1911, 128 pp.

IRVING, J. D., and EMMONS, S. F., Economic resources of northern Black Hills: Prof. Paper 26, 1904, pp. 53–212.

LARSEN, E. S., The economic geology of Carson camp, Hinsdale County, Colo.: Bull. 470, 1911, pp. 30–38.

LINDGREN, WALDEMAR, The gold-silver mines of Ophir, Cal.: Fourteenth Ann. Rept., pt. 2, 1894, pp. 243–284. $2.10.

——— The gold-quartz veins of the Nevada City and Grass Valley districts, California: Seventeenth Ann. Rept., pt. 2, 1896, pp. 1–262. $2.35.

——— The mining districts of the Idaho Basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept., pt. 3, 1898, pp. 625–736. $2.15.

——— The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept., pt. 3, 1900, pp. 75–256. $1.50.

——— The gold belt of the Blue Mountains of Oregon: Twenty-second Ann. Rept., pt. 2, 1902, pp. 551–776.

——— Mineral deposits of the Bitterroot Range and the Clearwater Mountains, Montana: Bull. 213, 1903, pp. 66–70. 25c.

——— Tests for gold and silver in shales from western Kansas: Bull. 202, 1902, 21 pp. 5c.

——— The production of gold in the United States in 1904: Bull. 260, 1905, pp. 32–38. 40c.

——— The production of silver in the United States in 1904: Bull. 260, 1905, pp. 39–44. 40c.

——— The Annie Laurie mine, Piute County, Utah: Bull. 285, 1906, pp. 87–90. Exhausted.

——— Notes on the Dahlonega mines: Bull. 293, 1906, pp. 119–128.

——— Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper 54, 1906, 516 pp.

——— A geological analysis of the silver production of the United States in 1906: Bull. 340, 1908, pp. 23–35. 30c.

Lindgren, Waldemar, Resources of the United States in gold, silver, copper, lead, and zinc: Bull. 394, 1909, pp. 114-156.

——— The Tertiary gravels of the Sierra Nevada of California: Prof. Paper 73, 1911, 226 pp.

Lindgren, Waldemar, and Graton, L. C., Mineral deposits of New Mexico: Bull. 285, 1906, pp. 74-86. Exhausted.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper 68, 1910, 361 pp.

Lindgren, Waldemar, and Ransome, F. L., The geological resurvey of the Cripple Creek district: Bull. 254, 1905, 36 pp.

Lord, Eliot, Comstock mining and miners: Mon., vol. 4, 1883, 451 pp. $1.50.

MacDonald, D. F., Economic features of northern Idaho and northeastern Montana: Bull. 285, 1906, pp. 41-52. Exhausted.

——— Notes on the Bohemia mining district, Oregon: Bull. 380, 1909, pp. 80-84.

——— The Weaverville-Trinity Center gold gravels, Trinity County, Cal.: Bull. 430, 1910, pp. 48-58.

McCaskey, H. D., Notes on some gold deposits of Alabama: Bull. 340, 1908, pp. 36-52. 30c.

——— Gold and silver: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 211-254.

McCaskey, H. D., and others, Gold, silver, copper, lead, and zinc (mine production) in Western, Central, and Eastern States: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 403-888.

Nitze, H. B. C., History of gold mining and metallurgy in the Southern States: Twentieth Ann. Rept., pt. 6, 1899, pp. 111-123.

Paige, Sidney, The ore deposits near Pinos Altos, N. Mex.: Bull. 470, 1911, pp. 109-124.

Pardee, J. T., Faulting and vein structure in the Cracker Creek gold district, Baker County, Oreg.: Bull. 380, 1909, pp. 85-93.

——— Placer gravels of the Sumpter and Granite districts, eastern Oregon: Bull. 430, 1910, pp. 59-65.

——— Geology and mineralization of the upper St. Joe River Basin, Idaho: Bull. 470, 1911, pp. 39-61.

Penrose, R. A. F., jr., Mining geology of the Cripple Creek district: Colorado: Sixteenth Ann. Rept., pt. 2, 1895, pp. 111-209. $1.25.

Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: Eighteenth Ann. Rept., pt. 3, 1898, pp. 745-850. $2.15.

Ransome, F. L., Report on the economic geology of the Silverton quadrangle, Colorado: Bull. 182, 1901, 265 pp. 50c.

——— The ore deposits of the Rico Mountains, Colorado: Twenty-second Ann. Rept., pt. 2, 1902, pp. 229-398.

——— Preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada: Bull. 303, 1907, pp. 7-83. 15c.

——— Geology and ore deposits of Goldfield, Nev.: Prof. Paper 66, 1909, 258 pp.

——— Some mining districts of Humboldt County, Nev.: Bull. 414, 1909, 75 pp.

——— The Hornsilver district, Nevada: Bull. 380, 1909, pp. 41-43.

——— Round Mountain, Nevada: Bull. 380, 1909, pp. 44-47.

——— Geology and ore deposits of the Breckenridge district, Colorado: Prof. Paper 75, 1911, 187 pp.

Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper 62, 1908, 203 pp. 85c.

Ransome, F. L., Emmons, W. H., and Garrey, G. H., Geology and ore deposits of the Bullfrog district, Nevada: Bull. 407, 1910, 128 pp.

Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. 340, 1908, pp. 53-84. 30c.

Schrader, F. C., The mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. 397, 1909, 226 pp.

——— Gold-bearing ground moraine in northwestern Montana: Bull. 470, 1911, pp. 62–74.

——— A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: Bull. 497, 1912, 162 pp.

Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: Bull. 315, 1907, pp. 71–88.

Smith, G. O., Gold mining in central Washington: Bull. 213, 1903, pp. 76–80. 25c.

——— Quartz veins in Maine and Vermont: Bull. 225, 1904, pp. 81–88. 35c.

Spurr, J. E., Economic geology of the Mercur mining district, Utah: Sixteenth Ann. Rept., pt. 2, 1895, pp. 343–455. $1.25.

——— Geology of the Aspen mining district, Colorado; with atlas: Mon., vol. 31, 1898, 260 pp. $3.60.

——— The ore deposits of Monte Cristo, Washington: Twenty-second Ann. Rept., pt. 2, 1902, pp. 777–866.

——— Ore deposits of Tonopah and neighboring districts, Nevada: Bull. 213, 1903, pp. 81–87. 25c.

——— Preliminary report on the ore deposits of Tonopah: Bull. 225, 1904, pp. 89–110. 35c.

——— Ore deposits of the Silver Creek quadrangle, Nevada: Bull. 225, 1904, pp. 111–117. 35c.

——— Notes on the geology of the Goldfield district, Nevada: Bull. 225, 1904, pp. 118–129. 35c.

——— The ores of Goldfield, Nev.: Bull. 260, 1905, pp. 132–139. 40c.

——— Development of Tonopah during 1904: Bull. 260, 1905, pp. 140–149. 40c.

——— Geology of the Tonopah mining district, Nevada: Prof. Paper 42, 1905, 295 pp.

——— Ore deposits of the Silver Peak quadrangle, Nevada: Prof. Paper 55, 1906, 174 pp.

Spurr, J. E., and Garrey, G. H., Preliminary report on the ore deposits of the Georgetown mining district, Colorado: Bull. 260, 1905, pp. 99–120. 40c.

——— The Idaho Springs mining district, Colorado: Bull. 285, 1906, pp. 35–40. Exhausted.

——— Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, with general geology by S. H. Ball. Prof. Paper 63, 1908, 422 pp.

Stone, R. W., Geologic relation of ore deposits in the Elkhorn Mountains, Montana: Bull. 470, 1911, pp. 75–98.

Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nineteenth Ann. Rept., pt. 3, 1899, pp. 601–767. $2.25.

Weed, W. H., Geology of the Little Belt Mountains, Montana, with notes on the mineral deposits of the Neihart, Barker, Yogo, and other districts: Twentieth Ann. Rept., pt. 3, 1900, pp. 271–461. $1.50.

——— Gold mines of the Marysville district, Montana: Bull. 213, 1903, pp. 88–89. 25c.

——— Notes on the gold veins near Great Falls, Md.: Bull. 260, 1905, pp. 128–131. 40c.

——— Geology and ore deposits of the Butte district, Montana: Prof. Paper 74, 1912, 262 pp.

Weed, W. H., and Barrell, Joseph, Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont.: Twenty-second Ann. Rept., pt. 2, 1902, pp. 399–550.

Weed, W. H., and Pirsson, L. V., Geology of the Castle Mountain mining district, Montana: Bull. 139, 1896, 164 pp. 15c.

Weed, W. H., Geology and mining resources of the Judith Mountains of Montana: Eighteenth Ann. Rept., pt. 3, 1898, pp. 446-616. $2.15.

Weeks, F. B., Geology and mineral resources of the Osceola mining district, White Pine County, Nev.: Bull. 340, 1908, pp. 117–133. 30c.

Williams, Albert, jr., Popular fallacies regarding precious-metal ore deposits Fourth Ann. Rept., 1884, pp. 253–271. $1.65.

Woolsey, L. H., Lake Fork extension of the Silverton mining area, Colorado Bull. 315, 1907, pp. 26–30.

# COPPER.

## THE TURQUOISE COPPER-MINING DISTRICT, ARIZONA.

By F. L. Ransome.

### INTRODUCTION.

The following notes are the record of a brief visit to the Turquoise district in October, 1911, when a little less than five days was spared from other work for an examination of the complex geologic relations of the copper deposits near Courtland and Gleeson. The results obtainable in so short a time are necessarily incomplete and are presented with the full realization that they are likely to be modified by later detailed study. They would be even more imperfect were it not for the facts that a topographic map by Mr. F. J. Gibbons, engineer of the Great Western Copper Co., was available for the part of the district adjacent to Courtland and that the geologic boundaries had been carefully traced for this area by Mr. W. G. McBride, general superintendent for the same company. The principal changes made in Mr. McBride's work, as presented in figure 17, are the interpretation of some of the boundaries as faults and the inclusion with the Cambrian dolomite and shale of some material originally mapped as quartzite. To both gentlemen I am much indebted for their courteous assistance.

### SITUATION OF THE DISTRICT.

The Turquoise mining district is situated on the east flank of the Dragoon Mountains, in Cochise County, Ariz., about 14 miles due east of Tombstone and about 18 miles north-northeast of Bisbee. It lies for the most part in a small group of hills that separate the south end of the main range from the broad expanse of Sulphur Springs Valley. The district is reached from the north by a branch of the Southern Pacific Railroad by way of Pearce and from the south by a branch of the El Paso & Southwestern Railroad from Douglas.

It contains two small settlements—Courtland, shown in figure 17, and the older town of Gleeson, about 1½ miles to the south.

## MINING DEVELOPMENT AND PRODUCTION.

During the eighties the Gleeson, Tejon, and a few other mines near Gleeson produced considerable quantities of oxidized ore, carrying gold, silver, lead, and copper, from deposits in a ridge of Carboniferous limestone east of town, but by 1902 these ore bodies had ceased to be profitable. The extension of the railroads into the district a few years ago made possible the utilization of lower-grade ores and at present the Copper Belle mine, near Gleeson, under lease to the Shannon Copper Co., is producing a low-grade pyritic ore.

The turquoise mines, from which the district gets its name, are on the west side of Turquoise Hill, northwest of Courtland (fig. 17). They are said to have been fairly productive, but they are now idle and very little could be learned of their history. Copper mining on an important scale began near Courtland on the Humbot claim about the year 1901, and it is reported that this mine yielded about $100,000 from a body of oxidized ore stoped near the surface. In 1907 and 1908 there was much activity in the vicinity of Courtland and extensive prospecting was carried on at several places by Phelps, Dodge & Co., the Calumet & Arizona Co., and the Great Western Copper Co. The work as a whole was rather disappointing, but the Calumet & Arizona Co. shipped 15,000 to 20,000 tons of 7 per cent oxidized copper ore from the Germania mine, and the Great Western Copper Co. had produced at the time of visit about 30,000 tons of ore from the Mary mine, which is on the same ore body as the Germania. About $250,000 was expended by the Calumet & Arizona Co. on the Leadville claims and some low-grade sulphide ore was found, but work was finally abandoned. Although there is known to be still some good ore in the Germania mine, the only mines in operation in 1911 were the Mary and Mame, both owned by the Great Western Copper Co. At the time of visit this company was shipping from all workings, but mainly from the Mary mine, at the rate of nine 50-ton cars a week.

## GENERAL GEOLOGY.

The Dragoon Range, which trends generally north-northwest, with a length of about 25 miles, is composed chiefly of Paleozoic rocks, ranging from the middle Cambrian to the Carboniferous (Pennsylvanian). These are cut by various igneous rocks, especially by a large mass of rather coarse textured granite, which makes up much of the northern part of the range.

The hills of the Turquoise district rise 1,000 to 1,500 feet above the adjacent Sulphur Springs Valley, the highest line of summits being composed of hard quartzite which is probably the equivalent of the middle Cambrian Bolsa quartzite of the Bisbee district. The original base of this quartzite was not seen in this reconnaissance, although

E. T. Dumble [1] has reported the occurrence of mica schist, presumably pre-Cambrian, in South Pass, 7 or 8 miles northwest of Courtland. In the vicinity of Courtland the quartzite rests upon a rather fine grained, very much decomposed granitic rock which apparently occupies much of the relatively low ground between the Turquoise Hills and the main Dragoon Range and forms some of the low hills into which that range subsides toward the south. This rock is too much decomposed for complete identification, but apparently it is a quartzose granite in which the feldspar has been wholly altered to sericite. The microscope shows that most of the quartz grains are minutely fissured, the fissures being filled with sericite. The contacts of this rock with the sedimentary rocks are generally covered by loose detritus, but some exposures in the saddle about half a mile southwest of Courtland (see fig. 17) show that the granite rock is intrusive into the quartzite, which has been rendered schistose at the contact. Farther south, between Courtland and Gleeson, it probably is intrusive into the Carboniferous limestone also, although no exposures of this contact were seen.

The quartzite, which forms the steep hills along the western edge of the area mapped in figure 17, strikes on the whole nearly north and south and dips generally eastward at angles ranging from 40° to 80°. It is overlain to the east by a formation of thin-bedded dolomite or dolomitic limestone and shale within which are the Leadville, Mame, and Humbot mines. These rocks, which are probably the stratigraphic equivalent of what was named the Abrigo limestone at Bisbee,[2] have been strongly metamorphosed through the formation of garnet and other silicates with sulphides, chiefly pyrite. Such resemblance as the rocks may once have had to the Abrigo as developed near Bisbee has been obscured by this metamorphism and still more by the oxidation of the pyrite and by the action on the rock of the sulphuric acid thus formed.

Northeast of the Cambrian dolomite and shale is a belt of gray limestone forming Monarch, Casey, and Reservoir hills. This limestone is sparingly fossiliferous and is undoubtedly of Carboniferous age, probably Mississippian. No Devonian rocks were recognized near Courtland, although Dumble [3] has noted the presence of rocks of this age elsewhere in the Dragoon Mountains. The Carboniferous limestone near Courtland has been irregularly invaded by monzonite porphyry and no longer has its original stratigraphic position with reference to the Cambrian beds. In some places it is faulted against these beds and in others it is separated from them by intrusive masses of porphyry.

[1] Notes on the geology of southeastern Arizona: Trans. Am. Inst. Min. Eng., vol. 31, 1902, p. 713.

[2] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904.

[3] Op. cit., p. 711.

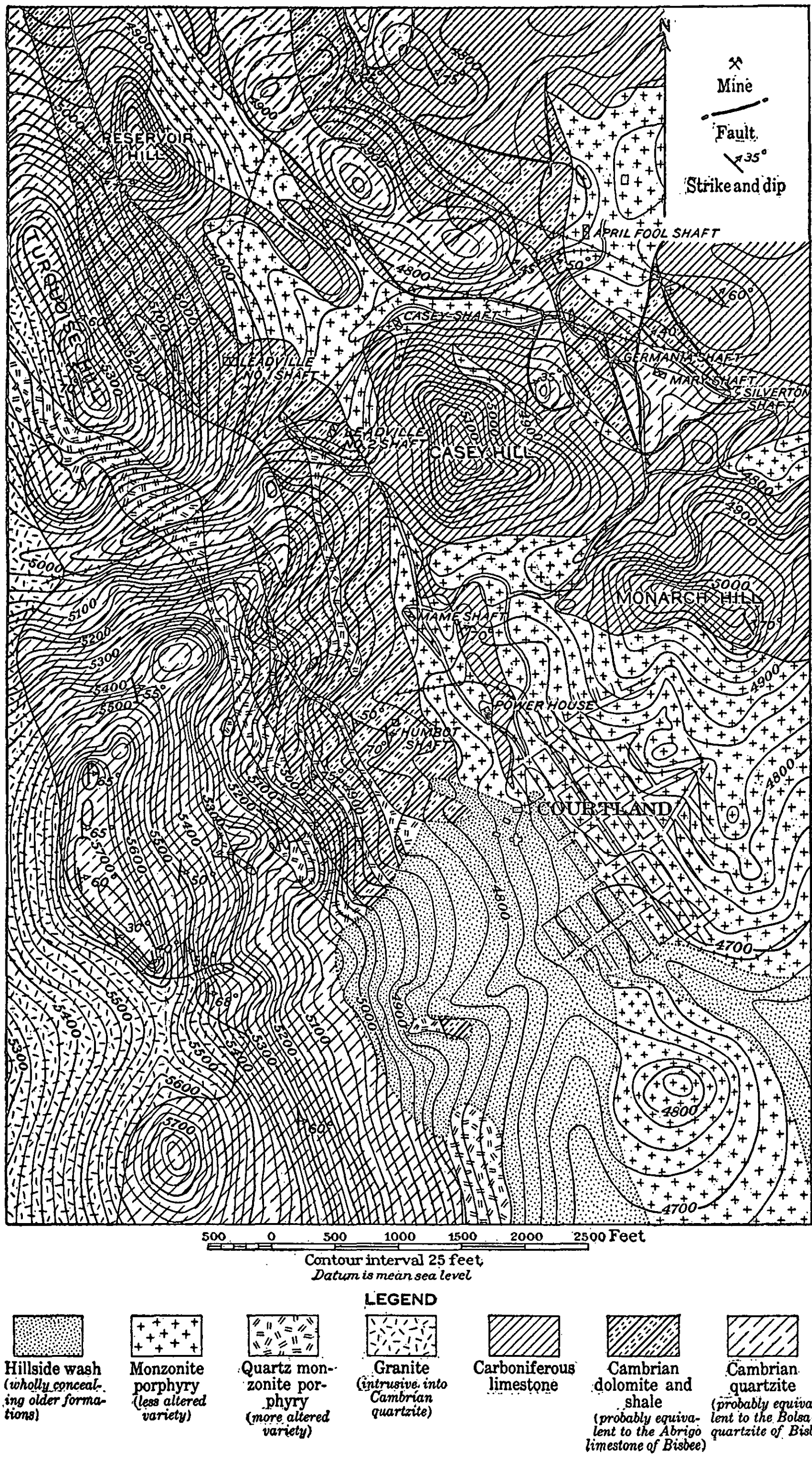



FIGURE 17.—Geologic reconnaissance map of a part of the Turquoise mining district, Arizona. Topography by F. J. Gibbons, engineer, and geologic boundaries by W. G. McBride, general superintendent, of the Great Western Copper Co.; with slight changes by F. L. Ransome.

Northeast of the limestone hills just mentioned lies another area of Cambrian rocks in which are the Mary and Germania mines. These rocks, as is clearly shown by the mine workings, rest on Carboniferous limestone and undoubtedly owe their present position to overthrust faulting. There are many puzzling features, however, in the structural relations of this part of the district and explanation of the overthrust in all its details would require much more than a hasty reconnaissance visit. A careful study of the workings connected with the Mary, Germania, Silverton, April Fool, and Casey shafts would probably clear up many obscurities; but unfortunately the Mary mine and a very small part of the Germania mine were the only openings that were readily accessible in 1911. The quartzite of this area is all much fractured, especially northeast of Casey Hill, and along the railroad north of that hill the principal fractures dip steeply to the northwest, suggesting that the mass may have been thrust from that direction. At the Mary shaft the shattered overthrust quartzite is 115 feet thick and caps the ore body.

The under surface of the overthrust mass is apparently irregular. It is probable that after the overthrust was accomplished the rocks were further dislocated by normal faulting and were deformed by the intrusion of the porphyry. These, however, are merely suggestions and considerable detailed work will be necessary to ascertain definitely the relations of the overthrust to other faulting and to the epoch of intrusion. Southeast of the Mary shaft the layer of brecciated material produced by the overthrust is steeply upturned and outcrops southwest of the Silverton shaft as masses of ferruginous gossan associated with brecciated quartzite and some oxidized copper ore. How far this local steepness of the thrust plane may be original and how far it may be due to later deformation are questions as yet unanswered.

Two varieties of porphyry are recognized near Courtland. One, which is possibly the older, is intrusive, in the form of irregular dikes, into the Cambrian beds in the western part of the area mapped in figure 17. This rock is everywhere much altered and decomposed so that its original character is not closely determinable. It is for the most part nearly white, although in surface exposures it may be stained with rust, and in many places it is not readily distinguishable from some of the altered Cambrian beds. Little can be seen of its original texture, and the microscope shows that the rock is largely a secondary aggregate of quartz and sericite with finely disseminated pyrite. Most specimens show faint outlines of feldspar phenocrysts and a few small corroded crystals of primary quartz. Provisionally the rock will be referred to as quartz monzonite porphyry. One large dike of this rock is represented in figure 17 as extending into the granite west of Turquoise Hill, but no close examination was made of the relations of the two rocks, which here weather much alike and are deeply decomposed.

The second variety of porphyry, which occupies considerable areas east and north of Courtland, is intrusive mainly into the Carboniferous limestone but is in igneous contact with the Cambrian beds also. Although nowhere fresh, this porphyry as a rule is darker in color and much less altered than the other variety. Where comparatively fresh this rock shows abundant phenocrysts of reddish feldspar which are mostly plagioclase, although some of the larger crystals are orthoclase. There are visible also a few small irregular grains of quartz and fairly abundant chloritic pseudomorphs after biotite. The microscope shows that this rock also is a quartz monzonite porphyry, although apparently it is less silicic than the variety first described. Even the freshest specimens are more decomposed than mere inspection of hand specimens suggests and the rock of the low rounded hill just south of Courtland, supposed from its texture to belong to the second variety, is altered and bleached to a product closely resembling the porphyry west of the Mame shaft.

It appears that the two varieties of porphyry here described belong to the same rock type—quartz monzonite porphyry—and it is possible that they represent contemporaneous intrusions of the same magma; but their general appearance is sufficiently different to justify their provisional distinction in a preliminary examination of the field.

The cause of the metamorphism of the dolomitic Cambrian beds is not entirely clear. The alteration is probably connected with the intrusion of the porphyries, but as the visible portions of these igneous masses have themselves undergone metamorphic changes it appears that the transformation must be due principally to some underlying body of eruptive rock.

West of the Copper Belle mine, near Gleeson, there is a decomposed rock with contorted flow banding and a dark color due to very abundant dendritic films of manganese oxide. This is apparently a rhyolite. The only other igneous rock noted in the district is a gray tuff-breccia that was cut in the workings of the Casey shaft. This rock is altered and contains finely disseminated pyrite but is clearly of andesitic or latitic character and perhaps records volcanic activity at the time of the porphyry intrusions. Its geologic relations could not be ascertained in 1911, but as it is abundant on the dump of the shaft it possibly has considerable extent underneath the overthrust mass of Cambrian quartzite.

## COPPER DEPOSITS.

The copper deposits of the Turquoise district may be grouped as follows: (1) Oxidized blanket deposits connected with thrust faulting, exemplified by the ore bodies of the Germania and Mary mines.

(2) Pyritic deposits with some associated bodies of oxidized ore in the Cambrian dolomitic limestone and shale, exemplified by the Mame and Leadville mines. (3) Pyritic deposits with associated bodies of oxidized or enriched ore in Carboniferous limestone, exemplified by the Copper Belle and other mines near Gleeson.

The general plan of the Mary-Germania ore body is shown in figure 18, the outline for the portion of the body within the Mary claim corresponding approximately to what is known of the extent of the ore, while the boundaries of that portion within the Germania claim are surmised from an inspection of the map of the

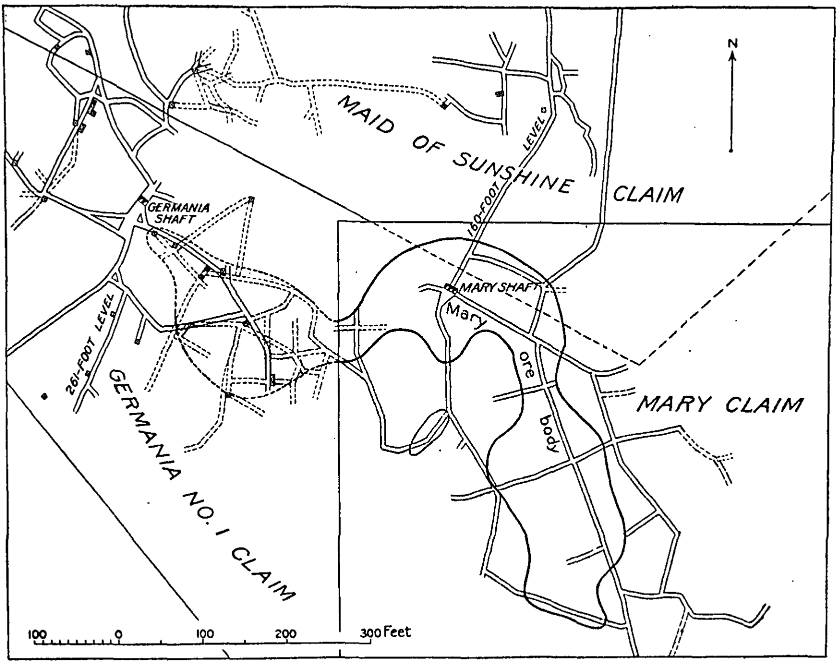



FIGURE 18.—Plan of parts of the 160-foot level of the Mary mine and of the 261-foot level of the Germania mine, Turquoise mining district, Arizona, showing the approximate outline of the main ore body.

underground workings of the Germania mine, the presence of sublevels and ore chutes being taken as indicative of stoping. Whether or not considerable ore occurs north of the Germania shaft was not ascertained. The ore is as irregular in thickness as in plan, the maximum being 50 feet and the average probably about 15 feet. The ore body is accompanied by much soft limonitic and clayey material, the whole closely resembling the oxidized ore and so-called "ledge matter" of some of the Bisbee mines. Definite boundaries are lacking, but the ore body as a whole rests on Carboniferous limestone and is overlain by shattered quartzite, which at the Mary shaft is 115 feet thick. Decomposed porphyry occurs with the quartzite above the ore, with the underlying limestone, and to some extent mingled with the ore, which in the main, however, is a replacement of the limestone.

The ore itself is as a rule a soft mass of earthy oxides of iron and copper, flecked and streaked with malachite and mingled with clay-like decomposition products of varied color and constitution. Here and there are irregular crevices or cavities lined with crusts of chrysocolla, malachite, and azurite. No sulphides have been found either in the ore or in the porphyry and limestone immediately under the ore, and the limestone is not metamorphosed.

The ore-bearing solutions evidently gained access to the broken ground along the thrust plane and replaced the shattered limestone by ore. The ore during deposition apparently was not limited in its downward extent by the zone of brecciation but replaced irregularly part of the underlying limestone, especially in the vicinity of fissures. Whether it was originally deposited as sulphides or was carried down from some overlying formation through the shattered quartzite and deposited directly in oxidized condition in the fault breccia and on top of the limestone is an open question. The view that the ore was deposited as sulphide and has been completely oxidized, essentially in place, by water that has percolated down through the porous quartzite capping is regarded as the more probable.

Northwest of the Mary and Germania mines and north of the Casey shaft there is a ridge of quartzite that apparently is part of the overthrust mass. Although it would be unsafe from a reconnaissance examination to predict the occurrence of ore bodies under this quartzite, it may be pointed out that there is a bare possibility of their existence. The exploratory drifts from the April Fool shaft do not extend far enough west to test this possibility thoroughly. Whether there are any drifts extending north from the Casey shaft and exploring the base of the quartzite in this ridge could not be learned in 1911. The Miami shaft, which is just north of the area covered by figure 17, was sunk by the Calumet & Arizona Co. through the small mass of quartzite that is shown about 2,000 feet northwest of the April Fool shaft, and extensive exploratory work was carried on in the underlying limestone, but without success.

Of the mines in the Cambrian dolomite and shale (Abrigo formation?) the Mame alone was open for examination in 1911. The Mame has reached a depth of 300 feet, but only the 100-foot level was examined in 1911, as time was short and according to Mr. MacBride the conditions on the lower levels are substantially the same as on the first level.

The general country rock of the Mame, Humbot, and Leadville mines is a series of shales and thin-bedded dolomitic limestones cut irregularly by many dikes and sheets of quartz monzonite porphyry. The beds have prevailingly steep dips to the east. The entire belt of these rocks from Courtland northward shows decided metamorphism. The calcareous beds have been transformed to hard fine-grained aggregates consisting largely of garnet, with perhaps other silicates, quartz, calcite, and pyrite. The porphyry has been altered to fine-granular aggregates of quartz, sericite, and pyrite. The pyrite, though widely disseminated through the rocks, is more abundant at some places than at others. The superficial weathering of this formation is accompanied by further changes. The oxidation of the pyrite, with the production of sulphuric acid and sulphates, bleaches portions of the rocks and leads to the accumulation of iron oxides in other portions. In connection with this weathering there has been some concentration of oxidized ore near the surface, especially at the Humbot mine, but such concentration is local and superficial.

At the Mame mine the oxidized ore is wholly inconsiderable and the work in progress during 1911 was directed to the exploration of the metamorphosed beds and the altered porphyry for bodies of pyritic ore. These are generally of lenticular form and lie with their greater dimensions approximately in the planes of bedding. They are said to be most abundant and largest close to the porphyry intrusions, which in their altered condition are difficult to distinguish underground from some of the metamorphosed sedimentary beds. These ore bodies have no sharp boundaries but are merely those portions of the formation where the pyrite is more thickly disseminated than elsewhere or where it has formed in solid masses by metasomatic replacement of the calcareous strata and probably, to some extent, of the porphyry also. Not all of the pyritic material contains enough copper to be classed as ore and numerous assays are necessary to determine the limits of each ore body. The deposition of the ore has no obvious relation to fissuring. The pyrite, together with the small proportion of chalcopyrite that gives the whole its value as a low-grade copper ore, was apparently formed during the general metamorphism of the formation by hot mobile solutions under such pressure that they were capable of moving along bedding planes and of penetrating the mass of the rock through minute openings and by molecular replacement.

At a few places in the Mame mine there has been a little chalcocitic enrichment, but the greater part of the ore has undergone no modification since it was first deposited.

In 1911 there had been shipped from the Mame mine about 1,500 tons of ore from development work, but stoping had not been begun.

The dump of the Leadville No. 1 shaft, about half a mile northwest of the Mame, shows considerable low-grade pyritic ore. The geologic conditions at the two mines are similar and if the Mame develops into a profitable mine this will probably lead to a resumption of work at the Leadville.

The Humbot shaft is situated about 800 feet south of the Mame and belongs to the same company. Although the rocks are identical with those of the Mame and although oxidized ore to the value of $100,000 is said to have been mined from open cuts near the shaft, considerable exploratory work on two levels has failed to show any sulphide ore bodies of workable size.

No special examination was made of the mines in Carboniferous limestone near Gleeson. The Copper Belle is opened by a 300-foot shaft with three levels. The country rock is gray limestone, which dips 30°–50° E. and contains a number of intrusive sheets of altered monzonitic or dioritic porphyry. The ore bodies of the Copper Belle occur along the contacts of this porphyry with two beds or slablike masses of limestone and have a total length from north to south of about 500 feet. The ore is mainly granular pyrite with a little chalcopyrite and scattered bunches of bornite, sphalerite, or galena. It has been deposited by irregular metasomatic replacement of the limestone, which shows no general metamorphism. The porphyry also is full of finely disseminated pyrite and carries small stringers of the same sulphide. The ore is graded into two classes and is shipped to the Clifton district, where its high percentage of sulphur and freedom from gangue make it valuable for smelting with other ores.

## TURQUOISE DEPOSITS.

The turquoise occurs in joints and small irregular fractures in a bed of Cambrian quartzite that dips 65° E. and outcrops along the west side of Turquoise Hill a few feet above the contact with the decomposed granitic rock previously referred to. At the opening examined the bed has been stoped to a width of 4 feet and a depth of 75 feet or more, the bottom of the shaft being now filled with water. A short distance north of this opening and near the western boundary of the area mapped other workings, perhaps a little more extensive than those visited, have been opened on the same bed of quartzite.

# 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 the copper resources of the districts of which they treat. This list does not include publications on Alaska, a list of which is given in Bulletin 520, the annual report on progress of the Survey's investigations in Alaska for 1911.

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.


Bain, H. F., and Ulrich, E. O., The copper deposits of Missouri: Bull. 260, 1905, pp. 233–235. 40c.

Ball, S. H., Copper deposits of the Hartville uplift, Wyoming: Bull. 315, 1907, pp. 93–107.

Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

Boutwell, J. M., Ore deposits of Bingham, Utah: Bull. 213, 1903, pp. 105–122. 25c.

——— Economic geology of the Bingham mining district, Utah: Prof. Paper 38, 1905, 413 pp.

——— Ore deposits of Bingham, Utah: Bull. 260, 1905, pp. 236–241. 40c.

Butler, B. S., Copper: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 255–313.

Collier, A. J., Ore deposits of the St. Joe River basin, Idaho: Bull. 285, 1906, pp. 129–139. Exhausted.

Diller, J. S., Copper deposits of the Redding region, California: Bull. 213, 1903, pp. 123–132. 25c.

——— Mining and mineral resources in the Redding district in 1903: Bull. 225, 1904, pp. 169–179. 35c.

Emmons, S. F., Geological distribution of the useful metals in the United States—Copper: Trans. Am. Inst. Min. Eng., vol. 22, 1894, p. 73.

——— Economic geology of the Butte (copper) district, Montana: Geol. Atlas U. S., folio 38, 1897. 25c.

——— Copper in the red beds of the Colorado Plateau region: Bull. 260, 1905, pp. 221–232. 40c.

——— The Cactus copper mine, Utah: Bull. 260, 1905, pp. 242–248. 40c.

Emmons, W. H., The Cashin mine, Montrose County, Colo.: Bull. 285, 1906, pp. 125–128. Exhausted.

——— Some ore deposits of Maine and the Milan mine, New Hampshire: Bull. 432, 1910, 62 pp.

EMMONS, W. H., and LANEY, F. B., Preliminary report on the mineral deposits of Ducktown, Tenn.: Bull. 470, 1911, pp. 151–172.

GALE, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: Bull. 430, 1910, pp. 112–121.

GRATON, L. C., The occurrence of copper in Shasta County, Cal.: Bull. 430, 1910, pp. 71–111.

HILL, J. M., Mining districts of the western United States: Bull. 507, 1912, 309 pp.

HOWE, H. M., Copper smelting: Bull. 26, 1885, 107 pp. Exhausted.

IRVING, R. D., The copper-bearing rocks of Lake Superior: Mon., vol. 5, 1883, 464 pp. $1.85.

IRVING, J. D., and BANCROFT, HOWLAND, Geology and ore deposits near Lake City, Colo.: Bull. 478, 1911, 128 pp.

LINDGREN, WALDEMAR, The copper deposits of the "Seven Devils," Idaho: Min. and Sci. Press, vol. 78, 1899, p. 125.

——— The copper deposits of the Seven Devils: Twentieth Ann. Rept., pt. 3, 1900, pp. 249–253. $1.50.

——— Copper deposits of Snake River and Powder River, Oregon: Twenty-second Ann. Rept., pt. 2, 1901, pp. 551–776. $2.25.

——— Copper deposits at Clifton, Ariz.: Bull. 213, 1903, pp. 133–140. 25c.

——— The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper 43, 1905, 375 pp.

——— Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: Bull. 340, 1908, pp. 157–174.

——— Resources of the United States in gold, silver, copper, lead, and zinc: Bull. 394, 1909, pp. 114–156.

LINDGREN, WALDEMAR, and GRATON, L. C., A reconnaissance of the mineral deposits of New Mexico: Bull. 285, 1906, pp. 74–86. Exhausted.

LINDGREN, WALDEMAR, GRATON, L. C., and GORDON, C. H., The ore deposits of New Mexico: Prof. Paper 68, 1910, 361 pp.

McCASKEY, H. D., and others, Gold, silver, copper, lead, and zinc (mine production) in Western, Central, and Eastern States: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 403–488.

PAIGE, SIDNEY, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: Bull. 470, 1911, 131–150.

PHALEN, W. C., Copper deposits near Luray, Va.: Bull. 285, 1906, pp. 140–143. Exhausted.

RANSOME, F. L., Copper deposits of Bisbee, Ariz.: Bull. 213, 1903, pp. 149–157. 25c.

——— The Globe copper district, Arizona: Prof. Paper 12, 1904, 168 pp. 70c.

——— Geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper 21, 1904, 168 pp. 55c.

——— The Yerington copper district, Nevada: Bull. 380, 1909, pp. 99–119.

——— Geology at Globe, Ariz.: Min. and Sci. Press, vol. 100, No. 7, 1910, pp. 256–257.

——— Geology and ore deposits of the Breckenridge district, Colorado: Prof. Paper 75, 1911, 187 pp.

RANSOME, F. L., and CALKINS, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper 62, 1908, 203 pp. 85c.

SCHRADER, F. C., A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: Bull. 497, 1912, 162 pp.

SPENCER, A. C., Mineral resources of the Encampment copper region, Wyoming: Bull. 213, 1903, pp. 158–162. 25c.

——— Reconnaissance examination of the copper deposits at Pearl, Colo.: Bull. 213, 1903, pp. 163–169. 25c.

SPENCER, A. C., Copper deposits of the Encampment district, Wyoming: Prof. Paper 25, 1904, 107 pp. 15c.

STOSE, G. W., The copper deposits of South Mountain in southern Pennsylvania: Bull. 430, 1910, pp. 122–131.

VAUGHAN, T. W., The copper mines of Santa Clara Province, Cuba: Eng. and Min. Jour., vol. 72, 1901, pp. 814–816.

WATSON, T. L., Notes on the Seminole copper deposits of Georgia: Bull. 225, 1904, pp. 182–186. 35c.

WEED, W. H., Types of copper deposits in the southern United States: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 449–504.

——— Copper mines of Las Vegas, Chihuahua, Mexico: Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 402–404.

——— Copper deposits near Jimenez, Chihuahua, Mexico: Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 404–405.

——— Copper deposits of Cananea, Sonora, Mexico: Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 428–435.

——— Ore deposits at Butte, Mont.: Bull. 213, 1903, pp. 170–180. 25c.

——— Copper deposits of the Appalachian States: Bull. 213, 1903, pp. 181–185. 25c.

——— Copper deposits in Georgia: Bull. 225, 1904, pp. 180–181. 35c.

——— The Griggstown, N. J., copper deposit: Bull. 225, 1904, pp. 187–189. 35c.

——— Notes on the copper mines of Vermont: Bull. 225, 1904, pp. 190–199. 35c.

——— The copper production of the United States: Bull. 260, 1905, pp. 211–216. 40c.

——— The copper deposits of eastern United States: Bull. 260, 1905, pp. 217–220. 40c.

——— The copper mines of the United States in 1905: Bull. 285, 1906, pp. 93–124. Exhausted.

——— Copper deposits of the Appalachian States: Bull. 455, 1911, 166 pp.

——— Geology and ore deposits of the Butte district, Montana: Prof. Paper 74, 1912, 262 pp.

WEED, W. H., and PIRSSON, L. V., Geology of the Castle Mountain mining district, Montana: Bull. 139, 1896, 164 pp. 15c.

WEEKS, F. B., and HEIKES, V. C., Notes on the Fort Hall mining district, Idaho: Bull. 340, 1908, pp. 175–183.

# LEAD AND ZINC.

## 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.


Adams, G. I., Zinc and lead deposits of northern Arkansas: Bull. 213, 1903, pp. 187–196. 25c.

Adams, G. I., and others, Zinc and lead deposits of northern Arkansas: Prof. Paper 24, 1904, 118 pp.

Bain, H. F., Lead and zinc deposits of Illinois: Bull. 225, 1904, pp. 202–207. 35c.

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

——— A Nevada zinc deposit: Bull. 285, 1906, pp. 166–169. Exhausted.

——— Zinc and lead deposits of northwestern Illinois: Bull. 246, 1905, 56 pp.

——— Zinc and lead deposits of the upper Mississippi Valley: Bull. 294, 1906, 155 pp.

——— Zinc and lead ores in 1905: Mineral Resources U. S. for 1905, 1906, pp. 379–392. $1.

Bain, H. F., Van Hise, C. R., and Adams, G. I., Preliminary report on the lead and zinc deposits of the Ozark region: Twenty-second Ann. Rept., pt. 2, 1902, pp. 23–228. $2.25.

Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

——— Lead and zinc deposits in the Metaline mining district, northeastern Washington: Bull. 470, 1911, pp. 188–200.

Becker, G. F., Geology of the Comstock lode and the Washoe district, with atlas: Mon., vol. 3, 1882, 422 pp. $11.

Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper 38, 1905, pp. 73–385.

Calkins, F. C., and MacDonald, D. F., A geologic reconnaissance in northern Idaho and northwestern Montana: Bull. 384, 1909, 112 pp.

Clerc, F. L., The mining and metallurgy of lead and zinc in the United States: Mineral Resources U. S. for 1882, 1883, pp. 358–386. 50c.

Cross, Whitman, Howe, Ernest, and Ransome, F. L., Silverton folio (No. 120), Geol. Atlas U. S., 1905. 25c.

Cross, Whitman, Spencer, A. C., and Ransome, F. L., Rico folio (No. 130), Geol. Atlas U. S., 1905. 25c.

CROSS, WHITMAN, and HOLE, A. D., Engineer Mountain folio (No. 171), Geol. Atlas U. S., 1910. 25c.

CURTIS, J. S., Silver-lead deposits of Eureka, Nev.: Mon., vol. 7, 1884, 200 pp. $1.20.

ELLIS, E. E., Zinc and lead mines near Dodgeville, Wis.: Bull. 260, 1905, pp. 311-315. 40c.

EMMONS, S. F., Geology and mining industry of Leadville, Colo., with atlas: Mon., vol. 12, 1886, 870 pp. Exhausted.

——— Economic geology of the Mercur mining district, Utah: Sixteenth Ann. Rept., pt. 2, 1895, pp. 349-369. $1.25.

——— The mines of Custer County, Colo.: Seventeenth Ann. Rept., pt. 2, 1896, pp. 411-472. $2.35.

EMMONS, S. F., and IRVING, J. D., The Downtown district of Leadville, Colo.: Bull. 320, 1907, 72 pp.

EMMONS, W. H., Some ore deposits in Maine and the Milan mine, New Hampshire: Bull. 432, 1910, 62 pp.

GRANT, U. S., Zinc and lead deposits of southwestern Wisconsin: Bull. 260, 1905, pp. 304-310. 40c.

GRANT, U. S., and BURCHARD, E. F., Lancaster-Mineral Point folio (No. 145), Geol. Atlas U. S., 1907. 25c.

HAGUE, ARNOLD, Geology of the Eureka district, Nevada: Mon., vol. 20, 1892, 419 pp. $5.25.

HAHN, O. H., The smelting of argentiferous lead ores in the far West: Mineral Resources U. S. for 1882, 1883, pp. 324-345. 50c.

HILL, J. M., Mining districts of the western United States: Bull. 507, 1912, 309 pp.

HOFFMAN, H. O., Recent improvements in desilverizing lead in the United States: Mineral Resources U. S. for 1883-84, 1885, pp. 462-473. 60c.

ILES, M. W., Lead slags: Mineral Resources U. S. for 1883-84, 1885, pp. 440-462. 60c.

IRVING, J. D., Ore deposits of the northern Black Hills: Bull. 260, 1905, pp. 50-77. 40c.

——— Ore deposits in the vicinity of Lake City, Colo.: Bull. 260, 1905, pp. 78-84. 40c.

IRVING, J. D., and BANCROFT, HOWLAND, Geology and ore deposits in the vicinity of Lake City, Colo.: Bull. 478, 1911, 128 pp.

IRVING, J. D., and EMMONS, S. F., Economic resources of the northern Black Hills: Prof. Paper 26, 1904, pp. 53-212.

KEITH, ARTHUR, Maynardville folio (No. 75), Geol. Atlas U. S., 1901. 25c.

——— Recent zinc mining in East Tennessee: Bull. 225, 1904, pp. 208-213. 35c.

LINDGREN, WALDEMAR, The mining districts of Idaho Basin and the Boise Ridge, Idaho: Eighteenth Ann. Rept., pt. 3, 1898, pp. 625-736. $2.15.

——— The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept., pt. 3, 1900, pp. 75-256. $1.50.

——— A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper 27, 1904, 123 pp.

——— The Tres Hermanas mining district, New Mexico: Bull. 380, 1909, pp. 123-128.

——— Resources of the United States in gold, silver, copper, lead, and zinc: Bull. 394, 1909, pp. 114-156.

LINDGREN, WALDEMAR, and GRATON, L. C., Mineral deposits of New Mexico: Bull 285, 1906, pp. 74-86. Exhausted.

LINDGREN, WALDEMAR, GRATON, L. C., and GORDON, C. H., The ore deposits of New Mexico: Prof. Paper 68, 1910, 361 pp.

McCaskey, H. D., and others, Gold, silver, copper, lead, and zinc (mine production) in Western, Central, and Eastern States: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 403–888.

MacDonald, D. F., Economic features of northern Idaho and northwestern Montana: Bull. 285, 1906, pp. 41–52. Exhausted.

Pepperberg, L. J., Notes on the mineral deposits of the Bearpaw Mountains, Montana: Bull. 430, 1910, pp. 135–146.

Ransome, F. L., Report on the economic geology of the Silverton quadrangle, Colorado: Bull. 182, 1901, 265 pp. 50c.

——— The ore deposits of the Rico Mountains, Colorado: Twenty-second Ann. Rept., pt. 2, 1902, pp. 229–398.

——— Geology and ore deposits of the Breckenridge district, Colorado: Prof. Paper, 75, 1911, 187 pp.

Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper 62, 1908, 203 pp. 85c.

Richards, R. W., Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: Bull. 470, 1911, pp. 177–187.

Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. 340, 1908, pp. 53–84. 30c.

——— The mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. 397, 1909, 226 pp.

Siebenthal, C. E., Mineral resources of northeastern Oklahoma: Bull. 340, 1908, pp. 187–228.

——— Lead: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 315–351.

——— Zinc: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 353–398.

Smith, G. O., Note on a mineral prospect in Maine: Bull. 315, 1907, pp. 118–119.

Smith, W. S. T., Lead and zinc deposits of the Joplin district, Missouri-Kansas: Bull. 213, 1903, pp. 197–204. 25c.

Smith, W. S. T., and Siebenthal, C. E., Joplin district folio (No. 148), Geol. Atlas U. S., 1907. 50c.

Spencer, A. C., The Mine Hill and Sterling Hill zinc deposits of Sussex County, N. J.: Ann. Rept. Geol. Survey New Jersey for 1908, 1909, pp. 25–52.

Spencer, A. C., Salisbury, R. D., and Kümmel, H. B., Franklin Furnace folio (No. 161), Geol. Atlas U. S., 1908. 25c.

Spurr, J. E., Geology of the Aspen mining district, Colorado, with atlas: Mon., vol. 31, 1898, 260 pp. $3.60.

——— The ore deposits of Monte Cristo, Wash.: Twenty-second Ann. Rept., pt. 2, 1902, pp. 777–866.

——— Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. 208, 1903, 229 pp. 25c.

Spurr, J. E., and Garrey, G. H., Preliminary report on the ore deposits of the Georgetown mining district, Colorado: Bull. 260, 1905, pp. 99–120. 40c.

——— The Idaho Springs mining district, Colorado: Bull. 285, 1906, pp. 35–40. Exhausted.

——— Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, with general geology by S. H. Ball: Prof. Paper 63, 1908, 422 pp.

Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nineteenth Ann. Rept., pt. 3, 1899, pp. 601–767. $2.25.

Tower, G. W., Smith, G. O., and Emmons, S. F., Tintic special folio (No. 65), Geol. Atlas U. S., 1900. 25c.

Ulrich, E. O., and Smith, W. S. T., Lead, zinc, and fluorspar deposits of western Kentucky: Bull. 213, 1903, pp. 205–213. 25c. Also Prof. Paper 36, 1905, 218 pp.

Weed, W. H., Fort Benton folio (No. 55), Geol. Atlas U. S., 1899. 25c.

WEED, W. H., Little Belt Mountains folio (No. 56), Geol. Atlas U. S., 1899. 25c.

——— Geology of the Little Belt Mountains, Montana, with notes on the mineral deposits of the Neihart, Barker, Yogo, and other districts: Twentieth Ann. Rept., pt. 3, 1900, pp. 271–461. $1.50.

WEED, W. H., and BARRELL, JOSEPH, Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont.: Twenty-second Ann. Rept., pt. 2, 1901, pp. 399–549.

WEED, W. H., and PIRSSON, L. V., Geology of the Castle Mountain mining district, Montana: Bull. 139, 1896, 164 pp. 15c.

WINSLOW, A., The disseminated lead ores of southeastern Missouri: Bull. 132, 1896, 31 pp. 5c.

WOLFF, J. E., Zinc and manganese deposits of Franklin Furnace N. J.: Bull. 213, 1903, pp. 214–217. 25c.

# RARE METALS.

## NOTES ON THE VANADIUM DEPOSITS NEAR PLACERVILLE, COLORADO.

By Frank L. Hess.

### INTRODUCTION.

Late in the nineties a dull-green sandstone in the steep valley walls near Placerville, Colo., was found to be vanadium-bearing, and

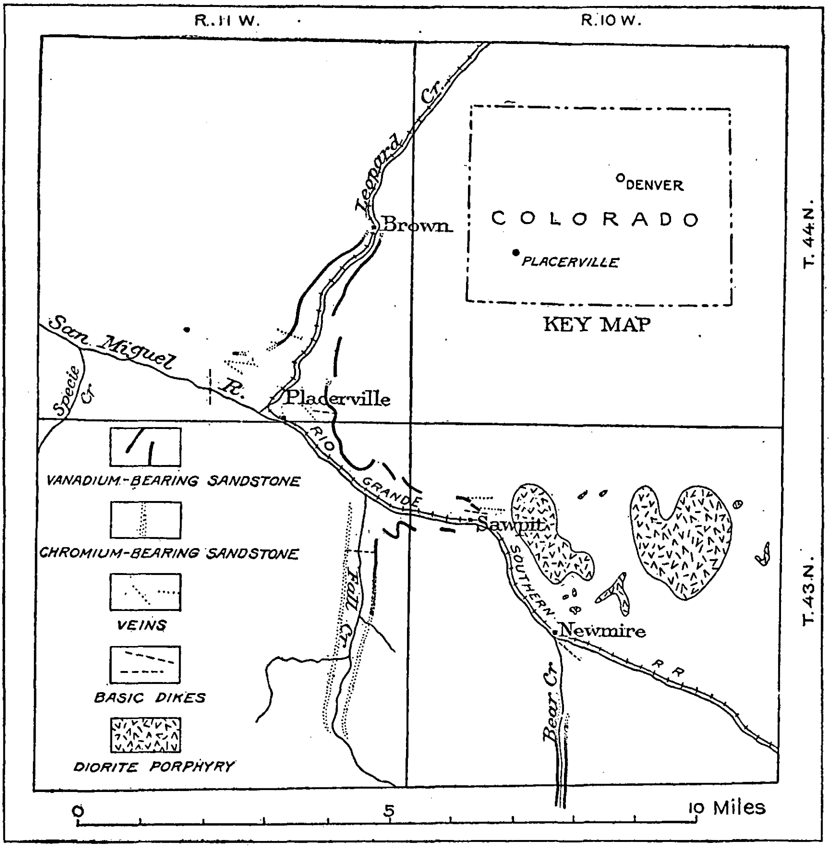



Figure 19.—Sketch map of the vanadium deposits near Placerville, Colo.

although its content of vanadium is low as expressed in percentage, the deposits have become of commercial value owing to the scarcity of sources from which vanadium can be obtained at a cost which will allow its profitable use in the arts and to the greatly increased demand caused by the use of vanadium in steel.

Placerville is located in San Miguel County, southwestern Colorado, at the western base of the Rocky Mountains. (See fig. 19.) It is on the east side of the deep, narrow valley of the San Miguel, which here has cut down to a depth of 1,500 to 2,000 feet below the mesa through which it runs. Sawpit is 4 miles and Newmire is 7 miles up the river (southeast) from Placerville. The Rio Grande Southern Railroad has a narrow-gage track following Leopard Creek and San Miguel River which furnishes passenger and freight connection with the centers of population and manufacture beyond the mountains.

In 1899, shortly after their discovery, the Placerville vanadium deposits were visited by F. L. Ransome, and descriptions of the geology and of the microscopical petrology of the deposits, to which were added chemical analyses and a discussion by W. F. Hillebrand on the composition of roscoelite, were published in 1900.[1] In 1905 this article was republished by the United States Geological Survey.[2]

In January, 1909, Herman Fleck and Sidney W. French[3] described the individual workings on the Placerville deposits and gave a large number of analyses for vanadium. In October of the same year Herman Fleck and William G. Haldane[4] published a short description of the vanadium-mining operations near Placerville with four pictures of the reduction plant at Newmire.

So far as is known to the present writer, practically nothing else has been written touching upon the economic geology of these deposits, but Whitman Cross and Chester W. Purington[5] have discussed the general geology of the Telluride quadrangle, which includes that part of the deposits which lies south and east of Sawpit. Although their work covered Newmire and Sawpit, it did not extend to Placerville. The notes on the stratigraphy given in this article are taken largely from Cross's descriptions.

No exhaustive study has yet been made of the deposits, and their origin and even the manner of deposition of the sandstone beds in which they occur have not been satisfactorily settled.

## GENERAL GEOLOGY.

The country rocks are flat-bedded sediments, mostly sandy but including a few limy strata. Near the ore deposits the beds are cut by a few basic dikes and there is some faulting. The sediments as determined by Cross are of Jurassic and Triassic age and have been

[1] Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 120-144.
[2] Bull. U. S. Geol. Survey No. 262, 1905, pp. 10-21.
[3] Quart. Colorado School of Mines, January, 1909.
[4] Idem, October, 1899, pp. 7-11.
[5] Telluride folio (No. 57), Geol. Atlas U. S., U. S. Geol. Survey, 1899.

divided by him into three formations, of which the Dolores is the lowest, the La Plata sandstone the middle, and the McElmo the uppermost.

The Dolores formation consists of a series of sandstones, grits, conglomerates, and arkoses, mostly reddish, and forms the lower 500 to 800 feet of the walls of the San Miguel Valley near Placerville.

The La Plata consists of two light-colored sandstones with a thin limestone between. Through much of their extent both sandstones are thick, fine and even grained, showing no horizontal bedding, but in the particular area under consideration the upper member is in many places rather thin bedded. The limestone varies from point to point in thickness and in character and may be either thinly lenticular or blocky. It ranges in thickness from 1 to 10 feet.

The lower sandstone member of the La Plata is everywhere the vanadium-bearing rock, and although it has heretofore been treated as a single bed it is probably made up of two beds with an unconformity between them. In most places where vanadium occurs in the sandstone (and it was only at these points that the sandstone was carefully examined by the writer) the portion above the apparent unconformity is yellowish and that below is gray, almost white. The apparent unconformity in some places almost or quite reaches the base of the limestone and in other places is probably two-thirds of the way to the bottom of the sandstone. This part of the La Plata is probably between 35 and 60 feet thick where the vanadium deposits are found and in places is cross-bedded. Although generally very fine grained, locally it contains pebbles as large as small peas. Ordinarily the sandstone is cemented with calcite and is very friable.

The coarser-grained parts of the sandstone have in places rounded outlines, and the finer-grained sandstone when mined may peel from them like the skin of an orange. The peculiar distribution of the coarser sand, the presence of cross-bedding over thousands of square miles, and the evenness and thinness of the beds have made their origin very difficult to explain. To the writer these conditions suggest a body of water so broad and so shallow that winds could pile the water deeply in one part and leave practically dry areas of many square miles. The currents induced by the wind would distribute the sediments comparatively evenly and cross-bed them and would at times cut temporary channels and gouges, later to be filled with sands of varying size, depending on the intensity of the currents.

The structure, composition, and texture of the sandstone have been important in the deposition of the vanadium ore.

Dikes are not numerous, but several occupy prominent positions in relation to the vanadium deposits. One which crosses the mouth of Bear Creek (see fig. 19) is 4 or 5 feet thick and is conspicuous from the little hamlet of Newmire. It is described by Cross[1] as "a very

[1] Op. cit., p. 7.

simple normal basalt." Diabase dikes 3 to 6 feet thick cut the rocks adjacent to the vanadium deposit on the Golden Era claim, north of Sawpit, on Fall Creek, and east of Placerville. A vanadium deposit carrying some rich ore and showing considerable carnotite staining is closely adjacent to the dike near Sawpit. At Placerville, as exposed at the surface, the dike pinches a few feet below the vanadium deposit, and through the deposit the strike of the dike is marked by a fault accompanied by about 10 inches of porous silicified breccia, adjacent to which on the northwest the vanadium deposit is between 15 and 20 feet thick, though not rich, and contains many small irregular silicified bodies of sandstone. North of the point where the diabase dike crosses Fall Creek the vanadium deposits are richer than at any other known place along the creek. A monchiquite dike cuts the rocks on the north side of the San Miguel about 1½ miles below Placerville but is not near the present vanadium deposits. On Cross's geologic map of the district he shows a large laccolith of diorite porphyry about three-fourths of a mile east of San Miguel River, between Sawpit and Newmire, with its edge parallel to the river for nearly 2 miles. Opposite Bear Creek, north of Newmire, are several smaller outcrops of the same rock. The dikes and the diorite porphyry may be very closely related.

The known vanadium deposits of the Placerville region extend through a distance of a little more than 9 miles S. 20° E. from Brown, a Rio Grande Southern Railroad station on Leopard Creek[1] 4 miles above Placerville, to a point on Bear Creek 3 miles south of Newmire, crossing the San Miguel Valley with a long slant. (See fig. 19.) The deposits occur on both sides of Leopard Creek, extending with short interruptions to the valley of the river; thence they continue along the northeast wall of the river valley for a mile upstream, and beyond that less continuously to a point north of Sawpit. On the opposite or southwest side of the river no deposits of importance have been found below Fall Creek, but some occur on the east side of that stream, extending for a distance of about a mile above the mouth, and others are found on the south side of San Miguel River for a mile or more above Fall Creek. No other deposits of value are known to occur between these and Bear Creek, along both sides of which the deposits extend for about a mile upstream from a point 2 miles above its mouth.

At Brown, on Leopard Creek, and at the south end of the deposits on Bear Creek the streams have cut their valley floors just to the level of the La Plata sandstone.

In appearance most of the vanadium-bearing rock is a dull green to almost black, fine, even-grained sandstone. The color probably

[1] Leopard Creek, as the stream is locally known, is shown on some maps as Rio del Codo.

darkens almost directly as the content of vanadium increases, although certain specimens contain some dark coloring matter which is possibly organic, and in others there is some coloring due to iron oxides formed from the decomposition of pyrite. In still other places the color is slightly yellowish green from admixed carnotite.

There is considerable variation of color and richness in individual beds, and where the vanadiferous part of the sandstone is cross-bedded, as in the Primos Chemical Co.'s deposits on Bear Creek, the bedding is marked by different shades of green and by black. Some of the ore shows many small sage-green dots from the size of a pinhead to one-eighth of an inch across, which appear to be nuclei around which the roscoelite has formed.

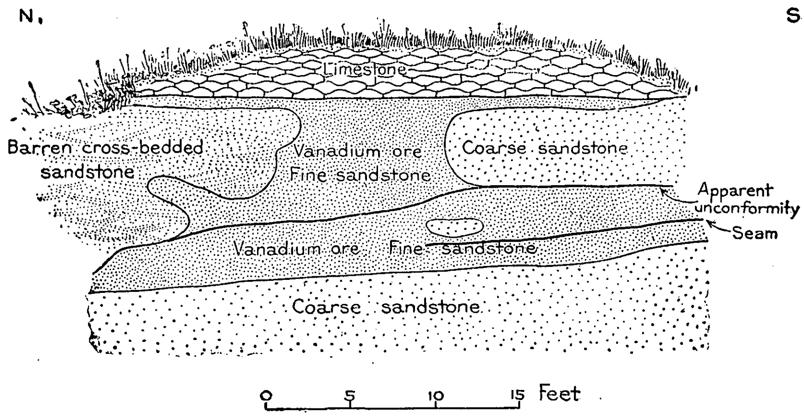



FIGURE 20.—Sketch of vanadium-bearing sandstone at Primos Chemical Co.'s mine on the east side of Bear Creek, near Newmire, Colo.

The vanadium deposits invariably follow the seam which indicates an apparent unconformity and may occur above, below, or on both sides of it, though probably most of the deposits are below it. In the deposits of the Primos Chemical Co. on the east side of Bear Creek, where the ore bed is very thick, there are two or possibly three such seams, but two are probably very local. (See fig. 20.)

In thickness the deposits range from 1 or 2 inches to over 30 feet. The richest ore is always near the seam and in many places a nearly black shaly layer from one-fourth to an inch thick which is said to be much the richest vanadium ore of the district lies along the seam. Such a thin layer of rich ore was seen on Bear Creek, north of Sawpit, east of Placerville, on the Rio claims on the south side of the San Miguel above Fall Creek, and on Fall Creek in the Vanadium claims. This layer is composed of roscoelite, quartz, and a little pyrite and is really a vein. The sandstone country rock evidently has been impregnated from it. Further remarks on the veins will be made in another paragraph.

The deposits are, broadly speaking, flat lens-shaped or tabular, the width, so far as has been shown, ranging up to at least 600 or 700 feet, with local thickenings or thinnings. The deposits were formerly very much larger, for they have been cut through by Bear Creek at the south end, and at one time there was undoubtedly a bed 1,000 feet across. (See fig. 19.) The same is true of the Leopard Creek and Fall Creek deposits, and the San Miguel must have eroded much more vanadiferous standstone than has been exposed by natural outcrops and prospecting, for the river has cut its valley half a mile to a mile wide almost lengthwise through the deposits.

In many places bands of nearly colorless quartzite from half an inch to 4 inches thick, known to the miners as "bone," alternate with the green sandstone and lie parallel to the line of apparent unconformity. There may be several such bands, generally though not always along the outside of the richest part of the deposit, or there may be alternate bands of rich ore and quartzite. A cross section of the deposit exposed in the workings on the Rio No. 1 claim, in a gulch tributary to the San Miguel just south of Fall Creek, is as follows:

*Section of vanadium deposit on Rio No. 1 claim.*

| | Inches. |
|---|---|
| Sandstone, somewhat iron stained, part quartzite | 3 |
| Dark vanadiferous sandstone | 4 |
| "Bone," quartzite | 2½ |
| Dark vanadiferous sandstone | 4½ |
| "Bone," quartzite | 2½ |
| Dark vanadiferous sandstone | 3½ |
| Bottom of drift. | |

The quartzite is generally barren of vanadium-bearing minerals, although on Bear Creek some silicified material appears to be vanadiferous. In other places, as in the deposit directly east of Placerville and in the Primos Chemical Co.'s deposit on the east side of Bear Creek, the quartzite forms exceedingly irregular masses scattered through the sandstone. The silicification seems to be, at least in part, later than the deposition of the roscoelite, for it incloses vanadiferous sections of the sandstone. There are in places similarly irregular bodies of sandstone stained by hydrous iron oxide.

It has been noted that in the deposits east of Placerville irregular spotting occurs in the main vanadium-bearing bed near a fault along which has been intruded a diabase dike that does not reach the vanadium deposits. At the mines of the Primos Chemical Co. the spotting occurs in 4 or 5 feet of rock above the main vanadium deposit. The uneven silicification causes very irregular breaking of the rock.

A little pyrite is scattered through the vanadium deposits, generally in minute grains, but along Bear Creek radial balls of pyrite one-half to three-fourths of an inch in diameter are occasionally found. The rusty spots and lines indicate that much of the pyrite has oxidized, and it is probable that if any of the deposits are opened into unoxidized ground much more pyrite will be found; in fact, some specimens from the faces of the longest drifts show thin strings of pyrite.

Faces along many joints of the vanadiferous sandstone are covered with canary-yellow, minutely crystalline carnotite which is clearly secondary and has evidently been leached from the ore-bearing rock. The quantity present varies from place to place. On Bear Creek there is very little, and the vanadium ore from the Primos Chemical Co.'s mines is said to show barely a trace of uranium. The vanadium ore here is green and shows little black in the richer portions. The ore from the deposits east of Placerville contains very much more carnotite, but it is irregularly distributed. Probably the Vanadium Nos. 3 and 4 claims on Fall Creek show the most carnotite of all the Placerville deposits. Here all joints, even those that are closely spaced, are brightly coated with carnotite. The vanadium ore is peculiarly black on these claims. In the deposit north of Sawpit the roscoelite vein is very dark and brownish rather than greenish, and there is more or less carnotite with it. The carnotite seems to be closely connected with the dark or black ores. The original mineral from which the carnotite was derived is unknown.

On the lower part of Bear Creek, on Leopard Creek, and along both sides of Fall Creek for several miles from the San Miguel Valley are lighter, brighter-green deposits which grade out from the vanadium deposits. In places the middle part may have the familiar dull green of the vanadiferous sandstone and carry up to 2 or 3 per cent of $V_2O_5$, but the lighter-green sandstone ordinarily gives no more than a trace. It receives its color from a chromium mica which is probably mariposite. That chromium gives the color is well known among the prospectors and miners of the region, who refer to the light-green sandstone as "chromite" sandstone, though chromite is, of course, quite another mineral from that coloring the sandstone.

Mariposite is found in small quantity in an arkose of the Dolores formation at Sawpit and in a recrystallized limestone of the Dolores northwest of Placerville.

Near both Placerville and Sawpit there are chromium stains in the La Plata sandstone several feet below the vanadium deposits. On the west side of lower Leopard Creek chromium stains reach 10 feet in thickness, with only a little vanadium present. There is also much of the chromium staining on Bear Creek north of the vanadium deposits.

## MICROSCOPIC APPEARANCE OF THE VANADIFEROUS SANDSTONE.

The sand of which the lower sandstone of the La Plata is composed is generally very fine, 0.05 to 0.15 millimeter in diameter, with here and there grains 0.5 to 0.9 millimeter thick. Much the larger part of the grains are quartz. Those less than 0.5 millimeter in diameter are subangular to angular, and many have an elongated cross section, being two or three times as long as broad. This is one of the striking features of some thin sections of the sandstone. The larger grains are beautifully rounded.

Among the grains are a few of feldspar, and other feldspar grains have been replaced by calcite, roscoelite, or roscoelite and quartz. There are also a few grains of chalcedony, vein quartz, an exceedingly fine grained quartzite, zircon, and tourmaline.

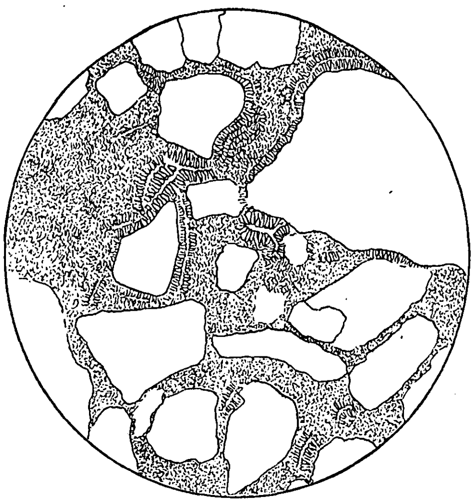


FIGURE 21.—Section of sandstone having wide pore spaces filled with roscoelite, partly radial. White space, quartz; shaded area, roscoelite. Enlarged about 225 diameters.

Roscoelite, yellowish green by transmitted light, forms most of the cementing material in the vanadiferous sandstone but occurs in flakes so fine that most of them appear indefinite even under high-power lenses. Generally some calcite is present and specimens that are poorer in roscoelite show more calcite. It is probable that where roscoelite occurs in the sandstone it has in general replaced calcite. In places the pore space has been large and the quartz grains are coated with roscoelite flakes standing on edge. (See fig. 21.) The flakes are so small that they do not everywhere fill the spaces, and quartz occupies the vug. Where roscoelite has replaced feldspar it shows a radial tendency.

The vein following the apparent unconformity is made up mostly of roscoelite and the individual flakes are large enough to show the optical character and allow identification. The roscoelite flakes combine in peculiar ropy forms which inclose lenticular spaces filled with clear quartz. (See fig. 22.) No quartz grains from the inclosing sandstone have been seen in the sections, but there are a few grains of tourmaline and zircon and a few round radial masses of roscoelite which are probably replacements of feldspar. If quartz grains were ever included in the vein they have been dissolved and removed or totally recrystallized.

## OTHER VEINS.

Gold deposits in the limestone bed in the La Plata sandstone, directly above the vanadium-bearing sandstone, were worked north of Sawpit before the vanadium deposits were discovered, and work was done also on several veins near Placerville. These veins are in the immediate vicinity of the vanadium deposits. The gold mines at Ophir are 7 miles southeast and the Telluride-Ouray group of mines 10 miles east. Neither of these groups of veins contains vanadium minerals, nor are they known to have other resemblance to the vanadium veins. The nearest known other deposits of vanadium ores are probably 30 or 40 miles west.

The gold deposits near Sawpit, on the Golden Era and the Belle Champion claims, which are no longer worked, were in close connection with the vanadium deposits and with a diabase dike. According to Purington[1] the ore bodies were replacements of the limestone and followed east-west fissures. The ore minerals were pyrite and galena and their decomposition products. Four-fifths of the value was in gold. Vertical veins filled with calcite extend downward into the red beds of the Dolores formation, and Purington thought that they might have acted as mineralizers for at least part of the ore bodies. He also recognized the possibility that the dike played some part in the mineralization. A narrow vein follows the dike on the Golden Era claim.

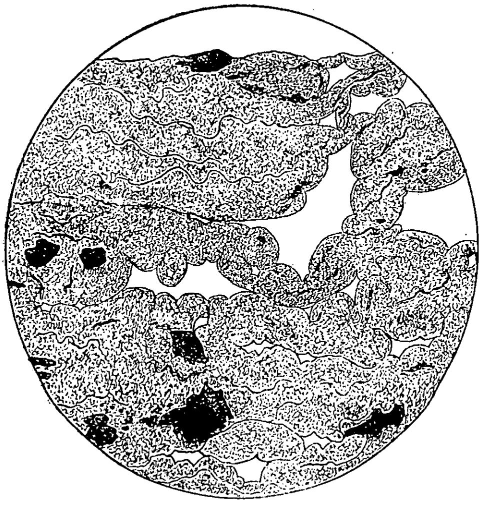


FIGURE 22.—Section of roscoelite vein. Shaded area, roscoelite; white area, quartz, except at the top, which shows the edge of the section; black area, pyrite. Enlarged about 225 diameters.

East of Placerville, about halfway between the river and the vanadium deposits, a vein striking northwest and dipping 80° SW., accompanied by 3 or 4 feet of crushed material, follows a normal fault of about 3 feet throw cutting the Dolores rocks. Considerable drifting has been done on the vein and some ore was sacked. The

[1] Cross, Whitman, and Purington, C. W., Telluride folio (No. 57), Geol. Atlas U. S., U. S. Geol. Survey 1899, p. 18.

ore consisted of chalcocite, chalcopyrite, azurite, and malachite in a gangue of barite and calcite. In the vein is also some hard shiny asphaltic material in small pellets and fragments one-eighth of an inch across.

A somewhat similar vein, also in the Dolores formation, occurs 1½ miles northwest of Placerville on the Evans claims, but its mineralization is more complicated. The vein is along a fault striking N. 60° W. and dipping 62° N. 30° E. On the footwall there is several feet of crushed rock and on the hanging wall more than a foot of alternating layers of a shiny black asphaltic material and calcite with barite. Here and there on the footwall side are irregular lenses of the asphaltic material. Azurite, malachite, chalcopyrite, chalcocite, molybdic ocher, molybdenite, galena, erythrite (cobalt arsenide), autunite, gold, silver, and vanadium also occur in the vein. Possibly more careful examination would reveal other minerals. Milton Evans, the owner of the claims, stated that a carload of ore from the vein, shipped in 1902, carried 14.8 per cent of copper and 0.11 ounce of gold and 3.5 ounces of silver to the ton. The asphaltic material at one place extends from the vein in small irregular pockets 1 to 4 inches thick into a limestone, in which, 50 feet north of the vein, it forms peculiar masses with an oblong cross section 1 or 2 inches wide by 4 or 5 inches long. The center is much the purest part of these masses, which become gradually poorer from the center outward until the limestone shows little or no asphaltic material. The central portions of some of these masses will break off in nearly concentric shells to an almost spherical ball half an inch or more in diameter. Other parts of the limestone show lesser impregnations. One test on the asphaltic material showed a fraction of 1 per cent of uranium and vanadium, both in the vein and in the limestone; another showed none. Orr J. Adams, of Telluride, stated that he had found uranium but no vanadium in the asphaltic material.

The presence of the asphaltic material with uranium, vanadium, and copper at once suggests comparison with the deposits in Wildhorse Canyon, in the San Rafael Swell, Utah, and with other deposits of the same State, where there is in a general way such an association of minerals.

Adjacent to the vein on the hanging-wall side is a peculiarly granular limestone, colored bright green by chromium mica, probably mariposite. The limestone has been recrystallized, probably by the solutions which brought in the chromium mica. The calcite granules are coated with the mariposite, and the rock was supposed to be a sandstone when examined in the field.

About 400 feet to the northeast is a barite vein along a vertical fault striking N. 80° W. The vein is said to carry some galena. On a cliff above this vein are vanadium and chromium stains, which are of small extent, but a thin seam is rich in mariposite, having a yellow-green to blue-green pleochroism.

On the west side of Leopard Creek, 1½ miles above Placerville, is a barite vein which reaches several feet in width. It contains also calcite, quartz, copper minerals, and a little gold and silver and is reported to carry some molybdenum. Copper-bearing minerals are said to occur also on the opposite side of the creek, but they were not examined.

## ORIGIN OF THE DEPOSITS.

The data at hand are insufficient to give a basis from which to form a definite conclusion as to the origin of the vanadium deposits, but they seem to indicate some important conditions of deposition. Some of the facts will be reviewed.

The deposits are found in the lower member of the La Plata sandstone. They follow a line which seems to indicate an unconformity in the sandstone and along which occurs a vein up to three-fourths of an inch thick, composed of roscoelite and quartz, with a little pyrite, and in places an unknown black mineral that may be organic. Along the parting marking the apparent unconformity, although the vein in many places is practically or wholly lacking, the sandstone is impregnated with roscoelite, accompanied by a little pyrite, which is generally oxidized, and probably a little organic matter.

The vanadiferous deposits in a number of places gradually diminish in their vanadium content both laterally and vertically and a chromium mica thought to be mariposite succeeds the roscoelite. At some points it occurs also in the sandstones a number of feet below the vanadium deposits. Mariposite is also found in a recrystallized limestone along a vein 1½ miles northwest of Placerville. The vanadium deposits are accompanied by carnotite, which occurs on the faces of joints and which is evidently secondary and has leached out of the vanadium deposits. The roscoelite and the mariposite, however, are primary.

The La Plata sandstone, like the rocks of the McElmo formation above and the Dolores below, has undergone no general alteration and is as a rule poorly cemented and friable, but near the vanadium deposits there is more or less quartzite, which is found nowhere else. However, quartz does not cement the parts in which the vanadium occurs and the quartzite is ordinarily practically free from vanadium.

No manner can be conceived for the formation of the quartzite except through the action of hot water, and this is equally true not only of the roscoelite veins along the parting representing the apparent unconformity but of the roscoelite and mariposite impregnating the sandstone.

The parting frequently referred to evidently furnished an excellent channel for the water. The roscoelite and quartz were first deposited, and the mariposite, which was apparently capable of remaining in solution in cooler water, was deposited farthest from the source of mineralization.

Whence the heated water came is less evident, but in this connection attention may be directed to the general parallelism of the dikes, the vanadium and other vein deposits, and the river valley, and to the fact that by far the larger part of the vanadium has been lost through the erosion of the river. That the asphaltum-bearing vein on the Evans claims probably once carried hot water is shown by the recrystallized limestone containing chromium mica. The dike east of Placerville was probably also accompanied by hot water, as shown by the silicified breccia along the fault where it cuts the vanadium beds. The deposit is thicker at the point of contact than at any other place in that particular deposit, and there is much silicification of the sandstone within 100 feet on the northwest. At Sawpit a deposit of vanadiferous sandstone of small extent and showing considerable silicification occurs close to a dike, as do also gold and silver bearing replacement deposits in the limestone, and a vein of calcite and iron oxide (probably from pyrite), 2 or 3 inches wide, follows the dike. These deposits indicate the circulation of hot water, and the vein along the dike indicates that the water may have accompanied the dike. On the Vanadium claims on Fall Creek, where a dike crosses the La Plata sandstone, there is an abrupt enrichment and silicification of the deposits that extends for several hundred feet to one side.

These data suggest but by no means show conclusively that the dikes may have had much to do with the mineralization. On the other hand, the richest known deposit, that of the Primos Chemical Co., on Bear Creek, has no visible connection with dikes. This fact, however, is not weighty evidence against the possible connection of the deposit with a dike, as the dike may be under cover and may never have reached the surface nor have been exposed by erosion.

On the south side of San Miguel River at Placerville is a spring, the water of which has a temperature of about 90° and gives evidence of having been much warmer at some time. It has deposited much sulphur and iron oxide, though at present it gives no evidence of hydrogen sulphide. This is only another item showing the quantity of hot water that has been available for depositing ore.

The parallelism of the dikes and veins to the river suggests that possible channels through which the ore may have ascended have been obliterated by erosion and its incident débris.

The laccolithic diorite porphyry intrusions near Sawpit and Newmire are close enough so that waters accompanying or subsequent to their intrusion might have traveled the distance to the deposits before their load of minerals was precipitated.

No vanadium minerals are known to have been found in the dikes or diorite porphyry.

## SIGNIFICANCE OF THE MARIPOSITE SANDSTONE.

Attention has been called to the fact that in places the roscoelite gives way to mariposite vertically and nearly everywhere laterally. Mariposite is reported to occur along Fall Creek for 4 or 5 miles and the writer followed it for the larger part of that distance. Nowhere else does it visibly extend so far from vanadium deposits and it seems possible that its great extent here may mean either that vanadium deposits with which it was more closely connected once existed in the rocks eroded from the present valley of Fall Creek or that it borders vanadium ores lying between Fall Creek and Bear Creek.

Ransome [1] reports similar green sandstones colored by chromium on the west side of Sinbad Valley, 60 miles west of Placerville, in proximity to the carnotite deposits, and Gale [2] has recorded a similar association in Routt County. Fleck and Haldane [3] also note the occurrence of green sandstone in the Roc Creek carnotite district, one specimen of which carried 0.11 per cent of $V_2O_5$. They mention the occurrence of green sandstone at several other places but give no details of composition. This sandstone may be chromiferous, for they seem to have noted the sandstones that are colored by copper. These occurrences of such unusual minerals with a common mineralogic association would seem to indicate a likeness of origin, and suggest that the carnotite of all the occurrences may have come from some easily decomposed uranium-vanadium mineral which was originally brought in by solutions that deposited roscoelite and mariposite with a very small quantity of the uranium-vanadium mineral in the Placerville area, mariposite with the uranium-vanadium mineral and a very little roscoelite where Roc Creek now is, and the uranium-vanadium mineral with copper minerals and little or none of the micas at other points. In other words, it seems possible that the deposits of the several areas may have been formed in similar manner, but that the minerals carried by the invading solutions carried different proportions of the minerals.

It is possible that when the workings in the Placerville area reach sufficiently far from the surface the unaltered uranium-vanadium mineral may be found, but from the solid appearance of the ore as now mined it will probably be in microscopic particles.

---

[1] Ransome, F. L., and Hillebrand, W. F., On carnotite and associated vanadiferous minerals in western Colorado: Bull. U. S. Geol. Survey No. 262, 1905, p. 14.

[2] Gale, H. S., Carnotite and associated minerals in western Routt County, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, p. 261.

[3] Fleck, Herman, and Haldane, W. G., A study of the uranium and vanadium belts of southern Colorado: Rept. Colorado Bur. Mines for 1905-6, Denver, 1907, pp. 80-81.

## WHY THE MINERALS ARE IN THE LA PLATA SANDSTONE.

Just why the vanadium deposit is in the lower sandstone of the La Plata rather than in another sandstone or a limestone lower down can only be conjectured. Conditions of water pressure below this level may have been such as to prevent the lateral flow of the solutions. The porosity, texture, and chemical composition of the vanadiferous rock can all be practically duplicated below the La Plata. However, the fissure marking the apparent unconformity in the lowest member of the La Plata made an excellent channel for the solutions to follow, and this they did for long distances. Though some feldspar grains have been replaced, they did not determine the selection of the locus of deposition, for some of the rocks below carry much more feldspar than the La Plata.

## ECONOMIC CONDITIONS.

The individual deposits may not be described on account of the objections of one of the principal companies.

As stated in the beginning, the Rio Grande Southern Railroad is a narrow-gage line, consequently it must transfer its freight to broad-gage cars at some point. The transfer, the heavy haul over the mountains, and the long distance to market make freight rates high.

The Primos Chemical Co. controls and operates the reduction plant built by the Vanadium Alloys Co. at Newmire in 1905, and it reduces its own ores to ferric vanadate, which is shipped to the East for reduction to ferrovanadium. The company has an ample supply of ore and buys none. The ore is reported to carry no more than a trace of uranium, and the little carnotite visible in the ore seems to bear out this statement. The two metals are said to be difficult to separate in a commercial way. As the company pays freight on a concentrated product it can presumably use an ore carrying a less percentage of vanadium than other companies.

So far as known, the General Vanadium Co. was the only firm buying ore in the field in 1911, though the General Vanadium Co. and the Standard Chemical Co. bought and mined carnotite ores from the Paradox Valley and shipped them through Placerville. The General Vanadium Co. ships its ore to Liverpool for reduction and to make a profit can handle nothing carrying less than 3 per cent metallic vanadium, and most of the ores of the Placerville area carry much less than that. It follows that when the ore is mined to sell under these conditions a large quantity which carries a considerable percentage of metal but is not up to the mark for shipping must be thrown aside or left in the ground.

[1] Carl, P. H., Vanadium as a staple Colorado product: Min. Sci., vol. 65, May 9, 1912, p. 409.

Ore has been bought or mined and shipped by the General Vanadium Co. from claims on Fall Creek, several points along the south side of San Miguel River between Fall Creek and Sawpit, from a deposit north of Sawpit, and possibly from a few other points on the north side of the river.

The claims along Leopard Creek have mostly shown lower-grade ore as developed and have considerable chromium staining, but individual specimens show good percentages of vanadium.

Analyses of samples collected by Sidney W. French[1] along Leopard Creek gave results varying from 0.21 to 3.23 per cent of metallic vanadium. More than half the samples collected gave less than 1 per cent of vanadium, about one-fourth gave between 1 and 2 per cent, and one-seventh gave more than 2 per cent. Only three or four analyses of samples from claims in other parts of the field gave more than 2 per cent of metallic vanadium. One analysis of material from Bear Creek showed 8.3 per cent. The specimen is described as "a piece of very dark green sandstone which occurs in a thin layer along a bedding plane."[2] It is undoubtedly a piece of a roscoelite vein.

The analyses are of use as indicating the richness of vanadium mineralization, but of course they give little idea of the quantities of ore available. It is safe to say that there are many thousands of tons of sandstone which will show between 1 and 2 per cent of metallic vanadium and much more running between 0.5 and 1 per cent. But to give a profit the rock will probably have to be treated on the ground, as is being done by the Primos Chemical Co. From present developments probably only a few thousand tons of ore carrying over 3 per cent can be mined profitably.

Sufficient ore has been mined in this area and to a less extent in the carnotite fields 40 or 50 miles farther west to cause the price to be reduced in the last three or four years from $5 a pound of metallic vanadium in ferrovanadium to $2.50 or less. The most seriously competing deposits are those of vanadium sulphide at Minasragra, Peru, controlled by the American Vanadium Co., of Pittsburgh, Pa.

[1] Quart. Colorado School of Mines, vol. 3, January, 1909, pp. 33-35.
[2] Idem, p. 30.

# VANADIUM IN THE SIERRA DE LOS CABALLOS, NEW MEXICO.

By FRANK L. HESS.

During 1910 and 1911 considerable attention was attracted to the vanadium deposits in the Sierra de los Caballos by numerous articles in the mining press,[1] which reported the erection of a plant at Cutter for the manufacture of vanadic oxide and the mining of the ore in the mountains 12 to 15 miles southwest of that place. Cutter is in Sierra County and is a station on the Atchison, Topeka & Santa Fe Railway, 149 miles south of Albuquerque and 104 miles north of El Paso.

The Sierra de los Caballos, in which are the vanadium deposits, lies along the east side of the Rio Grande and can be reached from Cutter or from Engle, 10 miles north of Cutter. As described by Schrader,[2] the mountains form a range trending nearly north and south and reaching a maximum height of 10,000 feet at Timber Hill, south of the vanadium deposits. He says:

> The range consists mainly of a monocline bounded on the west by a great north-south fault scarp overlooking the Rio Grande. * * * In the vicinity of Palomas Gap the average elevation of the crest is about 6,500 feet; the average width of the mountains is 4 to 6 miles, including a foothill belt several miles wide on the east. The most prominent feature of the mountains is the great limestone and quartzite series, 1,200 to 1,400 feet in thickness. It consists chiefly of heavy-bedded massive gray or blue limestone, with some intercalated shale, and has at its base about 100 feet of hard quartzite. Much of the limestone is semicrystalline, and some of it contains black flinty or cherty nodules or inclusions. Part of it is greatly crushed and recemented by calcite veins.
>
> The quartzite at the base of the limestone series ranges from 50 to perhaps 200 feet in thickness; it is massive or heavy bedded and consists of black and red beds resting upon the granite. Its age is probably Cambrian.

---

[1] Among the articles appearing upon the subject have been the following:

Leatherbee, Brigham, Sierra County, N. Mex., vanadium deposits: Min. World, vol. 33, Oct. 29, 1910, p. 799.

Carrera, J. C., Vanadium; its importance in the Southwest: El Paso Min. Jour., February, 1911.

Johnson, E. D., The vanadium industry in New Mexico: Min. Sci., vol. 63, Mar. 9, 1911, p. 259.

Larsh, P. A., Caballo Mountain vanadium mines: Eng. and Min. Jour., vol. 92, July 15, 1911, p. 118.

Allen, C. A., Vanadium deposits in the Caballo Mountains, N. Mex.: Min. and Sci. Press, vol. 103, Sept. 23, 1911, pp. 376-378.

Clifford, J. O., Vanadium in New Mexico; Caballos Mountains deposits: Min. and Eng. World, vol. 35, Oct. 28, 1911, pp. 857-858.

[2] Schrader, F. C., in Lindgren, Waldemar, and others, The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 284-285.

The granite is stated to be probably basal, but there are dioritic rocks that are apparently intrusive, and south of the vanadium deposits are porphyritic intrusive rocks. The limestones are of Carboniferous age and on the east are overlain by fine-grained red sandstones, also Carboniferous.

About two-thirds of the way toward the north end the range is cut by a narrow canyon known as Palomas Gap, in the vicinity of which are the vanadium mines. The mines were discovered in 1906 just after Schrader's visit to the locality.

At the mines the range proper shows nothing from the east side but the limestone. On the north side of the gap the limestone is in open folds. A valley follows the range here, running about N. 25° W. (magnetic), which suggests a fault separating the limestone and the red beds.

The vanadium-bearing veins lie at and about three-fourths of a mile south of Palomas Gap. They strike nearly northeast (magnetic) and dip from 60° NW. to vertical. They occupy fissures in limestone containing brecciated country rock cemented by calcite, with some white and amethystine fluorite, barite, and less quartz. The metallic minerals noted are galena, a little cerusite, copper carbonates, vanadinite, zinc-bearing cuprodescloizite, and another mineral which may be an amorphous form of cuprodescloizite. The galena alters to a black mineral that forms a narrow band around the crystals but occurs in too small quantity to determine. Besides these minerals, pyromorphite and wulfenite have been reported by others, although they were not recognized by the writer after diligent search for them during his short visit and on the specimens collected.

At Palomas Gap there are two such veins, one on either side, on the property of the Vanadium Mines Co. The vein on the north is known as the Dewey, and that on the south as the White Swan. Both are developed by shafts, but permission to enter them was refused, so that observations could be made only upon surface workings and a drift on the Dewey opening into Palomas Gap, across which the vein cuts. In the drift the vein has been taken out for a width of 6 to 12 feet and has been stoped to a height of 30 feet. The vein is spongy and much weathered. On the north side of the gap, which is not over 100 feet wide at this point, in a prospect hole 8 or 9 feet deep, part of the limestone is coated with a yellowish-green crust not over one-sixteenth of an inch thick. Under the microscope part of it is seen to be brown vanadinite with a thin powdering of the green material, but other specimens show much more of the green matter. Purer material from the Red Top claim is crystalline but seems to be the same green mineral, carries vanadium, lead, copper, and zinc, and is probably cuprodescloizite.

A shaft has been sunk on the east end of the outcrop of the vein. A keg of rich ore contained lumps of hair-brown vanadinite in a pinkish clayey material. The crystals reach one-eighth of an inch in diameter, many are hollow, and of those which are not hollow many show two distinct stages of growth in their cross fracture.

The White Swan vein, on the south side of the gap, has been developed by a shaft and by open-cut work. The vein is very similar to the Dewey but is vertical and is said to carry wulfenite (lead molybdate), though none was seen in the exposed portions of the vein nor in the ore on the dump. The visible portions of the vein carried calcite, quartz, barite, colorless and amethystine fluorspar, galena, copper carbonates in small quantity, and vanadinite.

The vanadinite is mostly in hair-brown crystals which are so small that cavities lived with them in the spongy calcareous gangue look velvety. Under strong magnification they form a beautiful bristling array, pointing in all directions from protuberances and surfaces. Many of the cavities lined are evidently left by the decomposition of galena. The crystals are so fine that there must be great loss unless the ore is very carefully handled.

Some very unpromising-looking limy material from the dump gave good reactions for vanadium, and microscopic examination showed that through the calcite were great numbers of colorless or nearly colorless vanadinite crystals so minute as to be invisible to the unaided eye.

Persons familiar with the ground stated that the shaft was 400 feet deep and that 800 or 900 feet of drifting had been done. It has also been stated that a fault, corresponding to the surface indications as mentioned, has been struck on the east.[1] The mined ore is hauled by wagon to a mill about 1½ miles south and the concentrates are hauled to Cutter, where a plant was erected for making vanadium oxide and lead sulphate. It is understood that a few hundred pounds of vanadium oxide had been produced up to the time the locality was visited.

Much money was expended to obtain water. A pumping plant was erected and a number of wells dug 4 miles east, and a disagreeably alkaline water was piped to the mill and mine. At the time the property was visited good water had been found across the narrow valley, only a few hundred feet from the mines.

About three-fourths of a mile south of the Dewey and White Swan veins Ralph Widener has claims known as the Gladys, Red Top, Red Top Annex, and Billiken, named seriatim from southwest to northeast. All are situated on the same vein. On the northeast J. H. Hardin has a claim called the Owl which is apparently also

[1] Allen, C. W., op. cit., p. 378.

on the same vein. The strike is parallel to the Dewey and White Swan veins (about northeast, magnetic), and on the Gladys claim the dip is 60° NW. (magnetic). In a prospect shaft 15 feet deep on the Gladys claim the vein was shown to be about 3 feet wide and appeared not to be fully exposed on the footwall side.

The vein consists of crushed limestone, considerably disintegrated and cemented by secondary calcite, with white and pink fluorspar. In the hasty examination made no barite or copper minerals and very little quartz were seen. Some galena is scattered through the ore. About a foot of the vein is very spongy, and the cavities are lined with small hair-brown crystals of vanadinite, in places shading into brownish yellow and colorless. The largest crystals are probably not over one-sixteenth of an inch long and very slender, so that although they make a beautiful appearance in the mine they are so fragile that it is almost impossible to transport good specimens, for all crystals not in cavities are broken by the almost inevitable rubbing incident to handling, and many others are broken by small fragments of rock which become loosened and strike them. The ore on the other claims is similar, but the exposures were not so good.

Some cuprodescloizite found on these claims is apparently fairly homogeneous and is crystalline. The determination was made on ore from the Red Top.

Across the valley to the northeast are other claims upon which vanadium minerals are said to have been found, but the time at the writer's disposal did not allow examination.

Nothing definite is known of the richness of the ores. The vanadium content has been estimated to be from a fraction of 1 per cent to 3 per cent, but the latter figure is probably much too high.

Other lead-bearing veins occur along the Sierra de los Caballos within a mile south of the Red Top, and these are reported by Larsh [1] and others to carry no vanadium, although the veins evidently belong to the same group, apparently have the same gangue minerals, and cut the same country rock.[2] These facts would seem to indicate that the vanadium did not come from the country rock. The veins do, however, carry wulfenite.

[1] Larsh, P A., op. cit., p. 118.

[2] Schrader, F. C., op. cit., p. 285.

# CARNOTITE NEAR GREEN RIVER, UTAH.

By Frank L. Hess.

On the east side of the San Rafael Swell, at a locality marked on some maps as Tidwell, about 15 miles S. 85° W. of Green River, Utah, attempts have been made for a number of years to exploit deposits of carnotite. The deposits were visited by Boutwell[1] in 1904 and briefly described. They are now being actively worked and were visited by the writer in July, 1911.

The San Rafael Swell is a broad, oval, mountainous elevation, the long axis of which runs somewhat east of north. The Swell is about 40 miles long and 10 to 20 miles wide and is possibly underlain by a broad intrusion of igneous rock. On the east side of the Swell a great series of sandstones, fine conglomerate, shales, and gypsum are tilted to angles of 10° to 60°. Some of the softer beds have been eroded, forming a valley which follows the Swell for miles. San Rafael River flows eastward across the northern part of the Swell, turns abruptly to the south, where it strikes the valley, and 2 miles below turns through the valley wall to the east on its course to Green River. The country is practically a desert, but there are arable lands along the valley of the San Rafael on which alfalfa and other crops are grown. The well water of the valley is disagreeably alkaline, but a good spring exists about a mile west of the carnotite deposits.

The carnotite deposits are situated on the east wall of the valley, extending from a point between 2 and 3 miles north of the portal through which the river leaves the Swell to a point a mile or more south of the river at Mexican Bend, its place of departure from the valley, a total length of probably between 5 and 6 miles.

The east wall rises about 300 feet above the floor of the valley and from the top slopes to the east at nearly the same angle as the strata, about 10° or 15°. As they dip to the east the strata form low hills whose relations to one another may be compared to those of the shingles on a house if they were reversed.

The rocks are thought to be the Flaming Gorge formation, regarded as the equivalent of the McElmo formation at Placerville, Colo.,

[1] Boutwell, J. M., Vanadium and uranium in southeastern Utah: Bull. U. S. Geol. Survey No. 260, 1905, pp. 208-209.

which there overlies the La Plata sandstone, the lower member of which contains deposits of vanadium. Most of the carnotite deposits are situated on the ridge overlooking the valley, but a little carnotite has been extracted from claims along a lower ridge half a mile to the east. All the deposits are in a coarse, loosely consolidated cross-bedded sandstone, which is in places finely conglomeratic. The sandstone is cemented with calcite and carries much petrified wood, many imperfect plant remains that appear to have been reeds, and many fossil bones. Some of the petrified wood is in logs 2 or 3 feet in diameter and 10 feet or more long. The structure of the wood is, however, not well preserved. The supposed reeds are represented by cavities crossed by numerous septa suggestive of cat-tail leaves. In some of these cavities there is apparently some carbonized organic matter left; others are partly filled by manganese dioxide or iron oxide. None of the fossils seen were well enough preserved to offer hope of their identification. The bones are in part black from organic matter and retain much phosphorus in their composition. All seen were too fragmental to promise a possibility of identification. The plant remains seem to occur largely along one horizon in the sandstone and the carnotite is closely associated with them.

At numerous places there has been some slipping between the strata at this horizon. This is probably due to the bending of the beds by the formation of the San Rafael Swell. Possibly the presence of the great number of plant remains made this particular stratum one of the weakest, and when a strain came it was the one to give way.

There are a few quartz veins not more than half an inch thick, and some minor crushed zones in the sandstone. Along one of these crushed zones, on a claim known as the Wardvern, directly opposite the portal of the San Rafael Canyon, a deposit of carnotite was being worked by V. C. Ward and others at the time of the writer's visit. A small fault striking N. 80° E. with an almost vertical southerly dip is accompanied by 2 to 6 inches of crushed material. The beds here contain many plant remains, which appear to be partly carbonized, and some fossil bones. Rock stained with carnotite was being quarried through a width of about 4 feet and to an equal depth. The rocks were much stained with iron oxides, and pieces of limonite appeared to have been derived from pyrite. Carnotite fills the cavities in the spaces which seem to have been occupied by reeds, impregnates the sandstone, and coats joint faces.

Under a microscope the filling of the cavities shows cracks as if it had been deposited like a soft clay that had shrunk upon drying. Along the cracks appears to be a very thin film of crystalline material, but the middle part is apparently amorphous. The carnotite forming a thin coating over sand grains, etc., is crystalline, the thin tabular plates standing edgewise.

A carload of ore was shipped to Europe during the year by Mr. Ward and his associates and is reported to have been sold on the basis of 6.11 per cent of the combined oxides of uranium and vanadium—2.24 per cent $U_3O_8$ and 3.87 per cent $V_2O_5$. Preliminary tests had indicated that the percentage carried was 2.52 per cent $U_3O_8$ and 4.80 per cent $V_2O_5$.

Half a mile N. 70° E. a small amount of work has been done on two claims known as the Little Bessie and Little Vernon. About 2 tons of ore similar to that described had been taken out from a wall 20 or 30 feet high and the deposit appeared to have nearly pinched. Carnotite stains show in the wall for 200 or 300 feet. There is not so much iron staining as on the Wardvern claim, and no signs of faulting were seen. Several black bones about the size of ox bones were exposed at one place.

Half a mile south of the Wardvern claim is another known at the time visited as the Little Hulda. No work was being done on it, but a carload of ore is said to have been shipped a number of years ago and it is probably the claim examined by Mr. Boutwell. The ore was taken from shallow trenches and is said to have been shipped to Europe. It is reported that no returns were ever made for it.

The ore of the Little Hulda shows none of the organic remains of the other deposits, but it follows a small slickensided fault dipping 40° S. 80° E. Only 2 or 3 inches of rock next to the fault shows much staining from carnotite, but lighter stains show through more than a foot of rock. There is much staining from iron and a little from manganese through 2 or 3 feet of rock along the fault.

Across the San Rafael, more than a mile to the south, carnotite has been found but was not examined.

North of the Wardvern claim carnotite stains were followed for possibly 2 miles. They are at the same horizon as those already described, along the slipping plane before referred to as probably due to the bending of the beds. In this area there are many of the vegetable remains, both of reeds and trees, and considerable iron staining. The fossil wood is ordinarily coated with carnotite along joint planes; but apparently no special significance attaches to this fact, for the wood seems to be thoroughly silicified and the carnotite is simply deposited in it, as in cracks and openings in the sandstone. The impregnation is usually light, from 2 inches to 3 feet thick, but generally a few inches thick and lacking for considerable distances.

There are said to be other occurrences between 2 and 3 miles farther north.

It is to be noted that no vanadium minerals that do not carry uranium, no chromium or copper minerals, and no asphalt have yet been found in these deposits. They carry only the very mobile secondary minerals, carnotite and iron oxide. A few thin quartz veins cut the rocks but are not noticeably mineralized. It is also to be noted that all the deposits examined, except one, visibly accompany faults. Their presence with the organic matter seems to be fortuitous and due to the convenient cavities provided by its decay and removal or to its cracking.

Deposits of uranium are known to occur near Fruita, at the south end of the San Rafael Swell, and in Wildhorse Canyon, southeast of the Swell, and it seems probable that deposits may be found at other points on the eastern and southern parts of its periphery.

# ZIRCONIFEROUS SANDSTONE NEAR ASHLAND, VIRGINIA.

By Thomas L. Watson and Frank L. Hess.

## INTRODUCTION.

In 1910 August Meyer, of Richmond, Va., submitted to one of the writers a specimen, obtained 3 miles west of Ashland, which was thought to contain rutile. The specimen was a fine-grained friable rock of dark reddish-brown color, in which grains of ilmenite or some similar black mineral were distinctly visible. The color of the other grains was apparently similar to that of the rutile found 10 or 15 miles to the southwest, in Hanover and Goochland counties, and under a hand lens no difference in appearance could be distinguished. As the rutile of these counties occurs with a very black ilmenite, it was thought that the specimen might possibly be a fine-grained mass of the titanium minerals. Microscopic examination of a thin section, however, showed the rock to be a sandstone composed of very small grains of ilmenite and zircon (zirconium silicate, $ZrSiO_4$), together with a few grains of other minerals, chiefly quartz and silicates, cemented with limonite.

In June, 1911, the writers, in company with Mr. Meyer, visited the locality from which he obtained the original specimen, on the farm of F. B. Sheldon, 3 miles west of Ashland, Hanover County, and about 20 miles north of Richmond.

## GENERAL GEOLOGY OF THE AREA.

The area of zirconiferous sandstone forms a part of the western edge of the Coastal Plain, near and along the overlap of the sediments upon the older crystalline rocks of the Piedmont Plateau. Along this edge (the "fall line") the surface is somewhat roughened from erosion, but to the east it becomes more gently rolling and is essentially flat and featureless. The area lies on the south side of South Anna River, but within its drainage basin and only a short distance southwest of its confluence with the North Anna to form Pamunkey River. There is much timber in the area, of comparatively young growth and small size.

The sandstone outcrops along a low ridge having gently sloping sides and a general direction of N. 20° E. At the point where the sandstone seems to be most abundant and perhaps richest in zircon the ridge marks the western edge of the Calvert formation, the lowest formation of the Chesapeake group (Miocene). Within this area and for some distance north and as far south as 25 miles from Petersburg the Calvert formation transgresses the underlying older Coastal Plain sedimentary formations, and its western margin rests upon the crystalline rocks of the Piedmont Plateau.[1] The Calvert formation in Virginia consists chiefly of sands, clays, marls, and diatomaceous earth, with fine-grained sands predominant. Diatomaceous earth has not been identified in the Ashland area.

Extending westward from the foot of the west slope of the low ridge mentioned above are the crystalline rocks of the Piedmont Plateau, chiefly granites and gneisses, which for the most part are of pre-Cambrian age. The contact between the sedimentary formations of the Coastal Plain and the crystalline rocks of the Piedmont Plateau extends across the State in a roughly north-south line and in position nearly coincides with the meridian 78° 30′.[2]

In the southern part of the State the Calvert formation is overlain by the St. Marys formation (middle Miocene), and along the western edge the St. Marys transgresses the Calvert and rests on the crystalline rocks.

## OCCURRENCE OF THE SANDSTONE.

In the Ashland area the sandstone does not outcrop in a continuous bed. It was seen only in the form of irregular flat fragments lying loose upon the surface. The fragments are of the same reddish-brown to yellow color as the specimen submitted by Mr. Meyer. In size the fragments range from those as large as a man's fist to some measuring 2 feet long, 2 feet broad, and 6 inches thick. There is as much variation in texture as in size, and the rock accordingly ranges from a fine-grained sandstone to a moderately coarse conglomerate. Much of it is very fine grained, showing little visible quartz. Other pieces are of varying degrees of coarseness, some containing quartz and quartzite pebbles 2 inches in diameter. Some pieces show cross-bedded structure.

The largest number of the sandstone fragments were seen on a small mound 150 yards southwest of Mr. Sheldon's house, and scattered fragments can be found both to the north and the south for a distance of half a mile. On J. B. Davis's farm, which adjoins the Sheldon farm on the north, there are many pieces of the sandstone, though generally of smaller size. However, many of the pieces, especially those found farther north, are of lighter color and lower specific gravity than the fragments from the Sheldon farm, though

[1] Bull. Virginia Geol. Survey No. 4, 1912, pp. 126 et seq.

[2] See the geologic map of Virginia published by Virginia Geol. Survey, Charlottesville, 1911.

one of the richest specimens collected was from the line between the Thomas Kies and John Boschen farms, half a mile north of the Sheldon land. The specific gravity is of value in field examination, for the specimens of low specific gravity collected show only a few scattered grains of zircon, whereas those of high specific gravity carry a large percentage of the mineral.

It is probable that the hard lumps of sandstone represent the local cementation of a sandy bed which, in most places, is soft or but slightly consolidated, a characteristic of the Chesapeake group (Miocene). Partly or wholly indurated sands, yielding somewhat highly ferruginous crusts and beds of sandstone, are by no means uncommon in the formations of the Virginia Coastal Plain near its western margin. So far as the writers are aware these ferruginous sandstones have been generally regarded as composed chiefly of quartz grains cemented by iron oxide. At no point beyond the Ashland area, so far as known, have they been tested for zircon or other uncommon heavy minerals.

At the home of Benjamin Wright, three-eighths of a mile southwest of Mr. Sheldon's house, a highly zirconiferous and but slightly consolidated sand bed was cut in the lower part of a well 14 feet deep. This bed is probably the same one from which the indurated or hardened fragments of zirconiferous sandstone have come. Almost perfectly rounded waterworn quartz and quartzite pebbles, mostly quartz, up to 3 inches in diameter and usually white in color, were taken from this well at a depth of 14 feet. None of the zirconiferous material was found south of Mr. Wright's well, and decomposed granite is exposed in a road 200 yards southwest of his house.

A hundred yards northwest of Mr. Sheldon's house a bed of zirconiferous sand, similar to that cut in the Wright well, was exposed in a shallow prospect hole. The zirconiferous sand was 18 inches thick and was underlain by clay and covered by a few inches of soil.

From the appearance of the float and the sand cut in the prospect hole, the zirconiferous bed is thought to be probably not more than 2 or 3 feet thick. The data at hand indicate that it is probably a narrow lens five-eighths of a mile long and of unknown but probably less width.

## TESTS.

The zircon was separated from six lump samples weighing from 50 to 100 grains each, as follows: The lumps were first treated with hydrochloric acid to dissolve the cement of limonite. In two specimens small lumps resisted dissolution and were treated with aqua regia on a steam bath for two days, which resulted in dissolving the cement and disintegrating the sand grains. After washing by decantation the sand was digested with a mixture of sulphuric and hydrochloric acids to remove ilmenite and quartz and then washed. The specimens thus treated yielded zircon as follows:

*Zircon obtained from sandstone near Ashland, Va.*

| Locality. | Gross weight of sample (grams). | Zircon. | |
|---|---|---|---|
| | | Grams. | Per cent. |
| Low hill on F. B. Sheldon's farm | 50 | 14.955 | 29.9 |
| Do | 100 | 25.375 | 25.4 |
| Do | 52 | 6.280 | 12.1 |
| 100 yards northwest of F. B. Sheldon's house | 100 | 15.890 | 15.9 |
| Benjamin Wright's well | 52 | 6.815 | 13.1 |
| Top of hill on line between Thomas Kies's and John Boschen's farms | 100 | 27.230 | 27.2 |
| | .......... | 96.545 | .......... |

Accessory heavy minerals in the form of impurities, such as cyanite, garnet, and staurolite, could not be separated from the zircon by the methods used, and the results given in the table above are perhaps 2 or 3 per cent too high, though certainly not more. Owing to possible losses through the severe treatment during separation and to the loss of fine zircon in decanting, the results are regarded to be as likely under as over the real quantity present. They are not, of course, to be regarded as exact, but the method of selecting random specimens from float rock would not warrant more accurate determinations.

The method used in separating the material is not thought to have introduced appreciable errors, as a blank test was run on finely pulverized zircon by treating it for three days with a mixture of sulphuric and hydrofluoric acids. At the end of three days the solution was tested and no trace of zircon was found.

The zircon crystals in the material are minute in size. Out of about 96 grams of zircon separated, a small quantity was caught on a sieve of 60 meshes to the linear inch; possibly 1 per cent would not pass through a sieve of 80 mesh; nearly 17 per cent (16.23 grams) passed through an 80-mesh and was caught on a 100-mesh sieve; 77 per cent (74.15 grams) passed through a 100-mesh sieve and was caught on a 150-mesh sieve; and more than 2 per cent (2.3 grams) passed through a 150-mesh sieve. Most of the accessory minerals (impurities) can be caught on an 80-mesh sieve.

## CHARACTER OF THE ZIRCON.

The zircon crystals, as separated above, are mostly of short, stout form, with a smaller number of elongated forms, possibly 1½ times as long as thick. In mass they are of pinkish or pinkish-brown color, but on heating to redness they become colorless. Under the microscope individual crystals appear pink or yellow, but much the largest number are colorless. In most specimens the fragments are found to be somewhat worn crystals, but in the material from the prospect hole northwest of Mr. Sheldon's house many of the individuals show beautiful crystal form under the microscope. Though many pieces are undoubtedly worn, the wear in general may be more apparent than real, as small zircon crystals examined in place very commonly have outlines which do not show good faces or angles.

## ASSOCIATED MINERALS.

Associated with the zircon are quartz and a variety of heavy minerals, including garnet(?), ilmenite, staurolite, cyanite, and an isotropic green mineral which has not been definitely determined but which may be pleonaste or hercynite. As stated above, these are all cemented with limonite, possibly in part siliceous.

Ilmenite is the most abundant mineral in the rich pieces and its grains are of about the same size as those of zircon. The quartz and cyanite grains are generally several times as large. In places the fine-grained zircon and ilmenite surround quartz pebbles an inch long with the other dimensions somewhat smaller.

No magnetite has been found in the material.

## GENESIS.

The zircon and ilmenite concentration evidently represents an old beach segregation along but within the western margin of the Miocene sediments of the Coastal Plain, of Calvert age, and is similar to the black-sand beaches of New Jersey, California, Oregon, and numerous other coasts and to the gold-bearing garnet (so-called "ruby") sands of the beaches at Nome, Alaska.

The zircon and other heavy minerals resistant to atmospheric agencies were derived by weathering processes from the crystalline rocks, chiefly granites and gneisses, of the Piedmont Plateau, which extend westward from the Coastal Plain contact. These formed the country rock of the shore, and the zircon and associated minerals derived from them by weathering were accumulated by waters near the mouth of a small stream or behind a sheltering point, while the quartz sand was largely worn and carried away by the currents af the sea.

Zircon is an almost constant minor accessory mineral in the crystalline rocks of this old shore and its extension westward, and in places it occurs in large masses. Near Goulden post office, 10 to 15 miles southwest of the Ashland area, pieces of zircon 3 inches in diameter weathered out of pegmatite dikes have been noted on the surface. Massive zircon without crystal outline and measuring 6 by 4 inches has been observed in the pegmatites of Amelia County, Va. Similar dikes occur in the gneiss-granite complex of the Piedmont Plateau, forming the old shore line which extends entirely across Virginia from Maryland into North Carolina, roughly coinciding with the meridian of 78° 30′. It seems probable that similar zircon-rich rocks may occur at numerous points along this old shore line. Many zircon-bearing deposits may be covered by later sediments and some may have been removed by erosion, but it is probable that others, which may be richer or poorer, will be discovered along the contact of the granite and gneiss of the Piedmont Plateau with the overlying sediments of the Coastal Plain.

It is probable that some magnetite was present with the ilmenite, and glauconite is abundant at places in the Calvert formation. The alteration of either of these minerals might produce limonite, which forms the cementing material, but the most probable source of the limonite is precipitation from ferruginous waters.

## USES.

Böhm[1] sums up the known and probable uses for zirconium substantially as follows:

Zirconia ($ZrO_2$) has been used in place of lime or magnesia as the incandescing material in the oxy-hydrogen blowpipe, and a very small quantity of zirconium nitrate is used in making mantles for gas lights. The use of zirconia in the Nernst lamp (a form of incandescent electric lamp in which a small stick of zirconia and yttria is used as a glower) formerly required large quantities, but the consumption is not now so large, owing to the competition of metallic filament lamps. Zirconium carbide has been used in making incandescent electric lamps, but it also has been superseded by the metallic filament lamps. The incandescent properties of zirconia have tempted arc-lamp manufacturers to use it in their electrodes, but thus far unsuccessfully, though this does not mean that the feat may not be accomplished. Zirconia is an excellent insulator for both electricity and heat and when mixed with a conductor can be used for electric heaters. In the Heræus iridium furnace the iridium may be protected by a glaze made from a zircon salt in place of the thorium or yttrium salts now used. Zirconia makes an excellent and very refractory crucible which is manufactured in many sizes by a German firm. Its refractoriness makes zirconia a suitable lining for electric furnaces, and Böhm suggests that it might be used for saggers, but for the ceramic trade it must be free from iron and cheap. He also suggests its use for the walls of furnaces, for the making of molds to withstand high temperatures, and for heat insulation. Owing to its inertness zirconia is suitable for chemical ware, and many forms are manufactured from it. The same property has led to its recommendation for certain medicinal uses, and in Röntgen ray therapy it is used in place of bismuth nitrate, which has sometimes given bad effects. Zirconia is a beautiful soft white powder which is well

[1] Böhm, C. R., Die technische Verwendung der Zirconerde: Chem. Zeitung, Jahr 35, Nov. 14, 1911, pp. 1261-1262.

adapted for making paints and lacquers, as it is unaffected by gases, acids, or alkalies and has good covering power. It makes a good opaque glass, but for this use the borate is better than the oxide. It is used for a polishing powder in place of tin oxide. Ferrozirconium is manufactured by one German firm for use in steel. Zirconium carbide is extremely hard and makes a valuable abrasive. Glass 7 milimeters (one-fourth of an inch) thick is cut with it as readily as with a diamond.

Clear zircons of brownish, orange, or reddish color are cut for gems and are then known as hyacinths. There is no likelihood of stones sufficiently large for cutting being found at the Ashland locality, but they may be present in some of the pegmatites.

## ECONOMIC ASPECTS.

The uses enumerated are largely suggested rather than actual and their practicability is mostly dependent on the cheapness of the zirconia and the quantity available. Böhm[1] states that large quantities of native zirconia (zirconium oxide) known as baddeleyite are found near São Paulo, Brazil, and that much has been shipped to Germany. This material at the time he wrote was being furnished at the following prices:

*Composition and prices of baddeleyite.*

| Designation. | $ZrO_2$ (per cent). | $Fe_2O_3$ (per cent). | $SiO_2$ (per cent). | Price per ton (2,000 pounds). |
|---|---|---|---|---|
| Zircon-S-Erz | 90-92 | 1 | 8 | $151 |
| Zircon-Z-Erz | 90-92 | 7 | 1 | 155 |
| Zircon-NS-Erz | 98 | 0.8 | [1] 1 | 215 |

[1] Remainder $H_2O$.

The mineral quoted is already in the form of oxide and for most purposes would be more desirable than zircon, which would have to be reduced to the oxide, and should sufficient native oxide be found to supply demands competition would be difficult for zircon. For ferrozirconium or zirconium carbide the zircon could possibly be used without reduction to the oxide.

Should the demand for zircon and further testing of the Ashland deposit warrant exploitation, operations could be carried on with comparative ease. The rock can be crushed easily, the zircon and associated heavy minerals could be separated from the quartz by shaking tables, and the ilmenite could be picked out by a magnetic separator.

[1] Op. cit., p. 1261.

# 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. No publications on Alaskan occurrences are listed here, but a list is given in Bulletin 520, the annual report on progress of the Survey's investigations in Alaska for 1911.

Bancroft, Howland, Notes on the occurrence of cinnabar in central western Arizona: Bull. 430, 1910, pp. 151–153.

——— Platinum in southeastern Nevada: Bull. 430, 1910, pp. 192–199.

——— Notes on tungsten deposits near Deer Park, Washington: Bull. 430, 1910, pp. 214–216.

——— Reconnaissance of the ore deposits in northern Yuma County, Ariz: Bull. 451, 1911, 130 pp.

Becker, G. F., Geology of the quicksilver deposits of the Pacific slope, with atlas: Mon., vol. 13, 1888, 486 pp. $2.

——— Quicksilver ore deposits: Mineral Resources U. S. for 1892, 1893, pp. 139–168. 50c.

Blake, W. P., Nickel; its ores, distribution, and metallurgy: Mineral Resources U. S. for 1882, 1883, pp. 399–420. 50c.

——— Tin ores and deposits: Mineral Resources U. S. for 1883–84, 1885, pp. 592–640. 60c.

Boutwell, J. M., Vanadium and uranium in southeastern Utah: Bull. 260, 1905, pp. 200–210. 40c.

Christy, S. B., Quicksilver reduction at New Almaden [Cal.]: Mineral Resources U. S. for 1883–84, 1885, pp. 503–536. 60c.

Collier, A. J., Chromite or chromic iron ore: Mineral Resources U. S. for 1906, 1907, pp. 541–542. $1.

Day, D. T., and Richards, R. H., Investigations of black sands from placer mines: Bull. 285, 1906, pp. 150–164. Exhausted.

Emmons, S. F., Platinum in copper ores in Wyoming: Bull. 213, 1903, pp. 94–97. 25c.

Gale, H. S., Carnotite in Rio Blanco County, Colo.: Bull. 315, 1907, pp. 110–117.

——— Carnotite and associated minerals in western Routt County, Colo.: Bull. 340, 1908, pp. 257–262. 30c.

Glenn, W., Chromic iron: Seventeenth Ann. Rept., pt. 3, 1896, pp. 261–273.

Graton, L. C., The Carolina tin belt: Bull. 260, 1905, pp. 188–195. 40c.

——— Reconnaissance of some gold and tin deposits in the southern Appalachians: Bull. 293, 1906, 134 pp.

Harder, E. C., Some chromite deposits in western and central California: Bull. 430, 1910, pp. 167–183.

Hess, F. L., Some molybdenum deposits of Maine, Utah, and California: Bull. 340, 1908, pp. 231–240. 30c.

——— The Arkansas antimony deposits: Bull. 340, 1908, pp. 241–256. 30c.

——— Note on a tungsten-bearing vein near Raymond, Cal.: Bull. 340, 1908, p. 271. 30c.

——— Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. 340, 1908, pp. 286–294. 30c.

——— Tin, tungsten, and tantalum deposits of South Dakota: Bull. 380, 1909, pp. 131–163.

——— Note on a wolframite deposit in the Whetstone Mountains, Arizona: Bull. 380, 1909, pp. 131–163.

——— Arsenic: Mineral Resources U. S. for 1908, pt. 2, 1909, pp. 599–601, 80c.; idem for 1911, pt. 2, 1912, pp. 855–856.

——— Antimony: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 709–711, 80c.; idem for 1911, pt. 1, 1912, pp. 973–975.

——— Bismuth: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 713–714, 80c.; idem for 1911, pt. 1, 1912, p. 976.

——— Lithium: Mineral Resources U. S. for 1909, pt. 2, 1911, pp. 649–653. 75c.

——— Selenium: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 715–717, 80c.; idem for 1911, pt. 1, 1912, p. 977.

——— Tellurium: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 719–720. 80c.

——— Tungsten, nickel, cobalt, vanadium, etc.: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 721–749, 80c.; idem for 1911, pt. 1, 1912, pp. 941–962.

——— Tin: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 771–779, 80c.; idem for 1911, pt. 1, 1912, pp. 963–972.

——— The arsenic deposits at Brinton, Va.: Bull. 470, 1911, pp. 205–211.

Hess, F. L., and Graton, L. C., The occurrence and distribution of tin: Bull. 260, 1905, pp. 161–187. 40c.

Hill, J. M., Note on the occurrence of tungsten minerals near Calabasas, Ariz.: Bull. 430, 1910, pp. 164–166.

——— Mining districts of the western United States: Bull. 507, 1912, 309 pp.

Hillebrand, W. F., Nitrogen in uraninite, and the composition of uraninite in general: Bull. 78, 1891, pp. 43–78. 80c.

——— Distribution and quantitative occurrence of vanadium and molybdenum in rocks of the United States: Bull. 167, 1900, pp. 49–55. 15c.

Hillebrand, W. F., and Ransome, F. L., On carnotite and associated vanadiferous minerals in western Colorado: Bull. 262, 1905, pp. 9–31.

Hillebrand, W. F., and Schaller, W. T., Mercury minerals from Terlingua, Tex.: Bull. 405, 1909, 174 pp. 20c.

Hobbs, W. H., The old tungsten mine at Trumbull, Conn.: Twenty-second Ann. Rept., pt. 2, 1902, pp. 7–22.

——— Tungsten mining at Trumbull, Conn.: Bull. 213, 1903, p. 98. 25c.

Kay, G. F., Nickel deposits of Nickel Mountain, Oregon: Bull. 315, 1907, pp. 120–127.

Kemp, J. F., The geological relations and distribution of platinum and associated metals: Bull. 193, 1902, 95 pp. 30c.

Lindgren, Waldemar, Platinum and allied metals: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 987–1003.

McCaskey, H. D., Quicksilver: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 889–991.

Packard, R. L., Genesis of nickel ores: Mineral Resources U. S. for 1892, 1893, pp. 170–177. 50c.

Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 103 pp.

Phalen, W. C., Chromic iron ore: Mineral Resources U. S. for 1911, pt. 1, 1912: pp. 979–986.

Richardson, G. B., Tin in the Franklin Mountains, Texas: Bull. 285, 1906, pp. 146–149. Exhausted.

——— Antimony in southern Utah: Bull. 340, 1908, pp. 253–256. 30c.

Rolker, C. M., The production of tin in various parts of the world: Sixteenth Ann. Rept., pt. 3, 1895, pp. 458–538. $1.20.

Schrader, F. C., An occurrence of monazite in northern Idaho: Bull. 430, 1910, pp. 184–191.

Schrader, F. C., and Hill, J. M., Some occurrences of molybdenite in the Santa Rita and Patagonia Mountains, Arizona: Bull. 430, 1910, pp. 154–163.

Siebenthal, C. E., Cadmium: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 399–401.

Smith, G. O., A molybdenite deposit in eastern Maine: Bull. 260, 1905, pp. 197–199. 40c.

Sterrett, D. B., Monazite deposits of the Carolinas: Bull. 340, 1908, pp. 272–285. 30c.

——— Monazite: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1193–1196.

Ulke, T., Occurrence of tin ore in North Carolina and Virginia: Mineral Resources U. S. for 1893, 1894, pp. 178–182. 50c.

Watson, T. L., and Taber, Stephen, The Virginia rutile deposits: Bull. 430, 1910, pp. 200–213.

Weed, W. H., The El Paso tin deposits [Texas]: Bull. 178, 1901, 15 pp. 5c.

——— Tin deposits at El Paso, Tex.: Bull. 213, 1903, pp. 99–102. 25c.

Weeks, F. B., Tungsten deposits in the Snake Range, White Pine County, eastern Nevada: Bull. 340, 1908, pp. 263–270. 30c.

# IRON AND MANGANESE.

## SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey or by members of its staff are listed below. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, 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 and folios from either that official or the Director of the Survey. 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.

——— Titaniferous iron ores of Iron Mountain, Wyoming: Bull. 315, 1907, pp. 206–212.

BANCROFT, HOWLAND, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

BARNES, PHINEAS, The present technical condition of the steel industry of the United States: Bull. 25, 1885, 85 pp. 10c.

BAYLEY, W. S., The Menominee iron-bearing district of Michigan: Mon., vol. 46, 1904, 513 pp. $1.75.

BAYLEY, W. S., and others, Passaic folio (No. 157), Geol. Atlas U. S., 1908. 25c.

BIRKINBINE, J., The production of iron ores in various parts of the world: Sixteenth Ann. Rept., pt. 3, 1894, pp. 21–218. $1.20.

BOUTWELL, J. M., Iron ores in the Uinta Mountains, Utah: Bull. 225, 1904, pp. 221–228. 35c.

BURCHARD, E. F., The iron ores of the Brookwood district, Alabama: Bull. 260, 1905, pp. 321–334. 40c.

——— The Clinton or red ores of the Birmingham district: Bull. 315, 1907, pp. 130–151.

——— The brown ores of the Russellville district, Alabama: Bull. 315, 1907, pp. 152–160.

——— The Clinton iron ore deposits in Alabama: Trans. Am. Inst. Min. Eng., vol. 39, 1908, pp. 997–1055.

——— An estimate of the tonnage of available Clinton iron ore in the Birmingham district, Alabama: Bull. 340, 1908, pp. 308–317.

Burchard, E. F., Tonnage estimates of Clinton iron ore in the Chattanooga region of Tennessee, Georgia, and Alabama: Bull. 380, 1909, pp. 169–187.

——— Iron ore, pig iron, and steel: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 119–190.

——— Manganes ore: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 191–208.

Burchard, E. F., Butts, Charles, and Eckel, E. C., Iron ores, fuels, and fluxes of the Birmingham district, Alabama: Bull. 400, 1910, 204 pp.

Butts, Charles, Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania: Bull. 279, 1906, 198 pp.

——— Iron ores in the Montevallo-Columbiana region: Bull. 470, 1911, pp. 215–230.

Clements, J. M., The Vermilion iron-bearing district of Minnesota: Mon., vol. 45, 1903, 463 pp. $3.50.

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., vol. 36, 1899, 512 pp. $2.

Diller, J. S., Iron ores of the Redding quadrangle, California: Bull. 213, 1903, pp. 219–220. 25c.

——— So-called iron ore near Portland, Oreg.: Bull. 260, 1905, pp. 343–347. 40c.

Eckel, E. C., Utilization of iron and steel slags: Bull. 213, 1903, pp. 221–231. 25c.

——— Iron ores of the United States: Bull. 260, 1905, pp. 317–320. 40c.

——— Limonite deposits of eastern New York and western New England: Bull. 260, 1905, pp. 335–342. 40c.

——— Iron ores of northeastern Texas: Bull. 260, 1905, pp. 348–354. 40c.

——— The Clinton hematite: Eng. and Min. Jour., vol. 79, 1905, pp. 897–898.

——— The iron industry of Texas, present and prospective: Iron Age, vol. 76, 1905, pp. 478–479.

——— The Clinton or red ores of northern Alabama: Bull. 285, 1906, pp. 172–179. Exhausted.

——— The Oriskany and Clinton iron ores of Virginia: Bull. 285, 1906, pp. 183–189. Exhausted.

Harder, E. C., Manganese deposits of the United States; with sections on foreign deposits, chemistry, and uses: Bull. 427, 1910, 208 pp.

——— The Taylor Peak and Whitepine iron-ore deposits, Colorado: Bull. 380 1909, pp. 188–198.

——— The iron ores of the Appalachian region in Virginia: Bull. 380, 1909, pp, 215–254.

——— Manganese deposits of the United States: Bull. 380, 1909, pp. 255–277.

——— Some iron ores of western and central California: Bull. 430, 1910, pp. 219–227.

——— 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., Geological relations of the iron ores in the Cartersville district, Georgia: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 403–419.

——— Manganese ores of the Cartersville district, Georgia: Bull. 213, 1903, p. 232. 25c.

——— Iron ores of the United States: Bull. 394, 1909, pp. 70–113.

Hayes, C. W., and Eckel, E. C., Iron ores of the Cartersville district, Georgia: Bull. 213, 1903, pp. 233–242. 25c.

Hill, J. M., Mining districts of the western United States: Bull. 507, 1912, 309 pp.

HOLDEN, R. J., The brown ores of the New River-Cripple Creek district, Virginia: Bull. 285, 1906, pp. 190–193. Exhausted.

IRVING, R. D., and VAN HISE, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: Tenth Ann. Rept., pt. 1, 1889, pp. 341–507. $2.35.

IRVING, R. D., and VAN HISE, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: Mon., vol. 19, 1892, 534 pp. $1.70.

KEITH, ARTHUR, Iron-ore deposits of the Cranberry district, North Carolina-Tennessee: Bull. 213, 1903, pp. 243–246. 25c.

KEMP, J. F., The titaniferous iron ores of the Adirondacks: Nineteenth Ann. Rept., pt. 3, 1899, pp. 377–422. $2.25.

KINDLE, E. M., The iron ores of Bath County, Ky.: Bull. 285, 1906, pp. 180–182. Exhausted.

LEITH, C. K., The Mesabi iron-bearing district of Minnesota: Mon., vol. 43, 1903, 316 pp. $1.50.

——— Geologic work in the Lake Superior iron district during 1902: Bull. 213, 1903, pp. 247–250. 25c.

——— 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.

——— Genesis of the Lake Superior iron ores: Econ. Geology, vol. 1, 1905, pp. 47–66.

——— Iron ores of the western United States and British Columbia: Bull. 285, 1906, pp. 194–200. Exhausted.

——— The geology of the Cuyuna iron range, Minnesota: Econ. Geology, vol. 2, 1907, pp. 145–152.

——— Iron ore reserves: Econ. Geology, vol. 1, 1906, pp. 360–368.

——— A summary of Lake Superior geology with special reference to recent studies of the iron-bearing series: Trans. Am. Inst. Min. Eng., vol. 35, 1904, pp. 454–507.

LEITH, C. K., and HARDER, E. C., The iron ores of the Iron Springs district, southern Utah: Bull. 338, 1908, 102 pp.

PAIGE, SIDNEY, The Hanover iron-ore deposits, New Mexico: Bull. 380, 1909, pp. 199–214.

——— Preliminary report on pre-Cambrian geology and iron ores of Llano County, Tex.: Bull. 430, 1910, pp. 256–268.

——— Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 102 pp.

PHALEN, W. C., Iron ores near Ellijay, Ga.: Bull. 340, 1908, pp. 330–334.

——— Origin and occurrence of certain iron ores in northeastern Kentucky: Econ. Geology, vol. 1, 1906, pp. 660–673.

——— Economic geology of the Kenova quadrangle (Kentucky, Ohio, and West Virginia): Bull. 349, 1908, 158 pp.

SMITH, G. O., and WILLIS, BAILEY, The Clealum iron ores, Washington: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 356–366.

SMITH, P. S., The gray iron ores of Talladega County, Ala.: Bull. 315, 1907, pp. 161–184.

SPENCER, A. C., The iron ores of Santiago, Cuba: Eng. and Min. Jour., vol. 72, 1901, pp. 633–634.

——— Manganese deposits of Santiago, Cuba: Bull. 213, 1903, pp. 251–255. 25c.

——— Magnetite deposits of the Cornwall type in Berks and Lebanon counties, Pa.: Bull. 315, 1907, pp. 185–189.

——— Three deposits of iron ore in Cuba: Bull. 340, 1908, pp. 318–329.

——— Magnetite deposits of the Cornwall type in Pennsylvania: Bull. 359, 1908, 102 pp.

——— The Jauss iron mine, Dillsburg, Pa.: Bull. 430, 1910, pp. 247–249.

SPENCER, A. C., and others, Franklin Furnace folio (No. 161), Geol. Atlas U. S., 1908. 25c.

SWANK, J. M., Iron and steel and allied industries in all countries: Eighteenth Ann. Rept., pt. 5, 1896, pp. 51-140.

VAN HISE, C. R., The iron-ore deposits of the Lake Superior region: Twenty-first Ann. Rept., pt. 3, 1901, pp. 305-434. $1.75.

VAN HISE, C. R., and BAYLEY, W. S., Menominee special folio (No. 62), Geol. Atlas U. S., 1900. 25c.

VAN HISE, C. R., and LEITH, C. K., The geology of the Lake Superior region: Mon., vol. 52, 1911, 626 pp. $2.50.

VAN HISE, C. R., BAYLEY, W. S., and SMYTH, H. L., Preliminary report on the Marquette iron-bearing district of Michigan: Fifteenth Ann. Rept., 1894, pp. 477-650. $1.70.

——— The Marquette iron-bearing district of Michigan, with atlas: Mon., vol. 28, 1897, 608 pp. $5.75.

WOLFF, J. E., Zinc and manganese deposits of Franklin Furnace, N. J.: Bull. 213, 1903, pp. 214-217. 25c.

# ALUNITE IN THE SAN CRISTOBAL QUADRANGLE, COLORADO.

By ESPER S. LARSEN.

## INTRODUCTION.

In the course of the geologic mapping of the San Cristobal quadrangle, Colorado, under the direction of Mr. Whitman Cross, the writer examined a number of large areas of altered rock and found that alunite is a common and in places abundant mineral in the alteration product. The recent development of the potash industry whereby alunite has become recognized as a possible source of potash, has given additional importance to occurrences of this mineral, and it is the purpose of this paper to discuss briefly the known alunite deposits in the San Cristobal quadrangle.

## GEOLOGY.

The greater part of the quadrangle is occupied by volcanic rocks of Tertiary age, and these rocks extend for many miles to the north, east, and west. They range in composition from rhyolite to basalt, but even the basaltic rocks commonly contain a considerable amount of potash feldspars. Lava flows form most of the material, but the area contains breccia beds and extensive intrusive bodies. In general the flows are flat and the structure is simple, but in places they are much faulted and tilted.

## ALUNITE ROCKS.

Areas of altered rock a mile or more across are common in the volcanic region. Some are elongated or lenslike and are associated with fractures or vein fillings, and in places, as at Carson, these narrow altered zones are very abundant; others are more irregular in form. The altered rock is nearly always bleached white, and it is commonly softer than the unaltered rock. Many of these white outcrops are conspicuous and can be recognized at a considerable distance. In some parts of the quadrangle the alteration has given rise to kaolinite or to sericite, but from the writer's observations these types of alteration are not so extensive as alunitization, which has been observed in basaltic as well as in rhyolitic rocks.

The alunitized rock is usually white and commonly contains rather prominent cavities. As a rule the original texture of the rock is partly preserved. The alunitized rock can generally be distinguished from kaolinized or sericitized rock by its more compact, crystalline appearance and vitreous rather than earthy luster. Crystals and cleavage faces of alunite can be seen in the more coarsely crystalline rock, but most of the material is very fine grained and only pyrite can be recognized in the hand specimen. The thin sections show chiefly quartz and alunite, with a little pyrite, and some specimens, especially those derived from rather basic rocks, contain kaolinite or bauxite. The alunite is in some places scattered through the altered rock, but much of that derived from the more basic rocks partly replaces the plagioclase or occurs scattered through the groundmass. In a felsitic rhyolite at the head of South River small crystals of alunite are scattered throughout the altered rock, which retains some of its original felsitic texture.

## OCCURRENCES OF ALUNITE.

*Head of Middle Fork of Piedra River.*—In the basin at the head of the west branch of the Middle Fork of Piedra River is a large area of altered breccia. The fresh rock contains abundant tabular crystals of labradorite and some augite and hypersthene in a groundmass of plagioclase and orthoclase. Quartz is generally present in the groundmass, which varies greatly in coarseness. The altered rock always contains abundant quartz and kaolinite or bauxite and usually a considerable amount of alunite. Pyrite is invariably present and gypsum is prominent locally. It is interesting to note that in the southeastern part of this area there are deposits of banded opal and sulphur rock and altered rock consisting of quartz, kaolinite, sulphur, and pyrite, but no alunite was observed associated with the sulphur type of alteration. This altered zone is in an area of intense faulting, and while no faulting was recognized in the immediate vicinity of the rocks showing alteration the two are probably related.

*Head of South River.*—At the head of South River, just east of Piedra Peak, the rhyolite which overlies the andesitic complex mentioned in the preceding paragraphs is intruded by a large body of diorite porphyry. About this intrusive the rhyolite is much altered and to the east of Piedra Peak the trail crosses a large body of this altered rock. Some prospecting for gold has been done in it, but the mineralized rock seems to be the only ore. The fresh rock is a fluidal felsitic rhyolite made up of quartz and orthoclase, with a little biotite. Three specimens of the altered rock were collected near the prospects and found to consist of a fine-grained aggregate of quartz, alunite, and pyrite.

A partial analysis of the typical altered rock was made by W. T. Schaller, with the results given on page 181 in column 1. The chemical composition of the fresh rock is not known, but the analysis of a similar rhyolite from California is given for comparison. A comparison of the two analyses shows a relative loss of some $Al_2O_3$, little change in the total iron and $SiO_2$, a loss of over half the $K_2O$, of more than half the $Na_2O$, and of nearly all the MgO and CaO. There has clearly been an addition of S and $SO_3$. The chemical analysis indicates that the rock contains about 69 per cent of quartz, 2 per cent of pyrite, and 29 per cent of alunite, and this agrees very well with the results obtained from a study of thin sections under the microscope.

*Analyses of rhyolite.*

| | 1 | 2 |
|---|---|---|
| $SiO_2$ | 69.24 | 74.65 |
| $Al_2O_3$ | 11.50 | 14.11 |
| $Fe_2O_3$ } total iron | 1.34 | 1.08 |
| FeO } total iron | | .29 |
| $K_2O$ | 1.99 | 4.59 |
| $Na_2O$ | .80 | 2.81 |
| MgO | ........ | .20 |
| CaO | ........ | .80 |

1. Alunitized rhyolite from head of South River. Analysis by W. T. Schaller.
2. Rhyolite from California. Analysis by W. F. Hillebrand.

*Carson.*—At the mining camp of Carson the quartz latite and other rocks carry numerous irregular or elongated areas of bleached and altered rock showing more or less mineralization. In general the alteration consists of kaolinization and sericitization, but near some of the veins quartz-alunite rock was found.[1]

*Slumgullion Gulch.*—The Slumgullion mud-flow is made up chiefly of andesitic rocks which were derived from the slopes above it. Much of the rock is greatly altered and somewhat mineralized, and to judge from the specimens collected much of the altered rock contains abundant alunite. The alunite occurs in rocks made up chiefly of opal, in which it lines cavities or is scattered through the opal. Alunite-quartz rocks were also collected. These rocks came from some of the large areas of altered rock that are so prominent about Slumgullion Gulch.

*Red Mountain.*—Red Mountain, a few miles southwest of Lake City, is formed of great flows of quartz latite. The rock is characterized by large crystals of feldspar, some quartz, biotite, and augite in an aphanitic groundmass. The large feldspars are in part orthoclase, in part andesine or microperthite. The groundmass is made up of quartz and orthoclase. The rock is rather rich in alkalies. Locally it has been much altered, and the largest body of altered rock covers an area of over a square mile, occupying the crest and slopes of Red Mountain. This rock is commonly stained red from iron, but

[1] Larsen, E. S., The economic geology of Carson camp, Hinsdale County, Colo.: Bull. U. S. Geol. Survey No. 470, 1911, p. 33.

otherwise it is nearly white. Bodies of opal and quartz are abundant, but by far the greatest part of the mass is made up of quartz or opal and alunite, with some pyrite and a varying amount of kaolinite. The alunite and quartz are locally present in a very fine grained aggregate, but commonly the alunite crystals are collected in the original feldspar crystals and to a less extent scattered through the groundmass. No analyses are available, but the microscopic study indicated a considerable amount of alunite.

## GENESIS.

All the alunite occurrences described are clearly the result of the alteration of igneous rocks. From a study of the thin sections and of the partial analyses of the South River rock it is believed that in the process of alunitization most of the silica of the rock remains as quartz and the iron as pyrite, and that most of the alumina goes into the alunite. The magnesia and lime are almost completely removed and the alkalies are much decreased, soda to a greater extent than potash. In the conversion of orthoclase to alunite and quartz without the removal of alumina two-thirds of the alkali is removed and there is an increase of about 14 per cent in weight and a somewhat smaller increase in volume. In the alunitization of a soda feldspar the increase in weight is nearly 20 per cent, and if some of the soda is replaced by potassium the change is even greater. Many of the alunitized rocks show porosity and other evidence that there was a decrease in volume on alunitization. This may be accounted for in part by the loss of the lime and magnesia but chiefly by the loss of alumina and possibly also of silica.

The character of the alunite rock, which consists of quartz, alunite, and pyrite, and the absence of any oxidation products point to some other origin for the rock than descending oxidizing solutions. The same suggestion is offered by the great extent of the alunite rock in the areas on South River and Red Mountain, each of which covers approximately a square mile, and the exposure for a vertical distance of nearly 2,000 feet on Red Mountain, the uniformity of the alteration, and the lack of large veins or other sulphide bodies associated with the alunitization. Sulphates are known to occur as original constituents in some of the sulphide veins of the region. Indeed, in the vein of the Golden Fleece mine, on the east slope of Red Mountain, the mineral hinsdalite, which has the composition $2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$ and is closely related to alunite, is an abundant original constituent in a quartz sulphide vein.[1]

[1] Larsen, E. S., jr., and Schaller, W. T., Hinsdalite, a new mineral: Am. Jour. Sci., 4th ser., vol. 32, 1911, p. 251. Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911, p. 54.

The evidence suggests hot ascending solutions as the cause of the alunitization. The field relations point strongly to deep-seated hot sulphuric acid solutions without the aid of surface agents. However, in view of the fact that geologists do not generally admit the presence of such solutions, the evidence in the present case is not sufficient to justify the assumption of such a source for the alunitization in the San Cristobal quadrangle. The alternative source is the mingling of hot ascending solutions or gases carrying $H_2S$ and of surface oxidizing waters.[1]

[1] For a discussion of the origin of alunite see Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912, p. 21.

# SURVEY PUBLICATIONS ON ALUMINUM ORES—BAUXITE, CRYOLITE, ETC.

The following reports published by the Survey or by members of its staff contain data on the occurrence of aluminum ores and on the metallurgy and uses of aluminum. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the folio from either that official or the Director of the Survey.


BURCHARD, E. F., Bauxite and aluminum: Mineral Resources U. S. for 1906, 1907, pp. 501–510. 50c.

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. 25c.

——— The Gila River alum deposits: Bull. 315, 1907, pp. 215–223.

HUNT, A. E., Mineral Resources U. S. for 1892, 1893, pp. 227–254. 50c.

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: Mineral Resources U. S. for 1907, pt. 1, 1908, pp. 693–705, $1; idem for 1911, pt. 1, 1912, pp. 923–939.

SCHNATTERBECK, C. C., Aluminum and bauxite: Mineral Resources U. S. for 1904, 1905, pp. 285–294. 50c.

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.

## NOTES ON THE CLAYS OF DELAWARE.

By George Charlton Matson.

### INTRODUCTION.

During the summer of 1909 the writer devoted about a month to the study of the underground-water resources of Delaware. While engaged in this work he found it possible to make some observations on the mode of occurrence and distribution of clays, and these were supplemented by visits to brick factories wherever practicable. The lack of any detailed reports on the clays and clay-working industries of Delaware has led to the assembling of the information presented in this paper. It is to be hoped that a thorough and systematic investigation of the subject may be made at some future time.

The development of Delaware clays began over 140 years ago with the exploitation of pottery clays near Wilmington. Refractory clay for fire brick and similar purposes was obtained near Newcastle in the early part of the nineteenth century, and brick clays were mined at several places prior to 1850. The production of refractory clays and clays used for pottery has continued to the present time, but the industry is of moderate extent because the deposits are small and the competition with kaolin from other States is keen. As the State has developed the increase in population has naturally caused a greater demand for ordinary building brick and the demand for better brick for fronts of buildings has led to the manufacture of pressed brick. In recent years some draintile has been produced in the State and there should be an increasing demand for it, as larger areas of marsh lands are being cultivated.

The location of the State of Delaware is favorable to the development of cities along the great highways of commerce across its northern portion, and it is that portion of the State which contains the best clay deposits. The city of Wilmington and the other large cities in neighboring States should furnish a market for clay products and thus present a favorable condition for the exploitation of brick clays for structural and ornamental purposes. South of the Chesapeake

& Delaware Canal the demand for clay products is apt to be comparatively small, as the population is largely rural and there are no important cities. However, even in this section of the State some brick can be produced for shipment to large cities, and there should be a local demand for both brick and draintile.

## GEOGRAPHY AND TOPOGRAPHY.

### GENERAL FEATURES.

Delaware occupies portions of two extensive physiographic provinces that may be separated approximately by a line along the Baltimore & Ohio Railroad. The part of the State south of this line lies in the Coastal Plain, which extends from New Jersey southward and westward beyond the Mexican boundary. This province extends beneath the sea to a line where its gently sloping surface gives place to an abrupt descent to the deep-sea floor. The seaward boundary of the Coastal Plain is marked approximately by a line joining points having depths of 100 fathoms; in most places beyond this line the slope of the sea bottom is so steep that it may be compared with that of a mountain range. The landward margin of the Coastal Plain follows the line where the loosely consolidated clays and sands give place to crystalline rocks.

The northern portion of Delaware belongs to the Piedmont Plateau, an extensive physiographic province lying between the nearly horizontal clays, sands, and limestones of the Coastal Plain on the east and the intensely folded rocks of the Appalachian Mountains on the west. This province includes only a small area in Delaware but has an extensive development outside of the State.

The drainage of Delaware is divided between Chesapeake and Delaware bays. The lower portions of the valleys of the streams entering Chesapeake Bay are broad, and the streams are usually affected by tides for some distance from the coast. Farther from the coast the valleys become narrower, their walls are steeper, and the streams themselves have greater fall. However, except in the highlands at the north end of the State the valleys are generally not more than 50 feet below the surrounding country. Near the northern boundary of the State, where the topography is more rugged, some of the larger streams flow in valleys over 350 feet below the tops of the adjacent hills.

### RECENT PLAIN.

The Coastal Plain of Delaware is occupied by unconsolidated or loosely coherent sands and clays showing slight relief. It has been divided into five plains [1] that rise one above another in the form of

---

[1] Dover folio (No. 137), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 1.

terraces. The lowermost of these terraces borders Delaware Bay and forms tidal flats and adjacent lowlands rising only a few feet above tide level. This plain stretches along the entire coast and is the subaerial portion of the plain that extends outward beneath the sea.

### TALBOT PLAIN.

Along the inner margin of the Recent plain, separated from it by a more or less well-developed scarp, is a second terrace known as the Talbot. This plain extends into all the valleys of the streams that enter Delaware Bay and is present also in the western part of the State along some of the streams tributary to Chesapeake Bay. The surface of the Talbot plain is less than 50 feet above sea level in Delaware and it is but little eroded. Over the interstream spaces it is nearly flat, and where it forms reentrants in the stream valleys its slope is scarcely perceptible. It is on the whole a level area such as might be expected where land has been raised above sea level after having been subjected to wave action that had removed the original irregularities of the surface.

### WICOMICO PLAIN.

Bordering the inner margin of the Talbot plain, separated from it by a scarp, is a third plain known as the Wicomico. This plain ranges in altitude from about 40 feet to over 80 feet and occupies a broad area in the Coastal Plain portion of the State. It has a gentle slope from the seaward margin northwestward toward the area of older land. It presents broad tracts of level land in the interstream spaces but narrows greatly in the valleys of the streams. The wider tracts are very nearly level, but the plain has been considerably dissected near some of the streams and locally shows comparatively steep slopes. The greatest amount of dissection is found near the older land in the northern part of the Coastal Plain, where the original surface has locally been destroyed by erosion.

### SUNDERLAND PLAIN.

A fourth plain, known as the Sunderland, lies between the Wicomico terrace and the uplands in the northern part of the State. This plain is higher than the Wicomico and has been longer exposed to erosion, so that it is represented by discontinuous remnants. The range in altitude is difficult to determine, but it is from somewhat less than 100 to more than 150 feet above sea level. The line of demarcation between the Sunderland and Wicomico plains is a scarp that is locally well defined, and a similar scarp marks the inner margin of the Sunderland plain.

### LAFAYETTE PLAIN.

In Maryland there is a plain higher than the Sunderland which has been described by Shattuck.[1] This plain is formed by the surface of the Lafayette formation and its equivalent is probably present in northern Delaware. Above the plains previously described are remnants of an upland rising to somewhat more than 400 feet above sea level. On the interstream spaces this upland has a plain surface that suggests its classification as Lafayette, but this correlation is somewhat uncertain.

## GEOLOGY.

### PRE-CAMBRIAN ROCKS.

The upland in the northern part of Delaware consists of massive crystalline rocks, regarded as pre-Cambrian. These rocks underlie the Delaware portion of the Piedmont Plateau and extend from the northern boundary of the State southward to the vicinity of the Baltimore & Ohio Railroad.

The pre-Cambrian rocks are of various kinds and some of them have undergone considerable metamorphism since they were originally formed, but their varied characteristics and their complex geologic history are not important in a discussion of clays. The only valuable clay deposits of these formations are masses of kaolin that are found in a few localities. This kaolin is the result of the decomposition of dikes of pegmatite that were formed in crevices in still older rocks. In their original state the dikes were composed of quartz and feldspar, with a small percentage of other minerals. When subjected to the agencies of weathering the feldspar of the dikes decomposed into kaolin containing the quartz grains of the original rock. It is these quartz grains that are called sand by the miners.

### CRETACEOUS ROCKS.

The deposits of Cretaceous age, which represent both the Upper Cretaceous and the Lower Cretaceous series, have been divided into several formations. However, for the purposes of this paper it will only be necessary to discuss the major divisions, with incidental reference to some of the clay-bearing formations.

#### LOWER CRETACEOUS SERIES.

The Patuxent formation, belonging at the base of the Lower Cretaceous, has not been recognized at the surface in Delaware, but it is thought to have been penetrated in some deep wells. The Patapsco formation of the Lower Cretaceous is represented by scattered

[1] Shattuck, G. B., Pliocene and Pleistocene: Maryland Geol. Survey, 1906, pp. 80-82.

exposures distributed across the north end of the State. It extends from the Delaware-Pennsylvania boundary in a southerly direction to Wilmington and thence westward to the Maryland-Delaware boundary southwest of Newark. The deposits belonging to this formation occupy a narrow band across this portion of Delaware, but they are obscured by the sands and clays belonging to younger formations, except in the valleys of some of the streams. From the area where the Lower Cretaceous rocks are at or near the surface they extend southward beneath the Coastal Plain, but they have a gentle dip toward the southeast that carries them several hundred feet below the surface beneath the central and southern portions of the State.

The Patapsco formation consists of sand and clay with local beds of gravel. At Wilmington and Newark fine sands are found at the contact with the underlying crystalline rocks, but at other places coarser materials may occur at this horizon. Above the basal beds are lenticular beds of clays and sands that are in most places bright colored but vary from bright red or yellow to gray or drab. The presence of iron concretions and sands or gravels cemented by iron oxide has been noted at many places, and the bright colors are due to iron oxide that may be evenly distributed, giving a uniform color, or may be restricted to patches, causing a mottled appearance. The presence of leaves and other organic matter at some localities gives rise to drab or dark-colored clays, but the areas of such clays are small.

### UPPER CRETACEOUS SERIES.

A narrow band lying south of the outcrop of the Lower Cretaceous rocks is occupied by formations of Upper Cretaceous age. The formations belonging to this series are poorly exposed, although the thickness of the overlying materials near the northern edge of the Coastal Plain is not great. The Upper Cretaceous formations have a general southeasterly dip that carries them far below the surface in the central and southern portions of Delaware; for example, at Lewes they are buried to a depth of more than 1,000 feet.

The lowermost formation (Raritan) of the Upper Cretaceous bears some resemblance to the underlying Patapsco formation, though the color of the materials of which the Raritan is composed is not so striking. This formation is composed of clays of drab, gray, or variegated colors interbedded with sand and here and there with gravel. The colors are due to substances similar to those that color the Patapsco formation, though the oxidation of the iron is usually not as complete as in the older formation. The beds are commonly lenticular and many changes in the character of the materials may be seen in comparatively small exposures.

To the south of the exposures of the Raritan formation is a belt of sands with local clay beds, and above these are greensands with some clay. These are the Upper Cretaceous formations that overlie the Raritan, from which they may usually be distinguished by their relatively smaller percentage of clay and lighter colors, or, in the case of some of the uppermost beds, by the presence of greensand.

## TERTIARY ROCKS.

### EOCENE AND MIOCENE SERIES.

With the exception of the Lafayette the formations belonging to the Tertiary consist, in the lower or Eocene portion, of greensand or of sand with thin beds of clay. Beds of marl are common at certain horizons, especially in the upper or Miocene portion of the Tertiary, and they contain many shells of marine organisms that serve to correlate the formations with exposures outside of the State. The Eocene and Miocene underlie all that portion of the State south of the area of beds of Upper Cretaceous age, but owing to the mantle of Quaternary formations exposures are rare. The clay beds of Tertiary age are thin and scattered. At present none of them are known to have been exploited and owing to the poor exposures it is doubtful if the Tertiary clays will ever be important. In the northern portion of the Coastal Plain of Delaware these formations are not present, but they underlie a large area in the central and southern portions of the State and attain a thickness of several hundred feet near the southern boundary.

### LAFAYETTE FORMATION (PLIOCENE?).

The distribution of the Lafayette formation has been outlined in the discussion of the topography of the Coastal Plain. The deposits included in this formation consist largely of varicolored sand and gravel with thin lenses of sandy clay. The materials are mainly sandy, with colors ranging from gray to yellow or red, the brighter shades predominating. The deposits belonging to this formation are relatively thin, probably averaging not more than 25 feet in thickness, and are therefore of little importance.

## QUATERNARY DEPOSITS.

The Pleistocene and Recent terraces have already been described and their distribution outlined (pp. 186–188). Some uncertainty exists concerning the boundaries of the Wicomico and Sunderland terraces in the northern part of Delaware, and the boundary between the Recent and the Talbot terraces has not yet been accurately determined.

The general character of all the Quaternary deposits is similar, though the materials beneath the Wicomico terrace are somewhat more sandy than those beneath the younger terraces. The Quaternary terraces are underlain by gray or light-yellow sands containing thin lenses of clay. The clay beds are in general only a few feet thick and the deposits are usually sandy, though in a few places they contain lenses of comparatively pure clay.

On the surfaces of the terraces are local deposits of fine-grained loam that as a rule do not exceed 4 or 5 feet in thickness. This loam ranges in color from dark blue near the base of the deposit to light buff at the surface, where the iron compounds have been oxidized. This surface deposit is widely distributed in discontinuous patches, but it is important because it is a source of good clay that can be easily mined.

## GEOLOGIC SECTIONS.

The following sections show the general character of the geologic formations occurring in the Coastal Plain of Delaware. Although these formations vary in composition at different places, the sections here given probably represent the average character of the material they contain. In utilizing sections previously published, the writer has copied the lithologic descriptions but has altered some of the correlations in order to adapt the sections to the major geologic subdivisions which form the units of discussion in this paper.

*Record of United States well at Fort Dupont.* [a]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Quaternary: | | |
| Yellowish sand and fine gravel; brackish water | 24 | 24 |
| Cretaceous: | | |
| Rancocas: | | |
| Gray, slightly clayey sand and fine gravel | 16 | 40 |
| Dark-greenish limy sand with shells; contains much glauconite | 20 | 60 |
| Monmouth: | | |
| Dark sandy micaceous clay | 80 | 140 |
| Medium gray sand with very little glauconite | 10 | 150 |
| Brownish-gray sandy clay with some glauconite | 30 | 180 |
| Matawan: | | |
| Dark coarse sand and clay with some glauconite | 17 | 197 |
| Hard light-red, slightly sandy clay | 26 | 223 |
| Dark micaceous sandy clay | 17 | 240 |
| Fine to medium drab or brownish-gray clayey sand with a little glauconite | 40 | 280 |
| Fine to coarse brownish micaceous clay with some glauconite | 20 | 300 |
| Magothy, in part: | | |
| Medium to coarse drab or brownish sand with varying amounts of glauconite and occasionally some clay | 118 | 418 |
| Fine to medium light-gray sand, no clay and very little glauconite | 3 | 421 |
| Raritan: | | |
| Light brick-red clay with some sand | 46 | 467 |
| Fine to medium, slightly clayey pinkish-buff or pinkish-brown sand | 33 | 500 |
| Fine to medium brownish-gray micaceous sand | 10 | 510 |
| Potomac: | | |
| Medium to fine pinkish-brown sand with red and white clay | 130 | 640 |
| Fine to medium light-brown micaceous sand and clay | 10 | 650 |
| Brownish-gray micaceous clayey sand containing lignite | 11 | 661 |
| Fine to medium pinkish-brown sand with beds of pink, red, and white clay and lignite | 49 | 710 |
| Medium varicolored sand with lignite | 15 | 725 |
| Coarse light pinkish-brown sand | 5 | 730 |
| Light-brown sand containing many brown granules; also lignite | 4 | 734 |
| Dark-brownish clay and coarse sand | 2 | 736 |
| Medium pinkish-brown clayey sand | 4 | 740 |
| Brown clay with coarse sand; contains lignite | 5 | 745 |
| Medium brownish clayey sand | 5 | 750 |
| Fine to coarse pinkish-brown sandy clay containing brown granules and lignite | 5 | 755 |
| Medium grayish-brown clayey sand | 7 | 762 |

[a] Fuller, M. L., and Sanford, Samuel, Record of deep-well drilling for 1905: Bull. U. S. Geol. Survey No. 298, 1906, pp. 194-195.

*Record of well at Hares Corner, Newcastle County, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| Quaternary: | *Feet.* | *Feet.* |
| Yellow clay and sand | 25 | 25 |
| Cretaceous: | | |
| Blue clay | 25 | 50 |
| Red clay | 5 | 55 |
| Yellow sand | 5 | 60 |
| Iron ore (?); very red water | 10 | 70 |
| Yellow sand and water | 10 | 80 |
| White and blue clay | 20 | 100 |
| Red clay; water at base | 75 | 175 |
| Blue clay | 25 | 200 |
| Bluish sand; lignite | 10 | 210 |
| Red and white clay | 10 | 220 |
| White sand; water | 18 | 228 |

[a] Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1896, p. 140.

*Record of well at Dover, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| Quaternary: | | |
| Talbot formation: | *Feet.* | *Feet.* |
| Yellow gravel | 7 | 7 |
| Deep orange-colored sand and clay | 4 | 11 |
| Coarse orange-colored sand | 15 | 26 |
| Tertiary (Miocene): | | |
| Calvert formation: | | |
| Light orange-colored sand, finer | 16 | 42 |
| Sandy clay with a few marine diatoms | 12 | 54 |
| Sandy and marly clay | 8 | 62 |
| Sand | 9 | 71 |
| Brownish clay and sand with marine diatoms | 12 | 83 |
| Sand and comminuted shells with marine diatoms and sponge spicules | 7 | 90 |
| Sand | 4 | 94 |
| Sand and broken shell | 6 | 100 |
| Marl | 9 | 109 |
| Micaceous marly sand; some reddish sand grains | 8 | 117 |
| Sand with bad water; comminuted shells, diatoms, and coccoliths | 3 | 120 |
| Sandy clay with diatoms | 8 | 128 |
| Clay with diatoms | 19 | 147 |
| Sand, shells, and diatoms | 3 | 150 |
| Clay with a few diatoms | 5 | 155 |
| Sand with good water | 2 | 157 |
| Clay with pyrite-covered diatoms | 10 | 167 |
| Dark sand, some grains as large as peas; good water | 29 | 196 |

[a] Adapted from Dover folio (No. 137), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 5.

*Record of well at Milford, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| Pleistocene: | *Feet.* | *Feet.* |
| Gravel | 11 | 11 |
| Miocene: | | |
| Blue-gray clay | 14 | 25 |
| Fine gray sand (water encountered at about 30 feet, flows to surface) | 19 | 44 |
| Blue-gray clay | 16 | 60 |
| Fine gray sand | 8 | 68 |
| Blue clay | 2 | 70 |
| Fine gray sand with white particles | 20 | 90 |
| Fine gray sand containing shells | 28 | 118 |
| Blue clay | 3 | 121 |
| Fine gray sand | 16 | 137 |
| Greenish clay | 3 | 140 |
| Fine blue-gray sand (water flows 2 feet above surface) | 20 | 160 |
| Diatomaceous clay | 47 | 207 |
| Gravel, shells, and sand, with water | 21 | 228 |
| Diatomaceous clay | 16 | 244 |

[a] Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1906, p. 178.

*Record of well at Delmar, Sussex County, Del.*[a]

| | Thickness. | Depth. |
|---|---|---|
| Miocene: | *Feet.* | *Feet.* |
| Fine sand at | ....... | 48 |
| Coarse sand (water at 80 feet) | 37 | 85 |
| Sand | 51 | 136 |
| White sand and soft sand (rock ?) | 21 | 157 |
| Black sandy clay | 11 | 168 |
| Sand, gravel, and pebbles; sand at top and bottom reddish | 39 | 207 |
| Light-colored bluish sand, very hard | 13 | 220 |
| Fine sand | 44 | 264 |
| Light-gray clay (fine white shells at 300 to 304 feet) | 42 | 306 |
| Hard sand | 35 | 341 |
| Marl or clay with fine shells | 33 | 374 |
| Sand | 12 | 386 |
| Clay | 16 | 402 |

a Woolman, Lewis, Artesian wells: Ann. Rept. New Jersey Geol. Survey, 1899, p. 112.

## CLAYS.

### GEOLOGIC AGE.

Practically all the major geologic subdivisions occurring in Delaware contain clays, though not all the clays are of equal economic importance. Moreover, the absence of good exposures prevents the exploitation of many of the older clays, but the Quaternary beds, lying at or near the surface over most of the State, have supplied considerable clay in the form of thin lenticular beds. In addition to the differences caused by the relative accessibility there are marked differences in the values of the different clays; thus a kaolin deposit differs in value from a bed of fire clay, and either of them, where it can be easily mined, will be worth far more than clay that can be used only for common brick. Even brick clays present great variations in value, ranging from those suitable for the manufacture of ordinary rough brick to those fitted for the manufacture of bricks used in the fronts of buildings and for purely ornamental work.

### CLAYS OF THE PIEDMONT PLATEAU.

The rocks of the Piedmont Plateau, when weathered, give rise to clays of various kinds, but the most important, commercially, is the kaolin that has been mined in the northern part of the State. Intruded into the older rocks are a number of masses of pegmatite, and these have weathered to kaolin containing some impurities, chiefly quartz. Kaolin of this type was mined near Hockessin over half a century ago and the industry is still important in that locality. Since it has been found possible to remove the impurities by washing the material has found a ready market. The kaolin deposits at Newark probably belong to the same class as those at Hockessin.

The kaolin deposits of the Piedmont Plateau are residual in origin and locally are covered by a varying thickness of worthless material that must be removed before mining can begin. Owing to the fact that the deposits are obscured by this overlying material it is possible that borings would discover new localities, but no systematic prospecting has yet been done. Where the kaolin underlies the sedimentary formations of the Coastal Plain it is still more effectually concealed, and if deeply buried it is inaccessible.

Kaolin from Delaware has been used chiefly in the production of pottery, but it is also valuable for use in manufacturing paper. The freedom from impurities that would color the burned product makes the Delaware kaolin useful for the manufacture of white burning ware, and it commands a good price for shipment to potteries located outside of the State.

Many of the residual clays of the Piedmont Plateau may be used for the manufacture of ornamental and common building brick. A small brickyard at Newark uses clay that may be either residual or reworked material from the weathered products of the underlying crystalline rocks. Unfortunately the exposures at this place are not extensive and at the time the brickyard was visited but little information could be obtained concerning the origin of the clay. However, it is clear that the crystalline rocks of the Piedmont Plateau were encountered in one end of the pit.

## CRETACEOUS CLAYS.

The Patapsco formation, of Lower Cretaceous age, contains important beds of clay in Delaware, but they have not been extensively utilized. Clay that may belong to this formation has been mined at the brickyard near Christiana, where a brick of good grade for fronts of buildings is produced. A section of the material in the clay pit is as follows:

*Section in clay pit at brickyard near Christiana, Del.*

| | Feet. |
|---|---|
| Buff surface clay | 2–14 |
| Red and mottled clay | 15–20 |
| Dense blue clay | 20+ |

This deposit is of Cretaceous age and belongs either to the Patapsco formation or to the Raritan formation. Similar clays occur along the belt where the Lower Cretaceous and the basal portion of the Upper Cretaceous outcrop across the north end of the State. In addition some kaolin may have been eroded from the Piedmont Plateau and redeposited in the Cretaceous areas, though it is doubtful if such materials have been sought by prospectors. The presence of refractory clays in beds of this age in Cecil County, Md.,[1] suggests the desirability of seeking similar deposits in Delaware.

With the exception of the Raritan the Upper Cretaceous formations are too sandy to be important sources of clay, though local

[1] Ries, Heinrich, Report on the clays of Maryland: Maryland Geol. Survey, vol. 4, pt. 3, 1902, pp. 405–406.

lenses may be present, especially in the Magothy formation, which overlies the Raritan. So far as is known clays of Upper Cretaceous age are not now being utilized in Delaware, and it is doubtful if future exploration of the deposits of this age will result in the discovery of any important clay beds except those in the Raritan formation.

### TERTIARY CLAYS.

The Tertiary formations of Delaware are not important sources of clay, because, with the exception of the Lafayette, the beds are composed largely of sand and greensand marls. For this reason it is as a rule not advisable to seek clay in any of the formations of Eocene or Miocene age, though in places such deposits exist in the form of thin beds. The deposits of the Lafayette formation are largely sand and gravel but contain some thin layers of clay that might be suitable for the manufacture of common brick, though too sandy for the manufacture of brick of the better grades such as are used for ornamental work. At various places on the upland there is a thin layer of yellow or gray loam that may possibly belong in part to the Lafayette. This loam is comparatively free from grit and is suitable for making both common and pressed brick. It is sufficiently plastic to be molded by the stiff-mud process and would doubtless be satisfactory for the manufacture of draintile and similar clay products.

### QUATERNARY CLAYS.

The Quaternary formations are widely distributed in Delaware and have furnished brick clays at many localities. In fact, nearly all the brickyards of the State, with the exception of one at Christiana, use clay from some one of the Quaternary formations. While there is a wide variation in the character of these clays from place to place, they are nearly all suitable for the manufacture of ordinary building brick or draintile, and in a few localities they might be utilized for making pressed brick.

#### CLAYS OF SUNDERLAND FORMATION.

The uppermost Pleistocene formation, known as the Sunderland, extends across the State in the form of a terrace from the vicinity of Newark to Wilmington and thence northeastward to the Pennsylvania-Delaware boundary. The clays of this formation are the probable source of supply for several brick factories in the area adjacent to the Baltimore & Ohio Railroad, but owing to the fact that the formation has not been mapped in detail it is not always possible to tell whether a particular factory is located on beds of the Sunderland formation or of the next younger Wicomico formation. Clay that is tentatively correlated with the Sunderland formation is being used in the factories of the Alvin Allen Brick Co., the Delaware Terra Cotta Co., the Wilmington Brick Co., and James B. Oberly.

These factories are all located in the vicinity of Wilmington and use a loam of buff or yellow color that forms the surface of a terrace of Sunderland or Wicomico age. This loam is widely distributed and it is an important source of clay for common and pressed brick. The clays of the Sunderland formation are usually in the form of thin beds and as a rule it does not pay to work them except where they lie near enough to the surface to be excavated without the necessity of removing a great amount of overburden. It is necessary also to have a large area of the clay beds in order to work the deposits profitably.

### CLAYS OF WICOMICO FORMATION.

The Wicomico formation lies at the surface over a large part of Delaware from the vicinity of the Baltimore & Ohio Railroad southward. In fact, it covers all of that portion of the State except near the coast and in the valleys of some of the streams, where the later Talbot formation is present. Clays form a relatively small percentage of the material in this formation, and where they occur they are in the shape of small lenses that in many places are only a few feet in thickness. Nearly all the clays are sandy, but they are considered satisfactory for the manufacture of common building brick and have been utilized at a large number of factories. The brickyards using these clays are scattered over the State from Delmar on the south nearly to Wilmington on the north. Most of the factories are small, many of them producing rough brick suitable for ordinary structural purposes, and the brickyards are usually located near places where there is a demand for the output. Except near Wilmington very few of the factories using these clays produce any bricks for shipment to distant cities. It is probable that many clays in the Wicomico formation might be utilized in the manufacture of draintile, but as yet there does not appear to be a very large demand for such tile and consequently it has been manufactured at only one or two places. At present the largest plant manufacturing draintile is the one located at Cheswold, near Wilmington.

Clay that has been mined at the following places for the manufacture of brick or tile is tentatively referred to the Wicomico formation, though in a few instances the accuracy of the correlation is uncertain: Blades, Cheswold, Delmar, Ellendale, Harrington, Houston, Laurel, Seaford, Stanton, Townsend, and Whitesville.

### CLAYS OF TALBOT FORMATION.

The Talbot formation contains surface loams and lenses of clay interbedded with more or less sand, and both loams and clays are utilized in the manufacture of ordinary brick. The area covered by this formation comprises a belt along the coast, ranging from 3 to over 6 miles in width, together with some narrow terraces along the streams. The clays are used from both the coastal belt and the fluviatile portions of terraces, the location of the factories being governed largely by the demand. The brick is chiefly intended for local markets and the selection of a site for the brickyard commonly depends on some demand for building brick in the immediate neighborhood. A large number of factories have been opened at several places, but many of them have subsequently been abandoned because of a cessation of the demand for brick.

The clays of the Talbot formation are used chiefly for common brick, but they might also be suitable for other purposes, such as the manufacture of draintile or, where they are especially pure, of other clay products for ornamental work. The following list includes some of the places where these clays have been used in manufacturing brick: Dagsboro, Dover(?), Magnolia (Neale), Milford, Milton, Ocean View, Smyrna, and Stockley(?).

## METHODS OF MANUFACTURE.

There are no factories in Delaware that utilize kaolin and all of this material that is mined is shipped outside of the State. The refractory clays used for fire brick and glass pots are also shipped to other States and only ordinary clays are used in the Delaware factories. The processes of manufacture, comprising the mining and molding of clay and its subsequent burning, differ slightly in different plants, and a brief outline of the methods used is here given.

### MINING.

In most places the clay is mined by hand and shoveled into small cars that convey it to the factory. In a few localities steam shovels are used, but in most of the factories the amount of clay required does not warrant the installation of such machinery. The clay is mined entirely from open pits, and the overburden, if there is any present, is removed either with shovels or, in the larger factories, by means of scrapers operated by horse power.

### MOLDING.

The clay is either molded dry or mixed with a certain amount of water, but the dry-press method is used only in the factory at Christiana. Here the clay is excavated and exposed to the air in open sheds for some time and after being "tempered" in this way it is ground very fine and then molded. The product of this factory is front and ornamental brick of high grade.

The other factories use either what is called the soft-mud or the stiff-mud process. In the soft-mud process the clay is mixed with a comparatively large percentage of water and each brick requires a separate mold. This process is not extensively employed, but it is used in factories near Dover and Wilmington and possibly also in some other localities. In the stiff-mud process the clay is mixed with a smaller percentage of water and is forced from the mold in the form of a long bar that is cut into the desired lengths by means of wires or some other mechanical contrivance. The bar may be shaped so that, in cutting, the severed ends represent the ends of the bricks, which are then commonly designated "end cut;" or it may be shaped so that the severed ends represent the sides of the bricks, which are then called "side cut." Apparently the stiff-mud process is satisfactory, for it is used in nearly all the Delaware factories. In general the bricks appear to be side cut rather than end cut.

For making pressed brick many of the factories in the vicinity of Wilmington permit the bricks that were molded by the stiff-mud process to dry in sheds heated by steam for about 24 hours, when they are taken from the drying sheds and passed through machines where they are re-pressed to give them a smooth surface. This process is employed at several of the larger factories in the vicinity of Wilmington, and the product is a brick of very good grade for use in fronts of buildings. After being molded the bricks are dried, either in open sheds, the moisture being allowed to evaporate gradually, or in sheds heated by steam. Steam drying is employed only in the large factories because the cost of installation of pipes for heating is too great to warrant the use of this method in small plants.

## BURNING.

After being dried the bricks are stacked in kilns and burned. The kilns are either temporary, being constructed each time that bricks are burned, or permanent. The permanent kilns are used only in some of the larger factories, the operators of smaller plants finding it more profitable to construct a kiln for each burning. In the larger factories coal is used for burning, but in the small brickyards wood is the principal fuel. Most of the bricks are bright red or a reddish yellow in color, but in many of the kilns some of the bricks are overburned and the result is a dark-colored product.

At Christiana, where the manufacture of pressed brick is an important industry, the brick are first burned by the use of ordinary coal and at the conclusion of this operation a quantity of readily combustible coal is thrown upon the fires and the kiln is sealed. This process, known as flashing, covers the surfaces of the bricks with a series of dark spots, giving them a mottled appearance and presumably rendering them more ornamental. The same process is used to a minor extent in some of the large factories located near Wilmington, but the demand for brick of this kind is small.

## LOCAL DETAILS.

The lack of published information concerning Delaware brick factories makes it seem desirable to include here some details about a few of the localities visited by the writer while collecting data for this paper. However, many of the plants were not visited and some new factories have been started since the field work was completed, so that the notes here given do not constitute a complete summary of the brickmaking industry in the State. Moreover, as the conditions governing the installation and maintenance of brick factories change from time to time, many plants come into existence, continue for a brief period, and then cease operations. For this reason the lists already given include some brickyards that have been abandoned and may omit others, especially those that have been recently started. For the same reason some of the plants described below may be no longer in operation.

The American brick-manufacturing plant, 1 mile from Christiana, produces a pressed brick of fine grade for use in the fronts of buildings and other ornamental work. The clay is obtained from one of the Cretaceous formations and is so hard that it must be blasted in order to get it from the pit. After being mined this clay is allowed to dry in open sheds and is then ground and molded by a dry-press method. The bricks are burned in a permanent kiln until they are light yellow in color and then volatile cannel coal is thrown upon the fires and the kilns are sealed. This process of flashing covers the surface of the bricks with a series of dark spots and gives the product a pleasing mottled appearance.

Johnson's brickyard, East Newark, uses a light-yellow clay, having a thickness of over 4 feet, resting on the crystalline rocks of the Piedmont Plateau. The clay is excavated by picks and shovels and is mixed in a pit by the use of a wheel rotated by horsepower. The bricks are molded by the soft-mud process and air dried, after which they are burned in permanent kilns until they have a bright-red or salmon color. The product is a common building brick of good grade.

The Alvin Allen brickyard, Elsmere, obtains clay from the Pleistocene terrace that has been referred to the Sunderland formation, although the accuracy of this correlation is uncertain. This clay has a thickness of 3 or 4 feet where it is being excavated, and it varies in color from a light yellow at the top to blue in the bottom of the pit. It is mined with pick and shovel and hauled in carts to the factory, where it is mixed by means of a modern pug mill and molded by the soft-mud process. After being molded the bricks are placed in sheds having roofs made of loose boards that can be removed to permit the sunshine to reach the bricks. The burned product has a pleasing red color and is used in construction work in Wilmington.

The Wilmington Brick Co.'s yard, Wilmington, uses clay much like that used at the Alvin Allen yard. A section in the pit shows from 4 to 6 feet of fine-grained clay grading in color from light yellow at the top to mottled and blue near the base. The clay is mined by pick and shovel and is first conveyed to a crusher for grinding and then to a pug mill for mixing. The stiff-mud process of molding is used in this factory and the bricks are cut by machinery from the clay bar as it leaves the mold. After being molded the bricks are placed on iron plates, resting on steam pipes, where they are dried before burning. For the manufacture of common brick the product is taken directly to the kilns, but a portion of the bricks are allowed to dry for 24 hours and then passed through a re-pressing machine, thoroughly dried, and burned in the same manner as the others. These re-pressed bricks are used for fronts of buildings and in ornamental work, and the number manufactured depends entirely on the demand. The bricks manufactured at this plant vary in color from light to dark red, depending on the character of the atmosphere in the kiln; the lighter colors being produced where there is an abundance of oxygen to oxidize the iron compounds and the darker colors resulting from a deficiency of oxygen.

At the Delaware Terra Cotta Brick Co.'s yard, Wilmington, the clay used is similar to that used by the Wilmington Brick Co., and the process of manufacture is essentially the same, except that a steam shovel is used in mining and the clay is conveyed from the pit to the mill by a horse car. Both common and re-pressed brick are manufactured and the product of the factory when properly burned has a pleasing red color.

At James B. Oberly's brickyard, Wilmington, the deposit used consists of about 4 feet of fine-grained clay varying in color from light yellow at the top to mottled or blue near the base. It is hauled a short distance from the pits to the plant, dumped upon a platform, and then shoveled into crushers. The clay from the crushers is mixed in a pug mill and is afterward molded by the stiff-mud process. The bricks are then dried in a shed heated by pipes through which the exhaust steam from the machinery is forced. After drying for 24 hours enough of the product is re-pressed to supply the demand for front and ornamental brick. After being thoroughly dried the re-pressed bricks are stacked in the center of the kiln and those that have not been re-pressed are placed around the outside. In burning, anthracite coal is first used and this is followed by ordinary bituminous coal and finally by gas-producing coal. This arrangement of the fuel gives the brick a darker color than it would have if burned in the ordinary manner, because the fire gases from the gas-producing coal reduce some of the ferric oxide to ferrous compounds.

The brick factory at Harrington uses a sandy clay from the Wicomico formation and produces common building brick. The clay is of light-gray color and the deposit is reported to have a thickness of 10 feet, although only about 4 feet of the upper portion is utilized. The clay is mined by pick and shovel and after being mixed in a pug mill is molded by the stiff-mud process. The bricks are burned in a temporary kiln, wood being used for fuel. The product is a porous sandy brick that varies in color from red or yellow in the upper part of the kiln to brown or black near the base, where the fire gases come into contact with the brick and prevent the complete oxidation of the iron compounds in the clay.

Similar brickyards are located near Houston, Bridgeville, and Delmar, and one of much the same sort was formerly operated near Townsend. All these plants used clay from the Wicomico formation.

The Dover Brick Co.'s yard, Dover, uses clay that has been referred to the Talbot formation. The deposit consists of about 12 feet of light-gray clay which is so pure that fine sand must be mixed with it to prevent excessive shrinking while the bricks are drying. It is covered by an overburden consisting of 3 feet of sand and gravel. The bricks are molded by the soft-mud process and burned in up-draft kilns, using either wood or coal for fuel. The product is a light to dark red brick that is extensively used in the construction of buildings in Dover.

# CLAY IN THE PORTLAND REGION, MAINE.

By Frank J. Katz.

## FIELD STUDIES.

This paper is based on geologic studies of the area in Maine covered by the Portland and Casco Bay sheets of the Geological Survey's topographic atlas of the United States. The field work was done in the summer of 1911 and was a detailed areal survey of the major part of the region, in the course of which many sections of the clay formation discussed below were studied and its boundaries mapped.

## THE CLAY.

*Distribution.*—The clay is distributed widely throughout the lowlands about Back Cove and the estuaries of Presumpscot, Fore, New, and Saco rivers. (See fig. 23.) Through the townships of Saco, Old Orchard, Scarboro, South Portland, and parts of Westbrook and Portland, the clay forms a practically continuous flat belt, roughly 6 miles wide, interrupted only by hills that are for the most part isolated and small. In a large part of this region the clay is concealed by overlying sands. To the west and north from this belt clay occupies the valleys and extends up several of them for some distance beyond the region here considered. Along the shore and around the estuaries the elevation of the top of the clay ranges from about tide level to 20 or 30 feet, and farther inland it slopes up to broad flats which are between 70 and 100 feet above the sea in the continuous belt just mentioned. The clay rises gradually in the valleys to the north and west to a maximum height, within the region studied, of about 200 feet on Little River, in the northwest corner of the Portland quadrangle.

*Appearance and character.*—The clay is for the most part olive-gray to blue-gray in color. It is exceedingly fine grained. The margins and base of the clay are in places sandy and such parts are yellowish or a light rusty brown. Although sporadic bowlders are found within the clay, it is remarkably free from sand and pebbles. The material is very uniform in grain and color (except where it is sandy) and no distinct bedding or other structures can be recognized in fresh exposures. However, when the clay in natural and artificial exposures dries, it breaks up into very small blocks bounded by uneven, approximately horizontal surfaces (bedding) and a roughly rectangular system of close and short, nearly vertical cracks. The cracks have very commonly a thin black stain. When thoroughly dry the clay is a light drab-gray in color and the stains bleach to brown.

*Recognition in the field.*—The clay has topographic forms so distinct that it is as a rule easily recognized in the field. The highest surfaces of the clay deposits are generally broad and flat or very gently sloping. All the flat or nearly flat areas in the Portland region are either clay or sand plains. The latter are readily distinguishable by

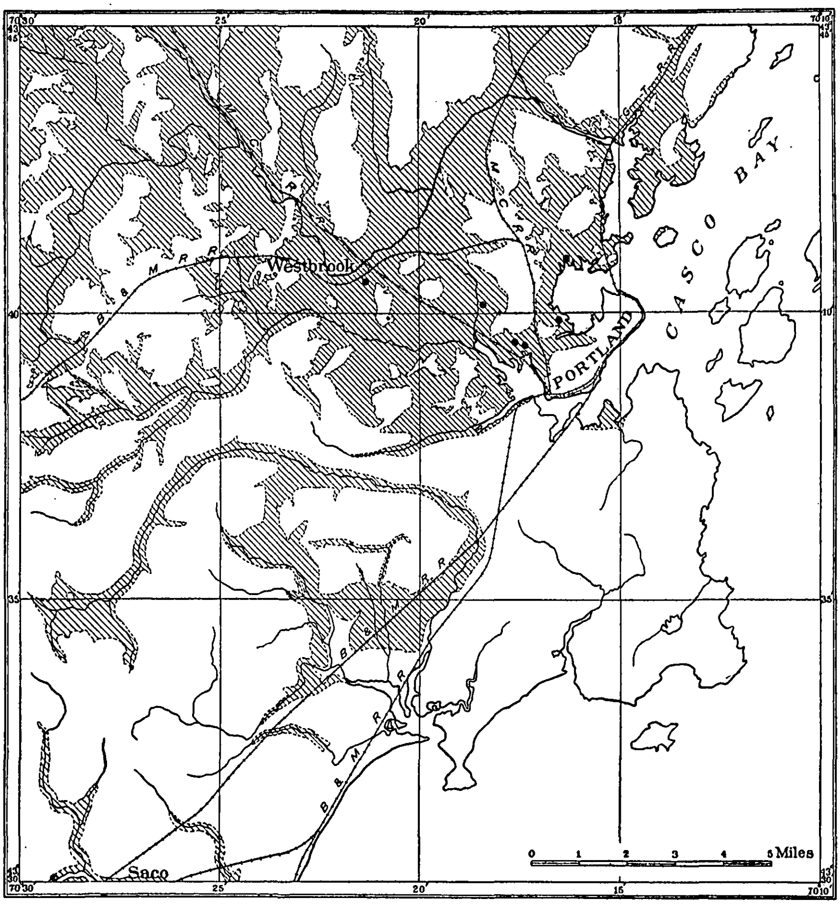



FIGURE 23.—Sketch map of the Portland region, Maine, showing location of principal clay deposits, brick yards, etc. Shaded areas indicate clay; ● clay bank, brickyard, or tile factory.

their sandy soils and especially by the heavy sandy roads which cross them. Some clay flats, particularly those in the lowlands, are unbroken by drainage lines throughout considerable areas, but for the most part the clay deposits are cut by steep-sided gullies, so that gullied surfaces with rounded contours are characteristic. In natural wave-cut exposures along the shore, in railway and road cuts, and in excavations the clay is readily recognized. There are good exposures along the shore in Falmouth Foreside, along the Maine Central Railroad in Portland and Windham, along the Portland-Saco electric line in Scarboro, and on many of the roads, particularly in Gorham. In those areas where the clay is covered by sands the larger streams have cut through the sands into the clay. Along such valleys the top and limit of exposure of the clay is marked by springs and seepages. The clay areas in general are characterized by an absence of bowlders, gravel, etc. The roads that are not surfaced also aid in the recognition of the clay. Where they traverse the clay they are free from pebbles and cobbles. In dry weather they are very hard and covered with fine light-gray dust, and in rainy weather with sticky gray mud. On slopes and where well crowned such roads remain hard even during periods of heavy rains and dry very quickly because of the compact and impervious character of the clay.

*Thickness.*—In the coastal region a thickness of approximately 70 feet of clay is indicated by drill records from Fore River, where the bottom of the clay has been found at some 50 feet below tide.[1] There is an aggregate thickness of about 100 feet on the sides of the valley of Little River. A well in the center of Scarboro Township pierces 43 feet of clay between sand above and gravel below. Inasmuch as the clay lies in depressions in the older formations its thickness may be expected to be irregular but in general to decrease toward the margins of the clay bodies.

## GEOLOGY.

The clay formation in the Portland region is a sheetlike body of fairly uniform character, whose thickness ranges up to about 100 feet. It has in general an approximately plane upper surface with gentle eastward and southeastward (seaward) slope. Locally it contains shells of marine animals. It lies unconformably upon glacial drift and is in part covered by considerable beds of sand which are traceable northwestward to the region where they appear to merge into glacial deposits. The clay is therefore assigned to the Pleistocene, the epoch of glacial occupation of Maine. The marine origin of the clay, which is suggested by its distribution along the coastal region and in the valleys tributary to the coast, is established by the marine shells it contains. The clay deposits are similar to the clam flats of the present day and are evidence that during the time of their deposition the ocean spread over and in places submerged to depths of more than 200 feet parts of the present coastal lands.

## UTILIZATION.

The clay of this region is used chiefly for making common brick. One plant uses local clay for draintile and mixes it with fire clay from other regions for the manufacture of refractory wares.

[1] Clapp, F. G., Underground waters of southern Maine: Water-Supply Paper U. S. Geol. Survey No. 223, 1909, p. 107.

In and near the city of Portland there were in 1911 three brickyards in operation, and near Saco there were two. The one plant in Westbrook was not running. Two of these plants make brick by the old wet-mud process, using horsepower for mixing, etc. The other plants employ modern power-driven machinery.

The plant of William Lucas, on Brighton Avenue in the outskirts of Portland, is on a wide, flat tract of clay, of which about 10 acres has been worked over. The clay here is of an olive-gray color and in its upper portion uniformly clean except for sporadic pebbles and small bowlders. At a few points where the bedrock surface is exposed in the bottom of the pit locally as much as 4 feet but generally only a thin layer of the clay is sandy, very fine textured, and yellowish or brownish in color. The banks are at present about 8 feet high. The clay in them is moderately dry and hard. It is mined by undercutting the face with pick and shovel and prying it down with bars. About 18 inches of overburden (sod and soil) is stripped and hauled off before the clay bank is broken down. The drainage of the pit is natural and easy to a brook near by. The floor is kept above the drainage level. All material broken from the face of the bank is trammed in horse cars to the foot of an incline leading to the mill, and before it ascends sand is thrown into each car in the proportion of approximately 1 part to 9 parts of clay. The cars are dumped on the upper floor of the mill, whence the material, to which water is added in dry weather, descends through a grinder and pug mill to auger brick machines with automatic cutting tables. The capacity of the machines is 45,000 common brick per day. The plant has two sets of machines, electrically driven, but only one is used at a time. The bricks are air-dried in sheds, 14 days being required for drying in fair weather. They are burned with wood fires for 12 days in common scove kilns. The shrinkage is one-eighth inch in length, about half being due to drying and half to burning. About 35 men are employed at the plant, which is operated only during the summer and which produces 4,000,000 common building brick a year. The market is entirely local.

The plant at the head of Douglas Street, Portland, belonging to the estate of Melvin Hamblet, has one set of machines driven by steam. In other mechanical respects and in its operation it is like the plant described above. Its output is 3,500,000 to 4,000,000 bricks yearly. There is another large plant of this type in the town of Saco just south of the region here discussed.

Adjoining the Hamblet plant is one operated by S. P. Densmore, where common building brick are made by the wet-mud process. The clay is worked on the floor of the pit and in simple one-horse machines. The bricks are dried in the open and burned in a scove kiln. The capacity of this plant is 18,000 bricks a day, or 1,000,000 to 1,200,000 a season. West of Saco there is a similar but smaller brick plant.

Winslow & Co. operate a large plant between the shore of Back Cove and Forest Avenue, in Portland, where they manufacture vitrified brick, sewer pipe, fire brick, flue lining, land tile, and various specialties in refractory and glazed wares. The operators estimate that on an average not more than 15 per cent of native clay is used in their products, the remainder being fire clay from New Jersey. The native clay is taken from banks on the north shore of Back Cove and landed at the company's wharf. The product is largely sewer pipe composed of 25 per cent native clay and 75 per cent fire clay. A small quantity of land tile, made entirely of native clay, is manufactured. In mixing, a small amount of water is added to the clays and they are mechanically carried to and put through two pug mills and a compound crusher and separator, from which the tempered clay is carried to hoppers and thence delivered to the molding machines. Drying is done in the lofts of the plant, which is warmed by coils through which the exhaust steam from the engines passes. Drying takes 2 to 3 days for small pieces, 8 days for fire brick, and 10 or 12 days for 36-inch pipe. The burning is done in coal-fired down-draft dome kilns, of which there are twenty-five 30 feet in diameter and one 40 feet in diameter. The capacity of the smaller kilns is from 4½ to 5 carloads and that of the larger 7½ to 8 carloads. Pipe, etc., is fired for 7 days and glazed after the sixth day. Fire brick is fired for 13 days. The kilns are two weeks in cooling.

The product is marketed in New England, freight rates making more distant shipments unprofitable.

## FURTHER DEVELOPMENT.

The abundance and variety of clays and the well-established clay industries of other Atlantic States would probably limit the market for present products of the clay of the Portland region, even if transportation rates were not restrictive. Extended utilization of the clay must therefore be dependent on the local market or on the development of other industries in which this clay might be used. Bastin[1] has called attention to the suitability of similar clay in the Penobscot Bay region for the manufacture of pressed and ornamental brick and of Portland cement. For the former industry the conditions would seem to be favorable at Portland.

[1] Bastin, E. S., Clays of the Penobscot Bay region, Maine: Bull. U. S. Geol. Survey No. 285, 1906, pp. 428–431; also Rockland folio (No. 158), Geol. Atlas U. S., U. S. Geol. Survey, 1908.

# DEVELOPED DEPOSITS OF FULLER'S EARTH IN ARKANSAS.

By Hugh D. Miser.

## INTRODUCTION.

Fuller's earth is a clay which has the property of decolorizing or clarifying oils. Its color is generally light brownish or grayish but varies to white, yellow, greenish gray, pink, or even black. The specific gravity is from 1.75 to 2.50. Like ordinary clays, it may or may not be plastic. It is an aluminum silicate, containing more combined water and less alumina than most other clays and an appreciable amount of hydrous silica. The chemical composition of fuller's earth from different localities varies widely and is of no significance as to its commercial value, which must be determined by practical tests with oils.

Fuller's earth is believed to be a decomposition product of hornblendes and augites, rather than of feldspars, which form ordinary clays. Gabbro, diorite, diabase, and basalt are mentioned by different writers as rocks from which fuller's earth is derived. The developed deposits of fuller's earth in Arkansas are of interest for the reason that the earth is found in place and has been derived from basaltic dikes. Residual deposits derived from diabase and gabbro are also known in Saxony. The deposits in Arkansas and Saxony are the only residual deposits known to the writer, the other known deposits being of sedimentary origin. Certain British deposits are stated [1] to belong to the Lower Greensand formation, and the "Fuller's earth group" is mentioned by Dana [2] and Geikie [3] as a subdivision in the Lower Oolite of the Jurassic period. The sedimentary deposits of fuller's earth in the United States belong to the Cretaceous, Tertiary, and Quaternary periods and occur in Alabama, Arkansas, California, Colorado, Florida, Georgia, Massachusetts, New York, South Carolina, South Dakota, and Texas.

---

[1] Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, pp. 408-411.
[2] Dana, J. D., Manual of geology, 1895, p. 775.
[3] Geikie, Archibald, Textbook of geology, 1903, pp. 1131, 1138, 1140.

## LOCATION AND TOPOGRAPHY.

The developed deposits of fuller's earth in Arkansas occur in an area of about 3 square miles which lies between Hot Springs and Benton. (See Pl. IV.) The St. Louis, Iron Mountain & Southern Railway passes through the area about 7 miles west of Benton.

The area in which these deposits occur is rather hilly. The height of the hills does not exceed 150 feet above the main watercourses, or 500 feet above sea level. The area is drained by small intermittent streams which flow to the southeast and empty into Saline River.

The region is wooded with pine and a little oak, but most of the commercial timber has been removed. Only a small portion of the area is under cultivation, as the larger part is too hilly and the soil is too meager and poor for farming.

## HISTORY.

The first deposit of fuller's earth within Arkansas to receive attention was a bed of Tertiary marl clay[1] near Alexander. This bed was opened in 1890 and samples of the earth were tested the same year. The results, however, did not prove altogether satisfactory. Later a bed of clay near Germania was opened, because it was found to possess some of the properties of fuller's earth. This clay was milled at Perrysmith, now Bauxite, but its use for fuller's earth was not successful.

The deposits near Benton were discovered in 1897 by John Olsen, of Benton. Mr. Olsen at first shipped the crude earth to the Fairbanks Packing Co., of St. Louis, by which it was milled and used. He later erected at Klondyke station a plant for milling his crude earth. At present the other operators owning plants within the area are the Fuller's Earth Union (Ltd.), of London, England; the Fuller's Earth Co., General, of Wilmington, Del.; and Fred Rossner, of Little Rock, Ark.

## GEOLOGY.

### GENERAL FEATURES OF THE OUACHITA MOUNTAINS.

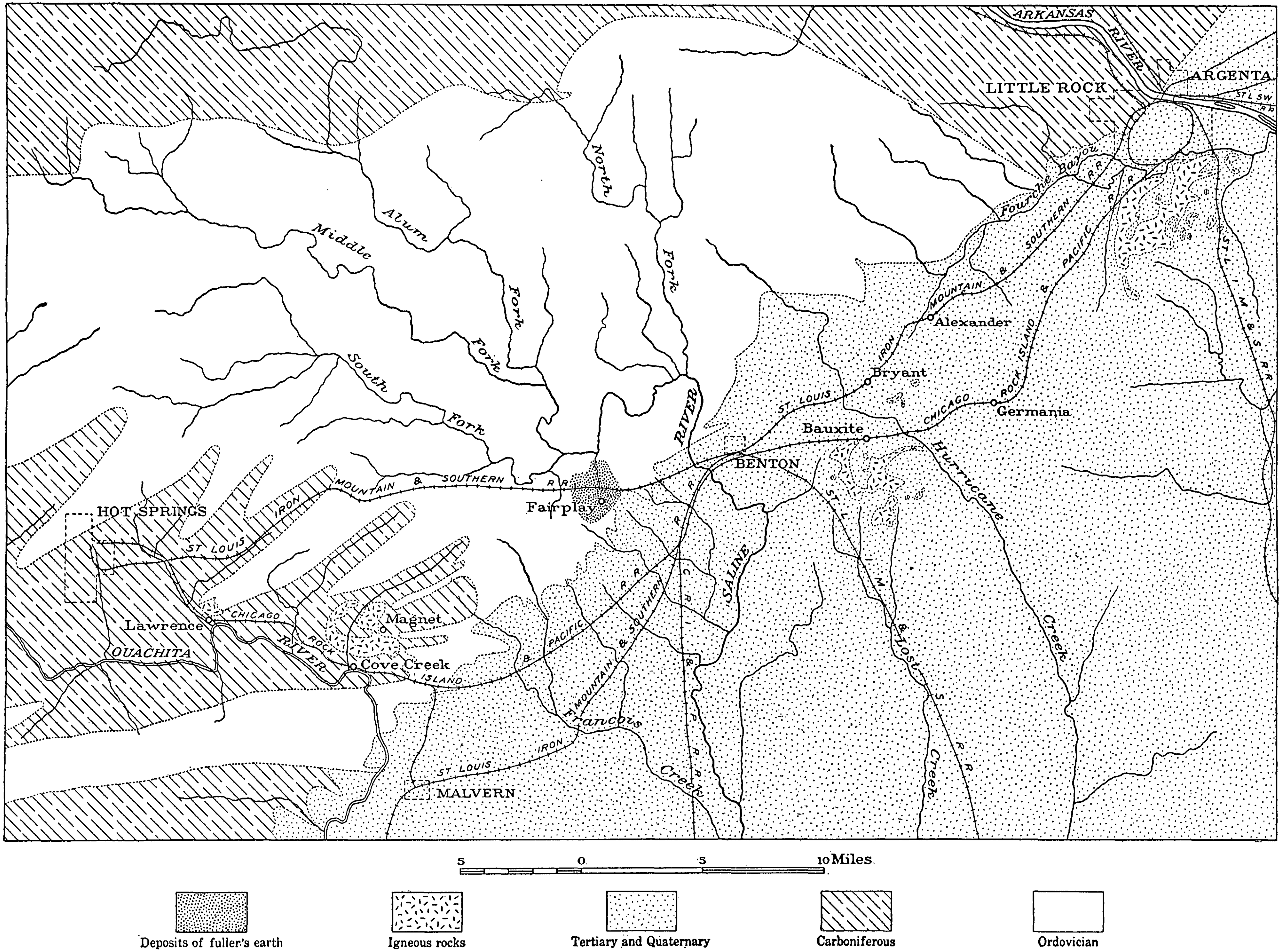
The mountainous area of Arkansas south of Arkansas River is known as the Ouachita Mountains. To the east of these mountains are the Mississippi lowlands, and to the south lies the Red River plain.

The principal structural feature of the Ouachita Mountains is the Ouachita anticline, described by Griswold[2] and Purdue,[3] which extends from the vicinity of Little Rock westward almost to the western border of the State. The truncated east end of this anticline

[1] Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 62-63.

[2] Griswold, L. S., Whetstones and novaculites of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 3, 1890, pp. 273 et seq.

[3] Purdue, A. H., The slates of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1909, pp. 41-45.




GEOLOGIC MAP OF SOUTHWEST-CENTRAL ARKANSAS, SHOWING LOCATION OF DEVELOPED DEPOSITS OF FULLER'S EARTH.

and the general geology of southwest-central Arkansas are shown on Plate IV. This master anticline consists of numerous simple anticlines and synclines, the whole thus constituting an anticlinorium. The folds are as a rule closely compressed, and the strata stand with a high dip.

The rock formations exposed within the center of this anticline belong to the Ordovician system and consist principally of shales, sandstones, and novaculites. North and south of the exposures of the Ordovician rocks there are enormous thicknesses of shales and sandstones of Carboniferous age. Limestones and unindurated clays, sands, and gravels of Cretaceous age cover a large area within the Red River plain, and like deposits of the Tertiary and Quaternary periods occur in the Mississippi lowlands.

Among these sedimentary formations are several small patches of igneous rocks,[1] the combined exposures of which do not exceed 14 square miles. All the larger masses of igneous rocks which are shown on Plate IV are situated in or near the anticlinal axis of the Ouachita uplift. The igneous rocks of Arkansas belong to the nephelite syenites and their associated dike rocks. They are of the abyssal and intrusive classes. The time of their intrusion is considered to have been about the close of the Cretaceous period. Numerous dikes [2] cut these masses of igneous rocks as well as the Paleozoic strata.

### SEDIMENTARY ROCKS.

The rock formations within the area herein described are the so-called "Ouachita" shale,[3] of Ordovician age, and a bed of gravel belonging to the Tertiary or Quaternary.

The "Ouachita" shale is exposed in relatively wide belts within the Ouachita anticline. It is a black graphitic clay shale which possesses slaty cleavage. The cleavage surfaces are ribboned with black and greenish bands; the former are the wider. These ribbons are well exposed in the fuller's earth mines and in natural exposures. It is from these bands and from siliceous layers in the shale that its dip can be determined. The cleavage as a rule has no relation whatever to the bedding. This shale is jointed and in places intensely crumpled, so that the underground water can circulate freely in it, as is shown by the fairly large amount of water in the mines and wells in this formation.

White quartz veins, having a maximum thickness of 4 feet, are numerous and occupy fissures and bedding planes. The thickness

[1] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890.

[2] For description and tabulation of many of these dikes, see Ann. Rept .Arkansas Geol. Survey, vol. 2, 1890, pp. 407-411.

[3] Purdue, A. H., The slates of Arkansas: Ann. Rept. Arkansas Geol. Survey, 1909, pp. 33-34.

of a single vein varies greatly within short distances. No other minerals are associated with the quartz. As seen in the mines the vein quartz is much shattered.

On weathering this shale changes to a plastic clay, which ranges from white to red in color. Residual vein quartz is abundant on the surface in certain localities. The soil, clay, and other débris covering the shale are not more than 2 feet thick, hence natural exposures are numerous along ravines and on hill slopes.

A bed of unconsolidated waterworn quartz and novaculite gravel, composed of pebbles 1 inch and less in diameter, caps many of the highest hills near the border of the Tertiary area. On the crest of the hill north of Fairplay spur there are several large novaculite bowlders embedded in this gravel; the largest is 6 by 12 feet on the exposed face. The nearest outcrop of novaculite is about 6 miles away, and it is not known how these bowlders reached their present position.

## IGNEOUS DIKES.

### GENERAL FEATURES OF OCCURRENCE.

Numerous dikes occur within the area under discussion. Because of their concealment by vegetation and overlying soil exposures are few and they were first discovered in the cuts along the St. Louis, Iron Mountain & Southern Railway. As the residual clay of these dikes was found to be fuller's earth, prospecting for other dikes was carried on and in this way many of them have been discovered.

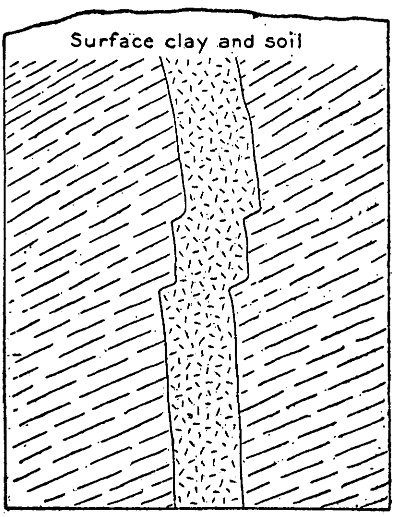



FIGURE 24.—Cross section showing dike altered to fuller's earth. Scale, one-fourth inch equals 1 foot.

The number of prospected and exposed dikes can not be determined because they have been revealed mainly in numerous shafts, mines, railroad cuts, and prospect trenches and can not be traced on the surface from one of these places to another. In the SE. ¼ sec. 23, T. 2 S., R. 16 W., the writer observed at least seven different dikes. In the southwest quarter of this section and the NW. ¼ sec. 26 of the same township and range there are about 24 shafts and openings, all of which are located on dikes. No doubt many of the shafts and openings here are on a single dike, as in the SE. ¼ sec. 23, where two dikes have been mined out from one shaft to another.

The general direction of the dikes is northeast and southwest; it is most likely influenced by the structure of the area, which is complicated by the crumpling and close folding of the shale. The direction of the folds is probably northeast and southwest, as this is the prevailing direction of the axes of the folds a few miles west and southwest of this area. The dip of most of the dikes, according to the writer's observation and statements of the miners, is to the southeast, at angles from 45° to 90°. Some are true dikes, occupying fissures; a few apparently are sills parallel with the bedding. A few occur in fissures beside older quartz veins. The longest dike thus far known is probably half a mile in length. This particular dike has been traced in worked-out mines and prospected for the greater part of this distance. As would be expected, the dikes are not every-

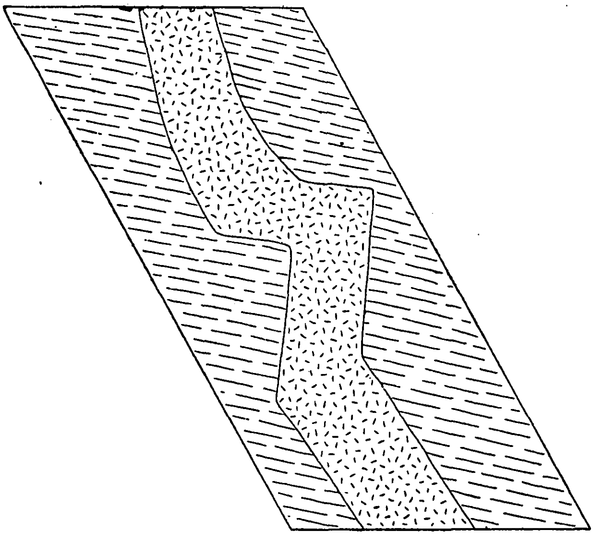


FIGURE 25.—Cross section, in mine, of dike altered to fuller's earth. Scale, one-eighth inch equals 1 foot.

where straight but in many places bend a few degrees to the right or left. A syenite dike, which is the only highly feldspathic dike known within the area, is reported to be 9 feet wide. The other dikes, which are basic, vary from a fraction of an inch to 4½ feet in width. This variation is known to take place in one mine. Within the mines small dikes or "feeders" are frequently observed leading away from the main dike. The walls on either side of some of the dikes are jagged and would in many places fit perfectly if brought together, as is illustrated by figures 24 and 25. One dike is known to occupy a fault plane.

The types of igneous rocks within the area described are ouachitite, syenite dike rock, and biotite monchiquite. E. S. Larsen, of the United States Geological Survey, has made petrologic examinations of the ouachitite and syenite dike rock. The localities of the specimens submitted to him are as follows:

1. Dike in railroad cut 400 feet east of Fuller spur.
2. Shaft 100 yards south of plant of Fuller's Earth Union.
3. Abandoned mine near old spur to west of Armour spur.
4. Shaft about one-fourth mile south of plant of Fuller's Earth Union.
5. Mine at plant of Fuller's Earth Bath Co. (not now in operation).

### OUACHITITE.

The dike in the railroad cut 400 feet east of Fuller spur and the specimen taken from the abandoned mine near the old spur west of Armour spur are stated by Mr. Larsen to be normal ouachitites. His description is as follows:

> The ouachitites are dense dark-colored rocks which usually show prominent biotite and abundant augite in the hand specimen; hornblende may be conspicuous in the hornblende variety. The thin sections show that these dark minerals, which form a large part of the rock, are embedded in an isotropic base. Accessory apatite, titanite, and iron ore and secondary calcite, analcite, and zeolites are always present. Small crystals of orthoclase occur in several of the specimens. The index of refraction of the isotropic base was measured by the immersion method in two specimens and found to be $1.490 \pm 0.005$, or sensibly equal to that of analcite. Williams and Kemp [1] describe it as glass, but it is probably analcite. Its character can be proved only by a chemical study of suitable material.

The rock taken from the shaft 100 yards south of the plant of the Fuller's Earth Union is stated by Mr. Larsen to "contain abundant brown hornblende and but little biotite; it is a hornblende ouachitite, but its poverty in biotite places it near the hornblende fourchites." "The specimen from the shaft one-fourth mile south of the same plant," Mr. Larsen states, is "ouachitite, poor in biotite, and with a few altered crystals of olivine; it is therefore near the biotite monchiquites."

### SYENITE DIKE ROCK.

Mr. Larsen describes the specimen from the plant of the Fuller's Earth Bath Co. as follows:

> It is a dense gray, finely crystalline rock which shows abundant lath-shaped crystals of feldspar and hornblende in the hand specimen. The rock consists chiefly of orthoclase, albite, brown hornblende, augite, and analcite. Apatite in large crystals, iron ore, and titanite are accessory minerals and secondary calcite is abundant. The orthoclase is in well-bounded lath-shaped crystals, which are locally collected in radial bundles; the plagioclase is less abundant than the orthoclase and is in larger but less regular crystals. The hornblende and augite are subordinate to the feldspars. The analcite is not abundant and occurs chiefly in areas which mold about the feldspars; it is either primary or is derived from a mineral, such as nephelite, which originally occupied this interstitial portion. The rock falls into Williams's division of syenite dike rocks [2] but does not fit accurately into any of his subdivisions.

---

[1] Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890.

[2] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol 2, 1890, pp. 83-99, 367-376.

### BIOTITE MONCHIQUITE.

The rock determined as biotite monchiquite has been taken in considerable quantities from an abandoned mine about 100 yards northwest of John Olsen's plant. It is a dense dark-colored rock. Many of the fragments show large biotite phenocrysts, as much as 1½ inches across the base, in a rather finely crystalline groundmass. The other fragments consist of abundant augite and serpentine embedded in a finer groundmass, as shown in the hand specimen. The writer examined thin sections of the latter variety. The groundmass is composed of much magnetite and small amounts of analcite and apatite, together with some augite and serpentine. Secondary limonite, chlorite, and abundant calcite are present. The augite and serpentine occur in about equal amounts in the section. The serpentine is altered olivine. The biotite is subordinate in amount to both the serpentine and the augite.

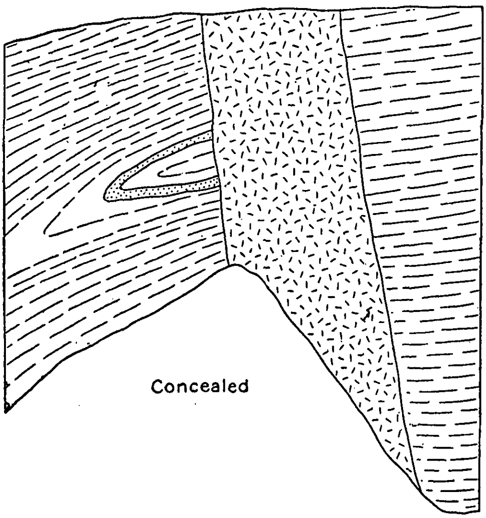



FIGURE 26.—Cross section showing dike occupying fault plane which cuts small fold. Scale, one-fourth inch equals 1 foot.

### DATE OF INTRUSION.

It is known from evidence obtained within this area that the date of intrusion was subsequent to the deformation of the "Ouachita" shale. This shale received the intense folding it now shows at the close of the Carboniferous period; it was probably gently folded at an earlier date. Although the strike of most of the dikes is apparently parallel with the axes of the sharp folds, two were observed to cut the folds of this shale transverse to their axes. Figure 26 illustrates this manner of occurrence. The quartz veins do not cut the dikes but terminate abruptly at the contact of the dike with the shale. This may be taken as proof that the dikes were intruded subsequent to the formation of these veins. Some of the veins also cut the folds in a manner similar to that of the two dikes just described. Many of the veins are therefore post-Carboniferous, and the dikes must have been intruded a considerable time after the close of the Carboniferous period. It was probably the intrusion of the dike material that produced the shattering of the quartz in these veins.

The types of rocks are the same as or similar to those in some of the dikes in other parts of the State. For this reason there seems to be little ground to doubt that all these dikes are genetically connected, and it would follow that their date of intrusion would most likely have been the same. Williams [1] considers the intrusion of the dikes and larger areas of igneous rocks of Arkansas to have taken place about the close of the Cretaceous period.

ALTERATION OF THE DIKES.

In the lack of chemical analyses of the unaltered rock and its residual clay, the exact nature of the bulk composition change from the original dike to the fuller's earth is not known. The alteration of these dikes into clay was brought about by the chemical action of descending meteoric water that contained salts and acids taken up in passing through the atmosphere and in filtering through the surficial layer of decaying organic matter and the clay and other decomposition products of the rocks at or near the surface.

As has been stated, it is believed that fuller's earth is a decomposition product of hornblendes and augites, rather than of feldspars, as are ordinary clays. This belief is apparently supported by the evidence within this area. The basic dikes, the residual clay of which is successfully used for fuller's earth, contain much augite and a less amount of hornblende, with practically no feldspars. On the other hand, the residual clay from the syenite dike has not proved satisfactory as a fuller's earth; most of its clay is derived from feldspars and only a small part from hornblende.

The alteration of these dikes into clay has extended downward in one place at least to a depth of more than 200 feet, which is the vertical distance from a point on a hill slope to the end of a drift on the lowest level of one mine. The shaft of this mine is in a hollow and is but 160 feet deep. This is the deepest mine within this area and it is said that at this depth only two hard masses of dike rock were encountered. Yet on the same dike and about 500 feet from the shaft of this mine unaltered rock was encountered at a depth of 110 feet from the top of another shaft. In many dikes alteration into clay has extended to depths not exceeding 60 feet.

Here and there bowlders of the dike rock are found in the clay. Many of these and fragments that are blasted from the larger masses in the bottom of the mines have been brought to the surface and are practically the only source from which even fairly fresh specimens of the dike rock can be obtained. Even such specimens are more or less altered, as indicated by the descriptions of the rock sections on page 212. They almost invariably contain secondary calcite, which occupies small cracks and pockets

[1] Williams, J. F., The igneous rocks of Arkansas: Ann. Rept. Arkansas Geol. Survey, vol. 2, 1890, p. 3.

## CHARACTER OF SHALE NEAR DIKES.

The shale into which these dikes have been intruded has weathered into clay only at the surface. Even in contact with the clay of the altered dike it shows little if any decomposition. It still retains its black graphitic nature and is fairly hard. When it is exposed in either the hanging wall or the footwall of a mine for a period of a year or more, it becomes "rotten" in local parlance, the term being used to denote soft or falling slate. Evidences of metamorphism of the shale adjacent to the dikes are not apparent.

The shale, in its natural exposures in the vicinity of the dikes which have altered to clay to the greatest depth, falls to pieces with a dead sound when struck by the hammer, and in weathering into clay it first changes to a light yellowish and greenish shale which is extremely soft. The shale near the dikes which have altered to less depth is much harder and falls to pieces with a somewhat slaty ring when struck by a hammer. It is apparently more siliceous than the shale near the dikes which have decomposed to the greatest depth. This difference in the character of the shale probably has some connection with the conditions favorable to the alteration of the dikes into clay to a greater or less depth. The variation in the shale is shown within short distances and may be due to dissimilar lithologic character of the shale beds. It is best marked in the railroad cuts, where the soft shale occurs nearest the Tertiary border.

## CHARACTER OF CRUDE FULLER'S EARTH.

The fuller's earth of the deposits herein described is the residual clay of igneous dikes, and the clay retains the texture of the unaltered dike. If the original rock contained biotite, as in the biotite monchiquite and ouachitite, this mica, though it is rotten and discolored, is present in the clay. The color of the exposed clay and that near the surface is yellowish to reddish brown and that of the clay which is not near the surface is a light gray to light olive-green. The crude earth has about the same range of hardness as ordinary clay. In proximity to the unaltered rock, where it is less altered, it is harder. All of the Arkansas earth is decidedly plastic, but its plasticity decreases with increasing depth.

The clay is usually jointed. Slickensides are well developed along many of the joints and on the shale in both the hanging wall and footwall. The movement that produced them is believed to have taken place during the decomposition of the dike rock, though nothing was observed that would prove this point.

The minerals commonly found in the clay, besides the aluminum silicates, are calcite, quartz, chalcopyrite, pyrite, and limonite. In a few places the calcite occurs as thin veins which form a network in the clay similar to those in the hard rock. Here and there is quartz which is considered as being an inclusion in the dike rock. It is white and the fragments are usually small. In one mine a beautiful coating of iridescent chalcopyrite upon quartz was seen. Pyrite exists as minute crystals scattered through the clay in the deeper part of one mine. Limonite occurs only within 30 feet of the surface and forms a yellow coating along joints and in cavities and a stain in the clay. Chalybeate water is present in many of the mines and stains the clay where it comes into contact with it. These relations make it apparent that the present deeper water contains carbonic acid but no free oxygen and that the iron has largely been removed from the clay.

## PROSPECTING.

The dikes which have decomposed into clay are exposed only in railroad cuts and here and there in ditches by the roadside; their residual clay is often found in the mats of uprooted trees. If such exposures are not found, it is necessary to dig shallow trenches or prospect pits from 2 to 3 feet deep. The presence of a dike may be detected by the yellowish to reddish-brown color of its clay. The bright-red clay of this area is either Tertiary clay or residual from the "Ouachita" shale. Much of the residual dike clay, when dry, has the appearance of joint clay. In many of the fresher specimens of the clay, even near the surface, the original porphyritic texture of the dike is visible. Where the original rock contained biotite, mica is always present in the surface exposures. The clay that is residual from the shale and occurs on either side of the dike may readily be recognized if it still contains some of its carbonaceous matter or retains its shaly structure. As quartz veins are not everywhere present in the shale, quartz is not always found in the residual clay from it. On the other hand, the residual clay from the dikes is always comparatively free from quartz. In prospecting, it would be well to keep in mind that where the shale has a dead sound when struck with the hammer the dikes have probably altered to a greater depth than where the shale is more sonorous.

## MINING.

At the time of the writer's visit, during the summer of 1909 and fall of 1910, most of the mines were either abandoned or worked out and were filled with water. The following is the general plan of mining followed within the area:

A vertical shaft is sunk in the exposure of the dike or on the foot-wall side to a depth of about 60 feet. Drifts are then driven along the dike. If the bottom of the shaft at this depth is not within the dike, it is necessary to make a crosscut to reach it. As a rule the crosscuts are driven to the southeast, for the reason that most of the dikes dip in this direction. The drifts are driven with a grade sufficient to permit natural drainage to the sump at the bottom of the shaft. They are usually from 200 to 300 feet long, 3 feet wide, and 6 feet high. The overhand stope, 30 feet high, is mined out by retreating from the far end of the drift toward the shaft or crosscut. As the stope is begun an upraise is driven to the surface at the end of the drift or a shaft is sunk from the surface to the stope in order to provide natural ventilation. When the stope is mined out, the shaft is sunk 30 feet farther, and, if necessary, a crosscut is driven to the dike. Drifts are next run in the dike and the stope is mined out in the same way as on the first level. This process of forming levels 30 feet apart is continued until a grade of earth too hard to work or solid rock is encountered, the mine then being abandoned. A pillar is left near the shaft.

The stope in the best-managed mines is not mined within 30 feet of the surface for the following reasons: Within this depth the clay is highly plastic, stained along joints, and mottled with iron oxide, much more so than at greater depth, and therefore does not make as good an earth as that which is deeper and less plastic and is not iron stained. By thus leaving some of the clay at the outcrop, surface water is prevented from flowing into the mine. Moreover, this clay supports the soft decomposed walls near the surface.

The stope is mined only across the width of the dike, and where the dike becomes too narrow for a man to work, that part of the mine is abandoned. In the best-managed mines props are usually put in rows in the stope and wherever else may be necessary to prevent shale from falling. What little shale does fall is removed from the mines. The shafts are usually well cribbed, sets are put in at regular intervals in the crosscuts and drifts, and lagging is put on the sides wherever necessary and always overhead.

The clay is sufficiently soft to be easily dug with a pick. Digging is especially easy where there are many joints in the clay, but in a few places the calcite veins in the clay make it difficult. When the clay is loosened it rolls or falls down into the drift, where it is shoveled into iron buckets that hold about 300 pounds each. These buckets are taken to and from the shaft upon specially designed trucks which have high handles and run on planks. Hoisting engines are used mostly; horse whims rarely. In many places the drifts turn a few degrees to the right or left in the following dikes. Where the dikes practically pinch out, small "feeders" may continue in the direction of their strike. The miners say that these feeders may be found to widen out again if they are followed.

## MILLING.

The mined clay is stored in sheds at the mines. Thence it is hauled in a farm wagon or two-wheeled cart to the mill, where it is again stored in sheds long enough to become more or less dry. It is next fed into a machine which crushes it to pieces about 1 inch across. Thence it is run into iron cylinders, where it is almost completely dried by hot air or a steam jacket. After drying, the earth is broken finer, then pulverized, and elevated into bolting reels such as are used in flour mills. In one mill reels are not used, but the fine earth is drawn off from the coarser material by an air current produced by a suction fan. At some plants the finished product is not coarser than 80-mesh; at others earth not coarser than 120-mesh is produced. After sizing, the earth is fed into sacks which contain from 225 to 400 pounds each. It is then ready for market.

Most of the earth is free from mica. Clay with a considerable amount of mica is not used, for the reason that the mica clogs the bolting cloth and is a waste product. Moreover, it is not known that the mica benefits the earth by possessing any desirable properties. Every dike of clay can not by itself be manufactured into a good earth. It is sometimes necessary to mix, in definite proportions, clay from two dikes of unlike texture and somewhat different composition in order to prepare an earth of marketable grade. The required proportions for mixing, when mixing is necessary, and the exact method of treatment in the manufacture are known to none except those of long experience in mining and milling the Arkansas earth. Because of the lack of this knowledge, much Arkansas earth that has been put on the market has proved unsatisfactory.

## OUTLOOK FOR THE INDUSTRY.

The area containing the deposits here described is near the center of the Arkansas region of igneous intrusions, on the east border of the area in which rocks of Paleozoic age are exposed. With the exception of those within the large masses of igneous rocks, no dikes are exposed outside of the Paleozoic area. None are known within the area of Tertiary rocks. Hence the prospecting of dikes for fuller's earth must necessarily be carried on within the Paleozoic area.

Igneous dikes are reported as far west as Crystal Springs, Montgomery County. Williams and Kemp[1] describe 280 dikes, and this number probably represents only a small portion of the dikes within the State, for the reason that the exposures of the dikes are not numerous over much of the area of intrusions, and again only small areas were carefully mapped for their report. Of this number but 11

[1] Williams, J. F., and Kemp, J. F., Ann. Rept. Arkansas Geol. Survey, 1890, vol. 2, pp. 407-427.

that are more than 1 foot thick are mentioned as being completely altered into clay, and it is only these 11 of the 280 that may possibly be mined for the production of fuller's earth. At least three of the 11 contain mica, which if present in large amount is objectionable in the milling of fuller's earth. The depth of the residual clay of these 11 dikes is not known, and it is likely that the clay of most of them does not extend downward more than a few feet.

During the progress of the field work in the Hot Springs area for folio publication by the United States Geological Survey, about 100 dikes, not previously reported by the Geological Survey of Arkansas, were discovered by the writer. Of this number nine are 2 feet or more in width and are completely altered into clay at the surface. It is not known to what depth the clay extends.

The dikes mentioned above do not include those of the area discussed in this paper. Hence it is possible that new deposits of fuller's earth will be discovered at places other than those where it is now mined. It is believed that all the difficulties now experienced in obtaining marketable earth will be encountered in developing new deposits.

## USES AND MARKETS.

The Arkansas earth is used for bleaching cottonseed oil, hog leaf lard, beef tallow, and stearine. When the right kind of crude earth and the proper method of manufacture are used, a satisfactory earth is produced. Yet because of lack of experience in this industry some poor grades of earth have been put on the market. The production of this inferior earth has retarded to some extent the introduction of the Arkansas earth to displace the English earth, which is used mainly by American cotton-oil companies and packers.

The Arkansas earth is not used in refining petroleum. It is said that tests with petroleum have been made and that they were not successful.

The principal markets are St. Louis, Kansas City, Chicago, and southern cities.

## PRODUCTION.

Arkansas was the second largest producer of fuller's earth in the United States from 1904 to 1907, Florida being first in amount of production. During 1909, 1910, and 1911 Arkansas was third in output and value, Florida being in first place and Georgia second.

The amount of fuller's earth produced in Arkansas in 1909 was 2,314 short tons, valued at $18,313; in 1910 it was 2,563 short tons, valued at $29,137.

## BIBLIOGRAPHY.

ALDEN, W. C., Fuller's earth and brick clays near Clinton, Mass.: Bull. U. S. Geol. Survey No. 430, 1910, pp. 402–404.

BRANNER, J. C., Cement materials of southwest Arkansas (contains analysis of fuller's earth from Alexander, Ark.): Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 42–63.

CALIFORNIA STATE MINING BUREAU, Fuller's earth: Bull. 38, 1906, pp. 273–275.

CAMERON, A. C. G. (of British Geological Survey), Geology, mining, and economic uses of fuller's earth: Fed. Inst. Min. Eng., Sept., 1893.

DANA, E. S., System of mineralogy, 1892, p. 695.

DANA, J. D., Manual of geology, 1895, p. 775.

GEIKIE, ARCHIBALD, Textbook of geology, 1893, p. 168; idem, 1903, vol. 2, pp. 1131, 1138, 1140.

GILPIN, J. E., and BRANSKY, O. E., The diffusion of crude petroleum through fuller's earth, with notes on its geologic significance: Bull. U. S. Geol. Survey No. 475, 1911, 50 pp.

MERRILL, G. P., Guide to the study of the collections in the section of applied geology—the nonmetallic minerals: Rept. U. S. Nat. Mus., 1899, pp. 337–339.

——— The nonmetallic minerals, New York, John Wiley & Sons, 1904, pp. 248–250.

MIDDLETON, JEFFERSON, Production of fuller's earth: Mineral Resources U. S. for 1911, pt. 2, U. S. Geol. Survey, 1912, pp. 1031–1035.

PORTER, J. T., Properties and tests of fuller's earth: Bull. U. S. Geol. Survey No. 315, 1907, pp. 268–290.

RIES, HEINRICH, [Fuller's earth]: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3 (cont.), 1896, pp. 876–880.

——— Fuller's earth of South Dakota: Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 333–335.

——— Fuller's earth [in England]: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, pp. 408–411.

——— Fuller's earth: Bull. New York State Mus. No. 35, 1900, pp. 848–851.

——— Fuller's earth: Clays, their occurrence, properties, and uses, New York, John Wiley & Sons, 1906, pp. 460–467.

SLOAN, EARLE, Preliminary report on clays of South Carolina, South Carolina Geol. Survey, 1904, pp. 59–61.

VAN HORN, F. B., Fuller's earth: Mineral Resources U. S. for 1907, pt. 2, U. S. Geol. Survey, 1908, pp. 731–734.

——— Fuller's earth: Mineral Resources U. S. for 1909, pt. 2, U. S. Geol. Survey, 1911, pp. 735–738.

VAUGHAN, T. W., Fuller's earth of southwestern Georgia and western Florida: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, pp. 922–934.

——— Fuller's earth of Florida and Georgia: Bull. U. S. Geol. Survey No. 213, 1903, pp. 392–399.

Mineral Resources of the United States for 1900, U. S. Geol. Survey, 1901, pp. 893–894.

Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5 (cont.), 1897, pp. 1351–1359.

Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, pp. 655–656.

Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1901, pp. 589–592.

# GYPSUM ALONG THE WEST FLANK OF THE SAN RAFAEL SWELL, UTAH.

By Charles T. Lupton.

## INTRODUCTION.

The San Rafael Swell, along the west flank of which outcrop the gypsum deposits here described, is an irregular, somewhat elliptical dome extending northeast and southwest in the east-central part of Utah, east of the Wasatch Plateau and west of Green River. (See Pl. V.) In 1911, while making an examination of the coal along the eastern edge of Castle Valley, which occupies a position low on the west slope of the Swell, the writer crossed the western flank of this uplift nearly to the center at several places. The south end of the dome and the north end of the Water Pocket Flexure also were visited in a reconnaissance way and the deposits of gypsum noted. Notes taken on these reconnaissance trips form the basis of this report.

The greater part of the San Rafael Swell has not been sectionized by the General Land Office. It is therefore impracticable to locate many of the deposits definitely. The accompanying map (Pl. V) is a copy of a portion of the General Land Office map of Utah, with the approximate locations of the outcrop and points where the gypsum beds were noted and examined. The numbers on the map along the lines showing the gypsum outcrop represent localities where the gypsum was examined. These exposures are discussed in order from north to south.

So far as the writer is aware, nothing regarding the gypsum of the San Rafael Swell has before been published.

## GEOGRAPHY.

### LOCATION AND EXTENT.

The San Rafael Swell is 60 to 80 miles long and 20 to 30 miles wide. It occupies the greater part of the area represented by the northwest quarter of the Geological Survey's San Rafael topographic sheet and lies between meridians 110° 15′ and 111° 15′ and parallels 38° 15′ and 39° 15′. The gypsum-bearing rocks in the area under discussion outcrop in a belt ranging in width from a few hundred feet in the vicinity of Cedar Mountain or Red Plateau, at the north end of the area, to 3 or 4 miles near the center of the west flank, along the road leading from Emery eastward to the Globe copper mine.

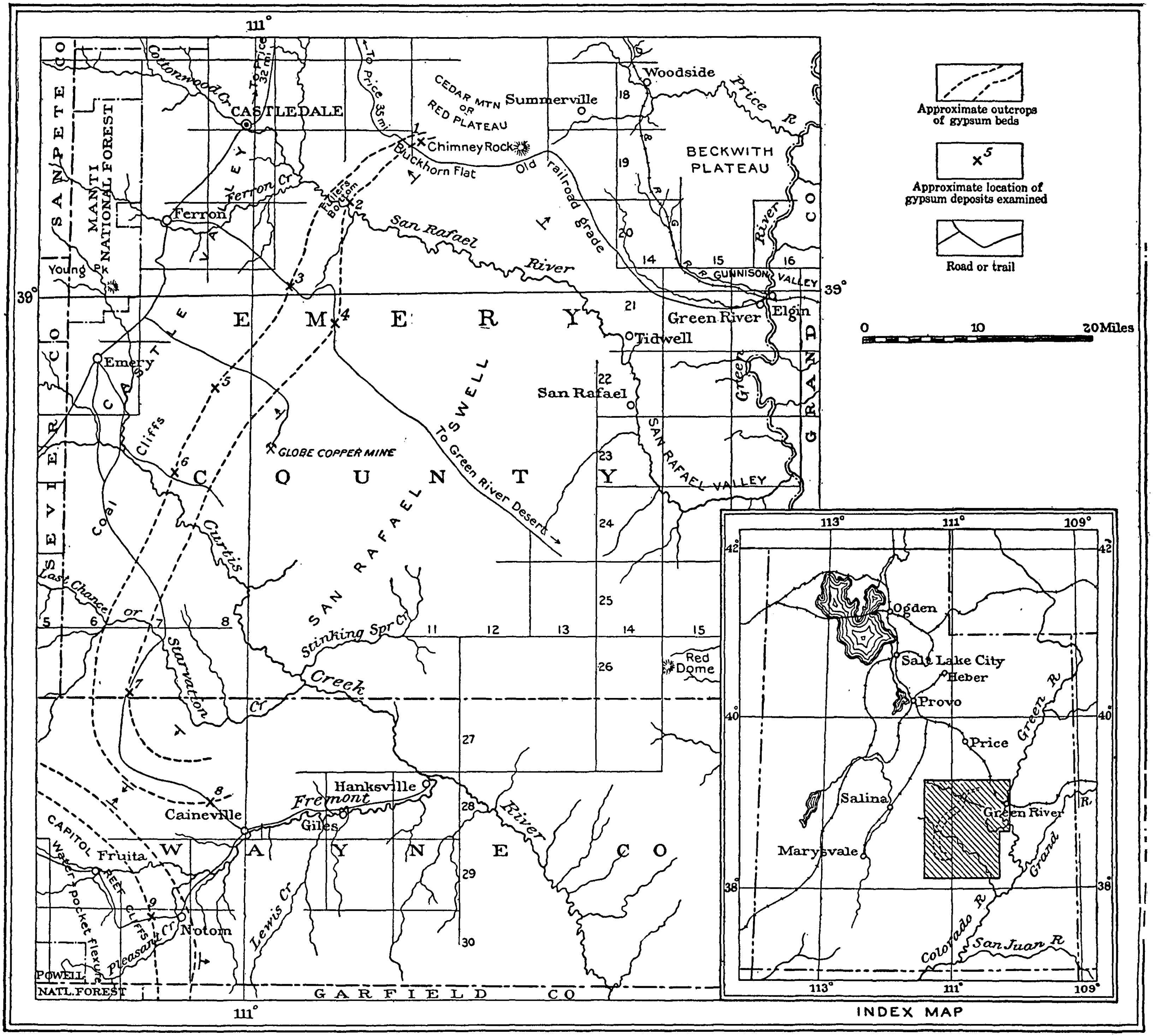
## ACCESSIBILITY.

The gypsum exposures can be most easily visited by leaving the Denver & Rio Grande Railroad at Price, from which a daily stage traverses approximately the entire length of Castle Valley to Emery, 63 miles to the southwest. At any of the towns between Price and Emery (Cleveland, Huntington, Castle Dale, and Ferron) conveyances may be obtained for a trip to the gypsum beds, which outcrop several miles to the east. Probably the most convenient point from which to visit the gypsum-bearing rocks is Cleveland, about 6 miles east of Huntington. A good road leads from Cleveland in a southeast direction to Buckhorn Flat, located directly south of Cedar Mountain or Red Plateau. At the east side of Buckhorn Flat the gypsum beds have been prospected and are reported to be well exposed. From Castle Dale one must follow eastward the course of Cottonwood Creek and San Rafael River. As the trail along the valleys of the streams is very poor, travel by horseback is advised. A fairly good wagon road leads from Ferron, through Molen, by way of Horn Silver Gulch, to the outcrop of the gypsum-bearing rocks about 10 miles to the southeast, in Horn Silver Gulch and Cold Wash. A good road has been built from Emery eastward across the outcrop of the gypsum to some copper prospects, known as the Globe copper mine, on the west flank of the Swell. Next to the wagon road leading from Cleveland to Buckhorn Flat, this road would be the best one over which to haul the gypsum should it be mined. From Emery another road 18 miles long has been built southeastward to a possible oil field on the north side of Muddy Creek and crosses the gypsum exposures.

Travel by rail may be terminated also at Salina, on the Rio Grande Western Railway, on the west side of the Wasatch Plateau, where conveyance can be obtained across this plateau to Emery, in Castle Valley. The gypsum exposures situated near the south end of the Swell in the vicinity of Caineville, and also those near the north end of the Water Pocket Flexure, near Notom post office, can be visited most easily by taking the stage from Salina to Loa, in Rabbit Valley, where conveyance can be obtained for the trip down Fremont River to Notom and Caineville.

## CLIMATE.

The climate of the San Rafael Swell is semiarid. A summary of the United States Weather Bureau records shows that the average annual rainfall is scanty, being about 7 inches. The excellent exposures of all the strata noted along the west flank of the San Rafael Swell are undoubtedly due to this semiarid climate.




MAP SHOWING DISTRIBUTION OF GYPSUM DEPOSITS ON THE WEST FLANK OF THE SAN RAFAEL SWELL, UTAH.

## TOPOGRAPHY.

The topography of the area under discussion is especially rugged. Forms cut from massive sandstone, approximately 800 feet thick, underlying the gypsum-bearing formation and outcropping east of it, are the most striking features of the topography in this region. The outcrop of the sandstone has been eroded into peculiar mesas and buttelike forms, which in places suggest castles. To these buttes and mesas Castle Valley undoubtedly owes its name. In many places the walls of these mesas, buttes, and scarps are almost vertical cliffs 300 feet or more high. The outcrop of this sandstone surrounds the central part of the Swell, which is locally known as Sinbad. The topography of the areas of gypsum-bearing rocks is in most places comparatively smooth, except along the streams, where badlands are common. The harder strata on the west flank of the Swell form the tops of "steps," and the softer strata the "risers" between them. The topography is of this character as far as the top of the Wasatch Plateau, the "steps" becoming higher as the plateau is approached. Taken as a whole, the topography of the San Rafael Swell is of badland character.

## GEOLOGY.

The gypsum-bearing rocks are of Upper Jurassic age and are the approximate equivalent of the Flaming Gorge formation of Powell.[1] They rest with apparent conformity on a massive cross-bedded sandstone, which is the Gray Cliff sandstone of Gilbert's Henry Mountains section, regarded as the same as the White Cliff sandstone (Upper Jurassic) of southern Utah and the Uinta Mountains. There are about 1,350 feet of strata, mainly reddish in color, with two gypsum-bearing zones, one 200 feet below the top and the other 200 feet above the base. Between the two gypsum zones there is a series of red and gray sandstone and sandy shale about 950 feet thick. The beds thus described correspond closely with the Flaming Gorge formation described by Gilbert [2] as occurring in the Henry Mountains region, a comparatively short distance south of the San Rafael Swell, where he determined the thickness to be approximately 1,200 feet.

Above these rocks lie 500 feet of conglomerate, sandstone, and sandy shale, greenish drab in color, which apparently corresponds to the larger part of the Henrys Fork formation as identified by Gilbert in the Henry Mountains but which probably should be classified with the Flaming Gorge formation of Powell. Overlying this conglomeratic member, with possible unconformity, is a sandstone that is thought to be the Dakota sandstone.

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto: U. S. Geol. and Geog. Survey Terr., 2d div., 1876, pp. 40, 50, 51, 68, 92, 146, 151-153, 157.

[2] Gilbert, G. K., Geology of the Henry Mountains, Utah: U. S. Geol. and Geog. Survey of the Rocky Mountain Region, 1877, p. 6.

The strata along the west flank of the Swell dip from 3° to 8° NW., but the strata along the east flank are in places much more steeply inclined, ranging from almost flat to approximately 70° SE.

## THE GYPSUM.

### GENERAL FEATURES OF OCCURRENCE.

The gypsum of this area, according to the classification of Hess,[1] belongs to his third group, "interbedded deposits," which were precipitated in a shallow sea into which a large amount of sediment was carried, especially at the beginning and end of the gypsum-forming period. The greater part of the deposits take the form of alabaster. The gypsum of the upper zone has a reddish tint and is not quite so pure as the lower deposits, which are white. The gypsum of both zones is so compact and firm that it can be readily carved. The upper and lower portions of both gypsum belts in most places contain considerable sandstone and sandy shale interbedded with the gypsum. These impure portions probably will never be of value for mining, considering the large amount of pure gypsum in the main parts of the beds.

At several places near the outcrop of the gypsum beds the overlying strata are contorted and deformed. This is probably due to the removal of portions of the underlying gypsum in solution by ground water, and the consequent sinking of the covering strata. The lower beds are purer and thicker than the upper. Sections of the exposures examined, given below in the discussion of the gypsum at the different localities, illustrate this point. Very little selenite or crystalline gypsum was noted.

In most places the upper gypsum bed outcrops in the face of cliffs. This position is due to the character of the overlying and underlying rocks, which are in most places fairly resistant sandstone. The lower beds containing gypsum usually outcrop in a monoclinal valley in a broad belt, which corresponds closely to a true dip slope. The rocks that underlie the gypsum are harder than those stratigraphically above it, and, as the gypsum is comparatively soft, it is eroded with the softer sandstone shales. East of Emery, along the Globe Copper mine road, the lower gypsum bed outcrops for more than a mile on one of these dip slopes.

[1] Hess, F. L. A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910, pp. 7-8.

## DETAILED DESCRIPTION OF LOCALITIES.

### SOUTH OF CEDAR MOUNTAIN.

A gypsum prospect directly south of Cedar Mountain or Red Plateau, at locality No. 1 (see Pl. V), near an unused roadbed of the Denver & Rio Grande Railroad, in the NW. ¼ SW. ¼ sec. 6, T. 19 S., R. 11 E., Salt Lake meridian, has a single opening, a pit about 8 feet deep and 8 feet in diameter. Only unconsolidated conglomerate was to be seen in this pit, on account of caving. On the dump was a large amount of grayish-green sandy shale and some pieces of glistening porous gypsum. It is reported by Parlan McFarlane, of Cleveland, Utah, that the gypsum is at least 30 feet thick and that a number of claims have been staked and recorded in this locality. From the stratigraphic position of the prospect pit this is the lower gypsum horizon. It is quite probable that when the mining of gypsum is begun in the San Rafael region the first shipment will be made from this locality, as there is a fairly good road leading through Cleveland to the railroad at Price and also a fair road leading to Green River on the railroad to the southeast. The gypsum can be mined and moved to the railroad from this place at probably a smaller cost than from any other locality hereinafter described.

### SAN RAFAEL VALLEY.

On the north side of San Rafael River, at the east end of Fullers Bottom, at locality No. 2 (see Pl. V), the lower gypsum-bearing zone was examined and the following section was measured:

*Section of gypsum-bearing rocks at the east end of Fullers Bottom along San Rafael River, Utah.*

| | Feet. |
|---|---|
| Sandstone, grayish, thin bedded, locally has a greenish tint. In many places these strata are much contorted and the strata at the outcrop have a wavy appearance | 50+ |
| Gypsum, fairly pure, becoming less pure at top and base | 30–35 |
| Sandstone, reddish, contains thin veins of gypsum | 10 |
| Gypsum, very pure | 7 |
| Sandstone, reddish, contains thin veins of gypsum | 5 |
| Sandstone, thin bedded, greenish gray | 12–15 |
| Total gypsum | 37–42 |

The route from Castle Dale to this locality is down Cottonwood Creek and San Rafael River. The trip is easily made on horseback, but for wagon or buggy the road is very poor. A good road for the removal of the gypsum from this place could probably best be made along the strike of the rocks to the north and northeast, through Buckhorn Flat to the main road leading from Cleveland to Green River, Utah, which follows closely the old grade of the Denver & Rio Grande Railroad.

A sample of gypsum taken near the center of the upper bench at this locality was analyzed by J. G. Fairchild in the United States Geological Survey chemical laboratory, with the following result:

*Partial analysis of gypsum from east end of Fullers Bottom along San Rafael River, Utah (No. 2).*

| | |
|---|---|
| Lime (CaO) | 32.47 |
| Sulphur trioxide ($SO_3$) | 45.63 |
| Water driven off at 300° C. | 20.54 |
| Chlorine (Cl) | .32 |
| Iron oxide ($Fe_2O_3$) | Trace. |

This analysis shows an equivalent of 97.3 per cent of gypsum. Practically no anhydrite is present. The percentages of lime, sulphur trioxide, and water given in the analysis approach very closely those of pure gypsum, which contains 32.6 per cent of lime, 46.5 per cent of sulphur trioxide, and 20.9 per cent of water. A striking characteristic of this gypsum is the unusually large amount of chlorine it contains, which is about 10 times greater than that in the gypsum from Alabaster, Mich. (See table of analyses, p. 230.)

## HORN SILVER GULCH.

In Horn Silver Gulch (No. 3, Pl. V), approximately 10 miles southeast of Ferron along the wagon road leading from Ferron to Green River Desert, the upper gypsum-bearing rocks are well exposed. The thickness of the only bed of gypsum noted in this immediate region was measured across an outcrop on the south side of the gulch. As noted in the general discussion of the gypsum, this bed has a slightly reddish tint and is much thinner than the beds at the lower horizon. The following section shows the character of the overlying and underlying rocks as well as the thickness of the gypsum at this place.

*Section of gypsum-bearing rocks in Horn Silver Gulch about 10 miles southeast of Ferron, Utah.*

| | Feet. |
|---|---|
| Sand and clay, gray, fine grained; sandstone, conglomeratic at top | 14 |
| Sandstone, yellowish gray to brown; upper 1½ feet very hard and forms a ledge | 4 |
| Gypsum, very slightly reddish, comparatively pure; contains nodules of variegated chert | 11 |
| Sandstone and sandy shale, in places ripple marked, thin bedded; some very resistant beds 2 to 3 feet thick; mainly reddish in color with a few thin bands and streaks of greenish-gray fine-grained sandstone (base unexposed) | 210 |
| Total gypsum | 11 |

A sample of the gypsum near the center of the bed was analyzed by J. G. Fairchild in the United States Geological Survey chemical laboratory as follows:

*Analysis of gypsum from Horn Silver Gulch 10 miles southeast of Ferron, Utah (No. 3).*

| | |
|---|---|
| Lime (CaO) | 32.49 |
| Sulphur trioxide ($SO_3$) | 45.88 |
| Water driven off at 300° C | 20.58 |
| Chlorine (Cl) | .39 |
| Iron oxide ($Fe_2O_3$) | Trace. |

This analysis shows an equivalent of 97.9 per cent of gypsum. Practically no anhydrite is present. The chlorine content is slightly more than that of the sample collected at locality No. 2 along San Rafael River.

The outcrop of this bed of gypsum is near the road connecting Ferron with Green River Desert. To take out the gypsum, however, it would be necessary to make a much better road than exists at present. A fair road leading in a direction north slightly east from a point near this locality and extending practically the entire length of Castle Valley could be used in moving the mined product to the railroad.

## COLD WASH.

In Cold Wash (No. 4, Pl. V), 20 miles east of Emery, gypsum which belongs to the lower horizon outcrops along the road from Ferron to the Green River Desert. A detailed section measured a short distance northwest of Dripping Spring, on the west side of Cold Wash, is as follows:

*Section of gypsum-bearing rocks on Cold Wash about 20 miles east of Emery, Utah.*

| | Feet. |
|---|---|
| Sandstone, thin bedded, grayish in places, tints of red and green. | 50+ |
| Gypsum | 35+ |
| Sandstone, greenish gray, thin bedded | 60± |
| Shale and sandstone, reddish, thin bedded | 18 |
| Sandstone, yellowish brown, thin bedded | 15 |
| Sandstone, yellowish brown, massive | 10 |
| Sandstone, maroon and yellowish buff, thin bedded | 15 |
| Total gypsum | 35+ |

In many places it is impossible to obtain an accurate measurement of the gypsum on account of its soluble character, the ground waters having dissolved part of the bed. At the locality above mentioned conditions were such that it was impossible to determine whether the total thickness of the gypsum was seen.

Dripping Spring issues from thin-bedded sandstone about 40 feet below the base of the gypsum bed and naturally it carries a great amount of gypsum. The water, which is cold, has a bitter taste that is emphasized when the water is heated. The bitterness possibly is due to the presence of epsomite, the sulphate of magnesium.

### COLT GULCH.

About 8 miles east of Emery, in an intermittent stream course known locally as Colt Gulch (No. 5, Pl. V), the following section of the upper gypsum rocks was measured:

*Section of gypsum-bearing rocks in Colt Gulch, about 8 miles east of Emery, Utah.*

| | Ft. | in. |
|---|---|---|
| Conglomerate, gray, fine grained; pebbles consist of chert and limestone, ranging from sand grains up to pebbles 3 inches in diameter; contains a few lenses of soft friable sandstone | 8± | |
| Sandstone, gray | 4 | |
| Gypsum, sandstone, and limestone, with some red, gray, and white sandy shale | 16 | 6 |
| Gypsum, pinkish, impure, and very shaly at base, fairly pure at top; contains chert fragments. (This portion of the bed probably corresponds with the section measured at locality No. 3 in Horn Silver Gulch) | 22 | |
| Shale, salmon red, in places greenish gray | 10 | 4 |
| Gypsum, almost pure white | 10 | |
| Shale, reddish, sandy | 1 | 3 |
| Gypsum, somewhat impure | 4 | |
| Clay shale, sandy, salmon-red | 11 | |
| Total gypsum | 36 | |

The above section was measured on the south side of Colt Gulch. There is no good road or trail leading into this gulch, and to take out the gypsum considerable expense for a road would be necessary. This section shows that there is much more gypsum here than in the section measured 8 or 10 miles to the northeast, in Horn Silver Gulch.

### MUDDY CREEK.

On the west side of Salt Wash, north of Muddy Creek (No. 6, Pl. V), 15 miles southeast of Emery and 6 to 8 miles south-southwest of Colt Gulch, a detailed section of the upper gypsum rocks was measured as follows:

*Section of gypsum-bearing rocks on the west side of Salt Wash, north of Muddy Creek, about 15 miles southeast of Emery, Utah.*

| | Feet. |
|---|---|
| Conglomerate | 5 |
| Gypsum; in places has a slightly reddish tint | 52 |
| Shale, interbedded with gray sandstone | 29 |
| Total gypsum | 52 |

It is quite probable that the gypsum shown in the above section may contain sandstone and shale partings, and portions of the bed may be somewhat impure, as the exposure was not good. The gypsum from this locality can be shipped with little difficulty, as an excellent road has been graded from Emery to a point a short distance east of the outcrop. At this locality the road, which follows an approximate dip slope of the strata, is on the gypsum for at least half a mile. Considerable deposits of quartz and gypsum sands cover the surface near the outcrop.

### LAST CHANCE CREEK.

Very little is known regarding the details of the gypsum beds for a distance of 15 to 18 miles to the south from the locality last described. Sections of the gypsum were not measured, but the presence of the upper zone is assured by the "float" and the character of the water in Last Chance Creek where it is crossed by the wagon trail connecting Caineville and Emery, which is stratigraphically above the lower gypsum horizon. The water of this creek is so thoroughly saturated with gypsum and possibly some epsomite that it is practically unfit for the use of man or beast. A few miles south of Last Chance Creek, also known as Starvation Creek (No. 7, Pl. V) a piece of gypsum "float" from the lower horizon was found near the Caineville-Emery wagon trail. The main bed was not seen, but the undulating, contorted character of the strata at this place suggested that as much gypsum lies a short distance beneath the surface as that measured at the exposure on San Rafael River (No. 2). A number of igneous sills and dikes were noted here and some of the pieces of gypsum suggest that it had been slightly metamorphosed by the heat from these intrusions.

### CAINEVILLE.

About 3 miles northwest of Caineville post office, approximately in the center of T. 28 S., R. 8 E., Salt Lake meridian (No. 8, Pl. V), the upper gypsum bed was observed outcropping for 2 miles along the canyon through which the Caineville-Emery wagon trail extends. The bed was not measured in detail, but is approximately 8 feet thick and seemed to be very pure.

### NOTOM.

Along the east flank of the Water Pocket Flexure, near the north side of T. 30 S., R. 7 E., Salt Lake meridian, about 2 miles west of Notom post office (No. 9, Pl. V), a bed of gypsum undoubtedly representing the lower horizon is exposed near the wagon road extending from Fruita to Notom. This outcrop, the exact thickness of which was not measured, is about 75 feet stratigraphically above the massive cross-bedded sandstone to which Gilbert applied the name Gray Cliff. Although the horizon of the upper gypsum bed was crossed in the vicinity of Notom it was not seen at any place. It is probably present, however, as it outcrops a few miles to the north in the vicinity of Caineville.

### OTHER EXPOSURES.

Along the road leading from Emery eastward to the Globe Copper mine both gypsum horizons were noted. The upper or pinkish bed has apparently the same thickness as that noted in Horn Silver Gulch (No. 3). It was impossible to obtain a measurement of the lower bed, as it outcrops on an approximate dip slope for a distance of more than a mile. Gypsum deposits were not observed elsewhere along the west flank of the Swell, but the writer believes that the beds of both horizons are continuous from the north to the south end of the Swell and that they may some day be valuable should transportation become less expensive.

### CHARACTER OF THE GYPSUM.

The gypsum of both horizons is comparatively pure. The lower bed, however, probably contains less impurity than the upper. The upper bed, in addition to the slight discoloration, contains numerous small chert nodules of various colors. These undoubtedly would cause some difficulty in the preparation of the gypsum for plaster of Paris. The lower deposits contain very little chert and are almost white. From these deposits gypsum which would make white plaster could probably be obtained. Certain portions of the upper pinkish bed, which is compact and fine grained, might be used as alabaster, giving a varied effect from the pure white. The lower bed could also be used in this way, as it is apparently as solid as the upper bed. The two analyses taken in this area, together with the analysis of gypsum from other localities in the United States, are given below in tabular form in order to compare the gypsum of this with other fields.

*Partial analyses of gypsum from the San Rafael Swell, Utah, compared with those from other parts of the United States.*

| Locality. | Percentage of gypsum. | CaO. | $SO_3$. | $H_2O$ driven off at 300°C. | Cl. | $Fe_2O_3$. | Analyst. |
|---|---|---|---|---|---|---|---|
| Near Palmdale, Cal. [a] | 72.1 | 27.5 | 33.5 | 15.6 | Trace. | 1.3 | George Steiger. |
| Kern County, Cal. [b] | 79.5 | 28.76 | 37.06 | 17.3 | Trace. | .71 | Do. |
| Alabaster, Mich. [c] | 99.3 | 32.33 | 46.18 | 20.96 | .03 | .08 | Do. |
| Black Hills, S. Dak. [c] | 97.7 | 32.44 | 45.45 | 20.80 | | | Do. |
| Nephi, Utah [c] | ([d]) | 35.29 | 48.14 | 15.88 | Trace. | | E. T. Allen. |
| Fullers Bottom, Utah (No. 2, present report) | 97.3 | 32.47 | 45.63 | 20.54 | .32 | Trace. | J. G. Fairchild. |
| Horn Silver Gulch, Utah (No. 3, present report) | 97.9 | 32.49 | 45.88 | 20.58 | .39 | Trace. | Do. |

[a] Hess, F. L., A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910, p. 30.
[b] Hess, F. L., Gypsum deposits near Cane Springs, Kern County, Cal.: Bull. U. S. Geol. Survey No. 430, 1909, p. 418.
[c] Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 220 (analyses B, C, and D.
[d] Probably contains anhydrite.

## DEVELOPMENT.

So far as is known to the writer no gypsum is now being mined in the San Rafael Swell region. Except at the prospects south of Cedar Mountain or Red Plateau, described above under locality No. 1, the gypsum of this district has not been prospected. On account of the excellent natural exposures, however, prospecting is unnecessary, as in most places the entire thickness of the beds is well exposed. It is possible that small quantities of gypsum have been used by ranchers and others desiring plaster of Paris or land plaster, but the quantity removed from the field is insignificant. From the description given it is evident that the San Rafael Swell contains an enormous supply of gypsum, but probably no great quantity will be mined until better transportation facilities are available. It would be a comparatively easy matter to extend a railroad spur from either Green River or Price to these gypsum-bearing rocks. A railroad grade has been made through the northern part of the San Rafael region connecting Green River with Price, and although the road has never been used it could be repaired with little labor and expense. As this grade crosses the gypsum beds in T. 19 S., R. 10 E., and as the gypsum-bearing rocks occupy a monoclinal valley, a railroad spur could be very easily projected through the center of the gypsum belt for its entire length. The raw product then could be mined and transported cheaply. Such a railroad would probably induce coal mining in the Cretaceous beds east and south of Emery along Muddy Creek and its tributaries.

Gypsum of the massive variety has a specific gravity of approximately 2.32. This is equivalent to about 145 pounds to the cubic foot. The following estimates are based on the considerations that the gypsum could be mined under cover to a distance of 2 miles from the outcrop, which, with the dip of 3° to 5°, would carry the bed about 800 feet below the surface, and that the gypsum-bearing beds are 60 miles in length on the west flank of the Swell. To be conservative the upper bed is assumed to average 10 feet in thickness, and the lower beds to contain an average of 30 feet of gypsum. These assumed thicknesses probably represent 25 to 50 per cent less than the true average. On this basis the beds of gypsum on the west flank of the San Rafael Swell are estimated to contain 9,701,600,000 tons—2,425,400,000 tons in the upper bed and 7,276,200,000 tons in the lower bed.

# GEOLOGY OF THE SALT AND GYPSUM DEPOSITS OF SOUTHWESTERN VIRGINIA.

By George W. Stose.

## LOCATION.

Large deposits of salt and gypsum are known to occur along a belt of country 20 miles long running northeastward from the village of Plasterco, Va., and lying in Washington and Smyth counties. Much of this territory is in or near the valley of the North Fork of Holston River, and this portion is made accessible to railroad trans-

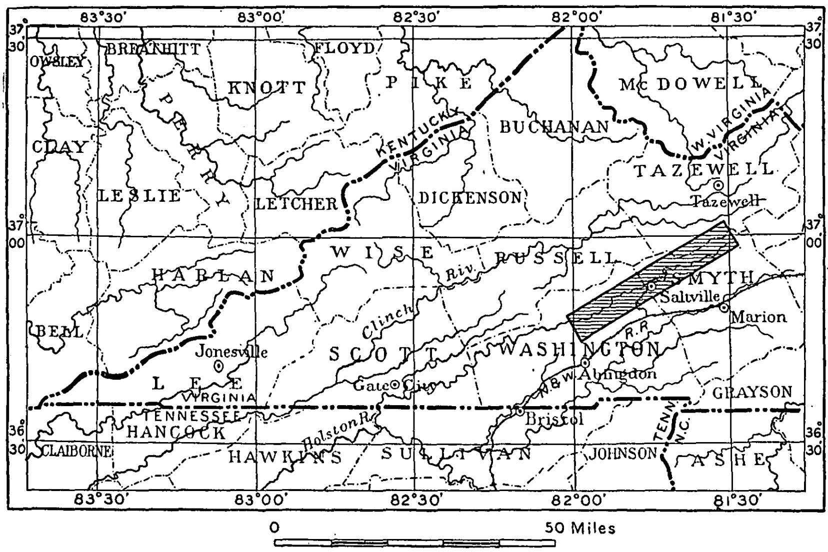



Figure 27.—Index map of southwestern Virginia. The area described and mapped in this report is indicated by the shaded rectangle. Railroad connections for this area only are shown.

portation by the Saltville branch of the Norfolk & Western Railway, which joins the main line at Glade Spring. The location and relations of this area are shown in figure 27. Two gypsum plants and one salt or alkali works are now in operation in this area. Numerous old gypsum workings and prospects indicate the extent of the deposits, some of which are at present not commercially workable because of lack of transportation facilities. The active mines, old workings, and prospects are shown on the geologic map in figure 28.

## TOPOGRAPHY.

The area represented on the accompanying map (fig. 28) comprises a mountain ridge 1,000 feet high separating parallel valleys and rising above an adjacent deeply dissected plateau. The ridge, named Pine Mountain at the southwest and Brushy Mountain at the northeast, trends in a general N. 70° E. direction and its elevation ranges from 2,500 to 3,000 feet. It is cut nearly at right angles by several deep water gaps through which pass the waters from Clinch Mountain that drain into the North Fork of Holston River. This stream flows southwestward, in general hugging the foot of Pine Mountain, and its valley descends from an altitude of 2,000 feet at the northeast to 1,500 feet in the southwestern part of the area. The plateau to the southeast ranges from 2,000 to 2,500 feet in altitude and its surface is dissected into narrow transverse ridges and rounded hills.

## GEOLOGY.

### STRATIGRAPHY.

The rocks in which the deposits occur are of Mississippian ("Lower Carboniferous") age. A generalized section of the Carboniferous rocks derived from several detailed sections in the vicinity of the mines is as follows:

*Generalized section of Carboniferous rocks in the vicinity of Saltville, Va.*

| | Feet. |
|---|---|
| Newman limestone: | |
| Hard argillaceous limestone or calcareous shale, with a few beds of crystalline limestone | 800+ |
| Red calcareous sandstone and coarse crinoidal limestone, with some beds of argillaceous limestone | 75 |
| Light-blue argillaceous limestone and calcareous shale, with a few thicker pure fossiliferous limestones | 1,100 |
| Largely thick even-grained blue fossiliferous limestone, with some beds of crystalline fossiliferous limestone, argillaceous limestone, and calcareous shale; hard bed of conglomerate of limestone and shale fragments near middle | 1,350 |
| | 3,325+ |
| Maccrady formation: | |
| Earthy limestone and shale, dark gray, weathering lighter and crumbly, abundantly fossiliferous | 470± |
| Gray sandstone, mostly calcareous and crumbly, and shaly argillaceous or earthy limestone; fossiliferous at the top | 240 |
| Soft rocks, including shaly limestone and probably earthy sandstone and red shale, largely concealed | 225 |
| Upper part red shale and shaly sandstone, with some gray shaly sandstone; lower part soft light-buff shale, with thin black carbonaceous shale and coal seamlets | 90 |
| | 1,025± |

| | Feet. |
|---|---|
| Price sandstone: | |
| Hard irregular-bedded rusty-gray sandstone, with some heavier beds | 150–165 |
| Largely shaly sandstone, with a few harder beds | 150–205 |
| Massive gray to reddish-gray sandstone, thin bedded toward top, and fine conglomerate with scattered white quartz pebbles generally at base | 27– 54 |
| | 327–424 |
| Devonian rocks: | |
| Thin-bedded sandstone and sandy shale containing brachiopods of Chemung age | 536 |
| Platy sandstone and slaty shale. | |

The Price sandstone is a hard ridge-making rock which forms the ridge known as Pine Mountain and Brushy Mountain. The southeastern face of this ridge is a dip slope of the hard rocks of this formation, which dip about 40° SE. The severed edges of the dipping strata are finely exposed in the gaps through the mountain and make picturesque ledges and cliffs. Less well exposed in the gaps and on the northwest slope of the ridge are the underlying shaly sandstones and shales which are sparingly fossiliferous and of Chemung age. Fossils have not been obtained from the Price sandstone in this area, but the presence of coal seamlets near the top, its lithologic character, and its general stratigraphic position indicate its equivalence to the Pocono, at the base of the Carboniferous system. In the adjacent region to the northeast the Price sandstone contains thick coal beds whose flora establishes its Mississippian age.

The Maccrady formation is composed of materials relatively so soft and easily disintegrated that it is deeply eroded and in general poorly exposed. It outcrops in the valley of the North Fork of the Holston and is largely covered by the terrace and flood-plain deposits of that stream. The basal black shale and reddish sandy beds are not uncommonly exposed in the lower spurs of Pine Mountain, but the earthy limestones and shales of the formation are seen in few places. A few fossils have been found in some of the thin calcareous beds, and certain dark shales near the middle are in places highly fossiliferous. At the base are coal seamlets and underclays that carry plant remains. The invertebrates have been assigned by George H. Girty to the upper Mississippian, and he correlates the formation with the Moorefield shale of Arkansas. It also probably represents the lower part of the Mauch Chunk of Pennsylvania. In places plastic red and olive to bluish clays with gypsum deposits occur in the midst of the Maccrady formation. Their occurrence and relations are discussed under the heading "Origin of the deposits," on pages 248–249. This formation has been called the Pulaski shale in geologic reports describing adjacent areas to the northeast, and this name would be used here were it not that Pulaski has a prior established usage for an Ordovician formation in New York. The new name Maccrady is here given to the formation, from the village of that name on the North Fork of Holston River, where the best section of the formation was measured.

The Newman limestone is calcareous throughout but contains shaly portions which weather readily to clay and soil. The limestone generally makes hills, which in most places assume rounded forms due to dissection by streams flowing across the trend of the beds into the larger longitudinal streams. The formation is highly fossiliferous and the fauna indicates its general equivalence with the Greenbrier limestone of West Virginia and Pennsylvania and the Maxville limestone of Ohio.

Pre-Carboniferous rocks are present in two tracts within the area represented on the map (fig. 28). Beneath the basal Carboniferous sandstone lie Devonian sediments, mostly shales and sandstones, about 2,700 feet thick, underlain in turn by Silurian sediments, also mostly shales and sandstones. These are not differentiated on the map, as they do not concern the problems here discussed. These rocks occupy the northwestern portion of the mapped area and form the slopes of Clinch Mountain, which is capped by the basal Silurian formation, the Clinch sandstone, of Medina age.

In the southeastern part of the area mapped are Cambrian strata, mostly hard gray to blue magnesian limestone and dolomite, which are also undifferentiated on the map. The oldest of these Cambrian rocks are adjacent to the Carboniferous, with successively younger beds to the southeast.

## STRUCTURE.

The Cambrian rocks on the southeast are part of a great overthrust mass which rode on a flat fault plane over the Carboniferous strata on the northwest, as shown in the structure sections in figures 29 and 30. The Cambrian strata dip rather uniformly 30°–40° SE., successively older Cambrian strata appearing at the northwest. Massive gray dolomite and magnesian limestone of Cambrian age are adjacent to the fault throughout most of its course in the mapped area and probably form the competent strata that carried the thrust. There is no indication of an anticlinal axis in these lower limestones southwest of Saltville, where this formation has a narrow outcrop, but northeast of Saltville there is close folding in the broad belt of this formation adjacent to the fault, with all dips overturned to the southeast. A still lower Cambrian formation of red argillaceous shale and sandstone is exposed over part of this area. This folded portion of the Cambrian may represent the axis of an overturned anticline,

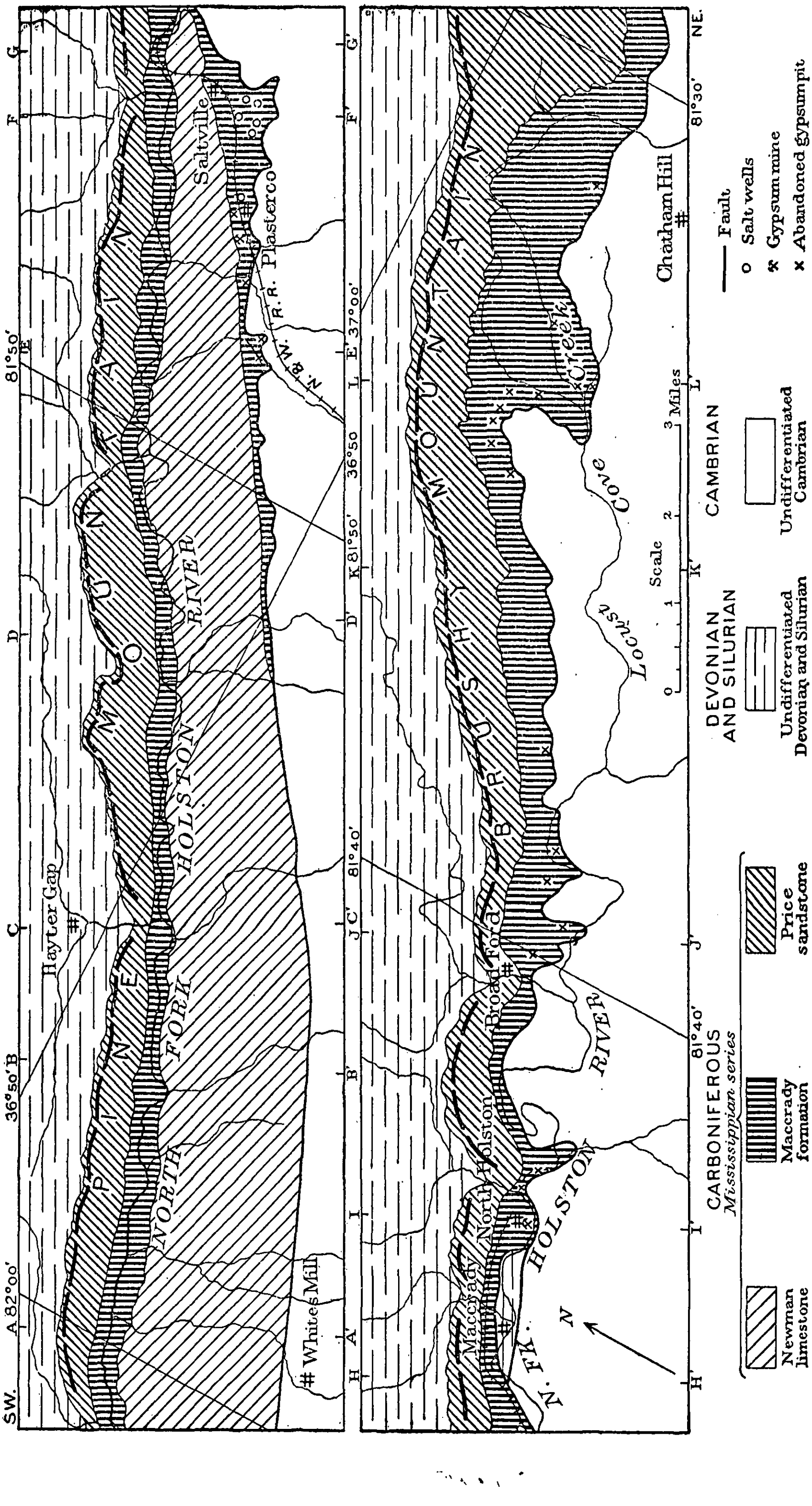



FIGURE 28.—Geologic map of Holston Valley in the vicinity of Saltville, Va. The crest of Pine and Brushy mountains is represented by a heavy broken line. Letters on margins indicate lines of sections in figures 29 and 30.

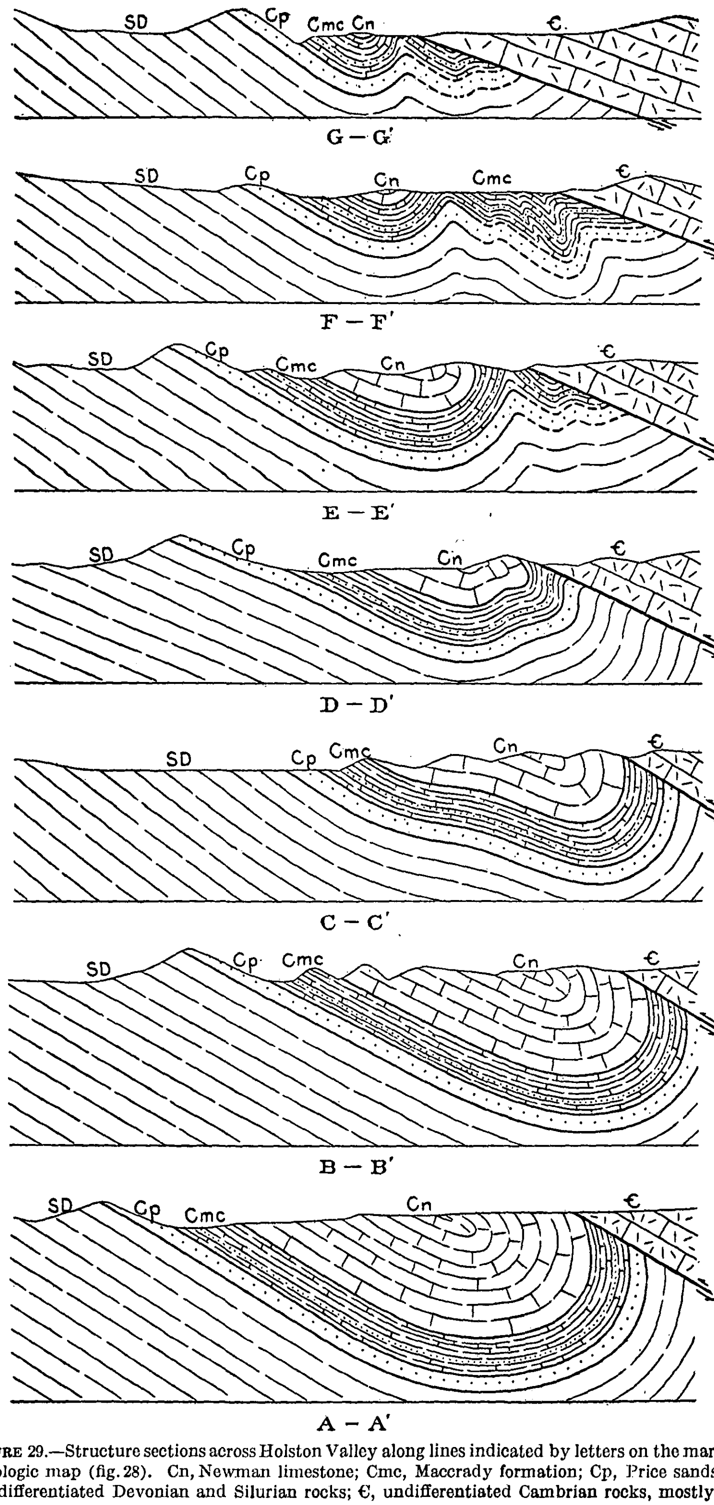



**FIGURE 29.**—Structure sections across Holston Valley along lines indicated by letters on the margins of the geologic map (fig. 28). Cn, Newman limestone; Cmc, Maccrady formation; Cp, Price sandstone; SD, undifferentiated Devonian and Silurian rocks; €, undifferentiated Cambrian rocks, mostly dolomite. Scale, double the scale of figure 28.

the breaking and overthrusting of which initiated the faulting. This is no local or minor fault, however, for it has been traced throughout the southern Appalachians into the Rome fault, which has been demonstrated to have a horizontal displacement of at least 5 miles in the vicinity of Rome, Ga. A thrust fault of such magnitude and length must have a deep-seated origin and its plane may be a shear plane cutting diagonally across the strata, without folding except that produced by friction or drag.

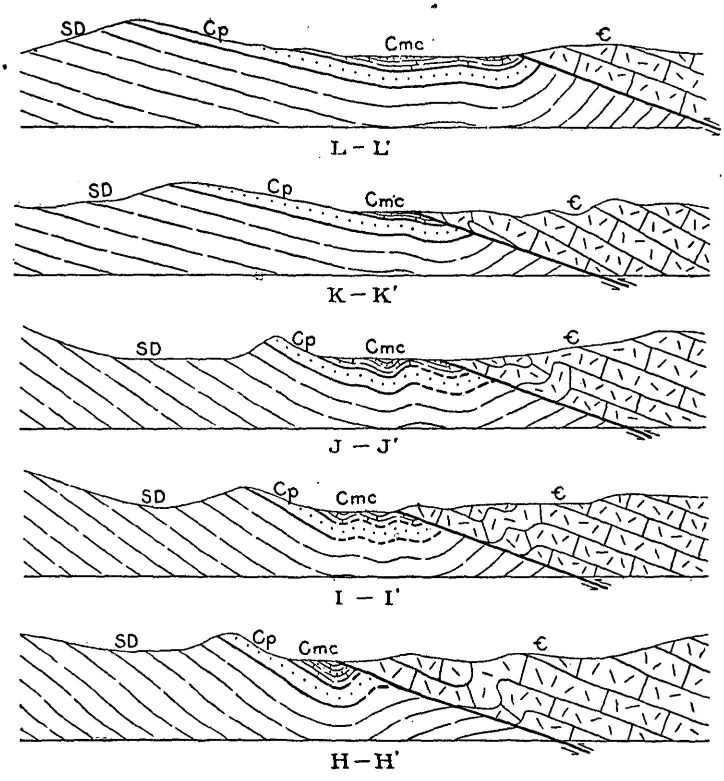



FIGURE 30.—Structure sections across Holston Valley along lines indicated by letters on the margins of the geologic map (fig. 28). Cn, Newman limestone; Cmc, Maccrady formation; Cp, Price sandstone; SD, undifferentiated Devonian and Silurian rocks; €, undifferentiated Cambrian rocks, mostly dolomite. Scale, double the scale of figure 28.

The fault plane is exposed at several places in the area, dipping southeast, and its inclination varies from 20° to 60°. Figure 31 is a sketch of the faulted rocks in the cliff west of Maccrady. Next to the fault plane the dolomite of the overthrust mass is hardened and the bedding obliterated, and the vertical beds farther from the plane of movement are jointed parallel to the plane. The softer shaly limestones beneath are mashed and altered by circulating waters to clay adjacent to the fault.

Another section of the fault laid bare by old gypsum workings 2 miles east of Broad Ford shows the Cambrian dolomite resting on red and green clay containing gypsum, with 1 foot of black banded carbonized calcareous clay gouge directly beneath the fault plane, which dips 20°–40° SE. In places a dolomite breccia of large and small masses marks the fault contact. In the railroad cut at Plasterco the cemented breccia is freshly exposed and its components are seen to be largely dolomite, with minor fragments of chert, limestone, and shale.

Opposite Maccrady Gap a mass of Clinch sandstone of Silurian age and associated rocks of sufficient size to make a hill 250 feet high and nearly 1 mile long was caught up along the fault and is shown on the map (fig. 28) by the fault dividing west of North Holston.

The outcrop of the fault plane is very crooked in the northeastern part of the area, owing to the fact that the plane is very flat in most places and is probably somewhat folded or wavy along the strike. Where the fault lies between the Cambrian dolomite and the shale of the Maccrady formation, it affords favorable channels for circulating underground water, from which springs issue at many places, and large solution channels are formed that may have aided in breaking down and removing the overlying dolomite at their outlets along the fault and may have assisted the formation of deep reentrants in the trace of the plane. These reentrants are invariably underlain by soft clays of the Maccrady formation, which form low flats generally without rock exposures. The reentrant at Saltville is one of the largest and is entirely barren of rock exposures. Another reentrant is at Broad Ford, where there are only a few outcrops of the lower harder beds in the Maccrady. Northwest of Chatham Hill is a still larger reentrant, due to the flattening of the general structure and a corresponding wider exposure of the softer rocks after being stripped of the overthrust Cambrian dolomite. These reentrant areas are the chief places where salt and gypsum deposits have been found and are of especial interest in the study of the distribution and origin of these products.

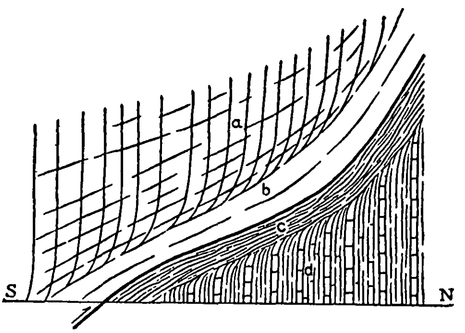



FIGURE 31.—Section of the faulted rocks in the cliff southwest of Maccrady, Va. a, Massive Cambrian dolomite, bedding vertical but indistinct, jointing parallel to fault; b, zone of altered dolomite, bedding entirely obliterated; c, zone of altered and crushed argillaceous material, banded parallel to the fault; d, earthy limestone and calcareous shale (Carboniferous).

The rocks northwest of the fault, except those immediately adjacent to it, lie in a monocline, dipping 25°–40° SE., which culminates in Clinch Mountain, northwest of the area mapped. The soft Carboniferous rocks near the fault are bent into an overturned syncline. The sections in figures 29 and 30 illustrate the progressive rise in this syncline from southwest to northeast. As the Newman limestone rises northward in the shallowing syncline, erosion has removed its upper portion and its remnant gradually diminishes in thickness from 3,300 feet in the most southern section until northeast of Saltville it is entirely absent. The soft underlying Maccrady formation does not extend all the way along the southeast side of the syncline but is faulted out in the southwestern part of the area. Where present on the southeast side it is vertical or overturned.

No outcrops are visible in the broad flat at Saltville, but the absence of hard outcropping strata and the record of only soft rocks of Maccrady type in the deep wells at this place indicate that the syncline is followed on the east by an anticline whose east limb carries the Price sandstone below the points reached by the drill but apparently not deep enough to bring the Newman limestone down to the surface, so on the sections the rocks are shown to be undulating in the portions under cover of the overthrust fault.

Northeast of Saltville the beds of the Maccrady formation are poorly exposed and their attitude is not generally shown. At the cliff west of Maccrady the last clear exposure of the syncline is preserved in the ledges of shale and sandstone. Just east of North Holston a small anticlinal roll of thin limestone in the Maccrady is an indication of the undulations probably existing throughout this band of soft rocks. East of Broad Ford a similar gentle fold is exposed in the small stream gully crossing the lowland.

Farther northeast the structure flattens more and more, and in the reentrant northwest of Chatham Hill a thin limestone in the Maccrady formation indicates a very gentle syncline, followed on the southeast by a gentle anticline and another syncline, which is sharply turned up at the fault. The gentle syncline is also shown in the southward swing of the Price sandstone outcrops forming Brushy Mountain at the northeast end of the area mapped.

From the overturned syncline of Newman limestone at the southwest it might at first be concluded that this was a syncline associated with an overturned anticline on the southeast, which broke and was thrust over upon the syncline. However, it is concluded from a wider study of the structure that the fault did not originate in a broken fold but is of deeper-seated origin, being manifest by a shear plane cutting diagonally across the strata and folding and crumpling those at the overridden contact by reason of friction and drag.

# SALT AND GYPSUM INDUSTRIES.

## SALT.

### EARLIER DEVELOPMENT.

Salt seepages were known to exist in the vicinity of Saltville in pioneer days, for this swampy flat was one of the salt licks frequented by wild animals and was sought by hunters and trappers and before them by the Indians. The early settlers dug shallow wells and extracted the salt from the brine that flowed from the springs. As early as 1836 W. B. Rogers, then director of the Geological Survey of Virginia, reported two wells in operation, King's and Preston's, each 212 feet deep. The brine was conveyed 2 miles in wooden pipes, and after the crude impurities were allowed to settle in large tanks, it was treated in kettles, of which there were 500. About 30,000 gallons of brine were boiled down daily, yielding an average of 1,000 bushels of salt. The annual production is reported by Watson[1] to have been about 200,000 bushels. Calcium sulphate, almost the only impurity in the brine, adhered to the bottom of the kettles, thus purifying the product. The salt was reported free from chlorides of calcium and magnesium, or bittern. Three grades of salt were produced—common salt, fine grained but slightly discolored; table salt, white and fine, produced by rapid boiling; and alum salt, thin satiny crystals of great purity produced by slow crystallization as the kettles cooled. During the Civil War the wells at Saltville were the main source of salt for the Confederacy.

The first shaft in the Saltville flat was sunk in 1840. After passing through 20 feet of clay and 195 feet of red clay and gypsum it struck rock salt at a depth of 215 feet, the first definite proof of the existence of rock salt in this region. The salt was reported by the owner, the Holston Salt & Plaster Co., to continue to a depth of nearly 600 feet. As the shaft was dry it was abandoned as a brine producer, but it is stated that after a number of years the shaft was connected by a drift with an artesian well near by, the water from which, becoming saturated with salt, was pumped from the shaft.

The following analyses of rock salt, brine, and commercial salt from Saltville, showing their purity, are taken from T. L. Watson's report,[1] quoted from C. B. Hayden:

*Analyses of salt and brine from Saltville, Va.*

| | Rock salt. | Evaporated brine. | Commercial salt. | |
|---|---|---|---|---|
| $NaCl$ | 99.084 | 97.792 | 98.540 | 98.146 |
| $CaCl_2$ | Trace. | .033 | .016 | .034 |
| $MgCl_2$ | | | | |
| $CaSO_4$ | .446 | 2.17 | 1.444 | 1.820 |
| $MgSO_4$ | | | | |
| $Al_2O_3$, $SiO_2$, and Fe | .470 | Trace. | | |

[1] Watson, T. L., Mineral resources of Virginia, Jamestown Exposition Com., 1907, p. 213.

Very little prospecting for salt seems to have been attempted beyond the Saltville area. Some borings have been made on the Robertson property, to the southwest, now leased by the United States Gypsum Co., but with what result is not known. Indications of brines have been reported at old gypsum workings to the northeast and at a depth of 300 feet in a shaft in the river bottom, presumably on the Cobbs farm. A well was reported to have been dug 500 feet deep for salt, before the Civil War, on the Buchanan property, 6 miles northeast of Broad Ford.

## PRESENT DEVELOPMENT.

The salt industry is now conducted by the Mathieson Alkali Works, with offices at Saltville. The Saltville Valley and surrounding country are owned and controlled by the company, and the town is well governed and kept clean, attractive, and wholesome. It has no superfluous stores, shops, houses, or churches; the houses are attractively built and have plenty of light, air, and yard; the public water supply is obtained from abundant springs protected from contamination; the town is illuminated by electricity.

Since 1895, when the Mathieson Co. came into control of the property, the brine has not been evaporated into salt, but is converted into other soda products, chiefly sodium bicarbonate, or baking soda, which is the basis of all baking powders and is used also to some extent in making soda water. A large part of the production is in the form of soda ash, used extensively in the manufacture of glass, pottery, etc. Sal soda is also made for this purpose. Caustic soda, put up in large hermetically sealed cans, is prepared for medicinal and other purposes.

Over 50 wells have been drilled in the vicinity of Saltville, about 25 of which are at present in operation. They range in depth from a few hundred feet to 2,280 feet, the average being about 1,000 feet. The shallower wells are on the northwest side of the flat and the deeper ones on the southeast side, near the fault. The former are dry wells and have to be flushed with water through the outer casing. The wells on the southeast side are wet and the brine flows in as fast as it is pumped out. In the wet wells the rocks become honeycombed and cave in, in some wells bending the pipe so as to cripple or entirely disable the well. The brine is raised by ordinary deep pumps each operated by a walking beam driven by an electric motor housed in a small shack at the well, and the brine is piped to an open reservoir in the town. From the reservoir it is piped to the company's plant covering several acres on the east bank of the North Fork of Holston River, about a mile distant, where it is converted into baking soda and the other sodium products.

For the conversion of salt to these compounds large quantities of pure calcium carbonate are used, and an aerial bucket tram carries crushed limestone from the company's quarry 3 miles southeast across the limestone hills. As the limestone must be free from magnesium and other impurities, satisfactory rock is difficult to obtain in quantity. Part of the present supply comes from quarries at Marion, Va., about 25 miles distant by rail on the main line of the Norfolk & Western Railway. About 600 tons is used daily.

### AMMONIA-SODA PROCESS.

The ammonia-soda or Solvay process is in general employed in the manufacture of bicarbonate of soda, but the details of method, process, and machinery used by the Mathieson Co. are not made public. The process in general is as follows:

The brine is first saturated with ammonia gas admitted through the perforated bottom of a tank and absorbed by the brine as it ascends through the liquid. The heat produced is taken up by coils of water-cooled pipes.

The saturated ammoniacal brine is pumped into tall carbonating tanks, and carbon dioxide is allowed to bubble through the liquor from a pipe near the bottom, the two being thoroughly mixed by means of a series of perforated diaphragms. As the brine from the Saltville wells is nearly free from iron, magnesium, and other impurities, except calcium, common to most brines, the reaction is not complicated by the presence of foreign elements. The reaction is $NaCl + NH_3 + H_2O + CO_2 = NH_4Cl + NaHCO_3$. The heat evolved in the chemical reaction is absorbed by water-cooled pipes or jacket. The bicarbonate of soda, being but slightly soluble in cold ammoniacal brine, is precipitated and settles slowly toward the bottom. The temperature must be carefully controlled to insure the best results, as some of the soda will remain in solution or the precipitate will be too fine to filter if the solution is too warm or too cold.

The thick milky liquid drawn off at the bottom contains admixtures of salt and ammonium chloride, and after filtration of the precipitate, or its concentration by centrifugal machines, these impurities are partly removed by washing the soda with water. The bicarbonate of soda is dried in a carbon dioxide atmosphere at about 90° C. and is ready for use as baking soda, except as it needs further refining and purifying.

To form soda ash, the acid bicarbonate is calcined in large pans or ovens, a process which also drives off any ammonia and water present. Heating $2NaHCO_3$ produces $Na_2CO_3 + CO_2 + H_2O$. This is generally a very pure sodium carbonate containing only a trace of salt and bicarbonate of soda and is entirely free from caustic soda, sulphide, or sulphate.

Soda crystal, or sal soda ($Na_2CO_3.10H_2O$), is produced by dissolving soda ash in warm water and crystallizing the clarified liquid by cooling in tanks. Large crystals of sal soda are formed which contain 60 per cent of water but are otherwise very pure, as the crystallization further purifies the product. A very pure bicarbonate may be obtained by exposing the sal soda crystals to a carbon dioxide atmosphere on a grating, the water being driven out and dropping through the grating, under the reaction $Na_2CO_3.10H_2O + CO_2 = 2NaHCO_3 + 9H_2O$.

Caustic soda (sodium hydroxide or hydrate) may be made from soda ash in solution by adding calcium hydroxide: $Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH$. The calcium carbonate is insoluble and precipitates as a lime mud. The sodium hydroxide is evaporated to dryness and is packed into hermetically sealed cans.

Saving the ammonia and carbon dioxide and avoiding the waste of by-products are essential in order to make the process profitable. The ammonia that escapes from the top of the carbonating tank and is removed from the bicarbonate in the process of purifying and calcining is saved by a special gas-collecting apparatus. The liquid in the carbonating tank after the bicarbonate is precipitated contains ammonium carbonate and sodium chloride, as well as ammonium chloride, and is passed through the ammonia still to extract and save the ammonia. Steam is admitted through the bottom and as it bubbles up through the liquid it decomposes the ammonium carbonate into ammonia, carbon dioxide, and water. The ammonium chloride settles to the bottom and is decomposed by calcium hydroxide, as follows: $2NH_4Cl + Ca(OH)_2 = CaCl_2 + 2H_2O + 2NH_3$. The calcium chloride remains in solution and is wasted.

Carbon dioxide for the soda process is obtained by burning limestone in kilns, the lime (CaO) being used in the manufacture of caustic soda. Part of the carbon dioxide is obtained in the calcination of the bicarbonate of soda. The limestone used in the process is largely converted back to lime mud in the caustic soda process and thus far has proved a waste. Attempts to briquet it for use in the roasters have not proved feasible and its waste is a great loss, amounting in the operations of the Mathieson Alkali Co. to several hundred tons daily. Some day a use will be found for this residual material and it will not only become a by-product, but the acres of lime mud now confined in settling ponds on the bottom lands will be a rich mine of pure calcium carbonate.

The following analyses of the limestone from the Mathieson Co.'s quarry are given by Watson:[1]

*Analysis of limestone from Mathieson quarry, 3 miles east of Saltville, Va.*

| | 1 | 2 |
|---|---|---|
| $CaCO_3$ | 97.03 | 96.73 |
| $MgCO_3$ | 1.24 | 1.37 |
| $SiO_2$, $Al_2O_3$, Fe | 1.64 | 1.80 |

## GYPSUM.

### EARLIER DEVELOPMENT.

Gypsum has been used for fertilizer for many years, and as early as 1835 Rogers mentioned the great possibilities of this deposit as a source of supply for the agricultural lands of Virginia. Over a decade ago gypsum was converted to plaster of Paris by roasting on only a small scale, as the product did not then have wide usage, but the adoption of this kind of plaster for walls in buildings, especially as a finishing coating, because of its superior hardness and whiteness, has made its production a large and profitable industry. When mixed with cement it acts as a retarder, greatly increasing the value of that product, and for gypsum to be used in this way there is now a large demand. As land plaster or fertilizer the gypsum is simply ground and not roasted. It has proved very beneficial to certain soils and for certain crops, being highly recommended for peanut cultivation.

Rogers in 1836 described these deposits as great detached masses of gypsum distributed along the Holston River belt for 40 miles. He reported an almost solid mass of gypsum 25 feet deep, 50 feet long, and 15 feet wide opened at McCall's quarry (probably one of the pits on the Robertson place), borings indicating that it extended to a depth of 100 feet, and stated that small openings had been made in the extensive exposures at the Buchanan banks in Walker Valley (Locust Cove), which indicated a great abundance of gypsum there.

Stevenson in 1885 reported extensive mining on the Robertson tract, at the southwest end of the Saltville Valley, where some large masses close to the surface had already been worked out. He also reported that plaster had been dug for five years to a depth of 60 feet at Pierson's (North Holston), 5 miles east of Saltville, and under the limestone bluff south of the river on the Miller farm; in a deep shaft in the river bottom on the Taylor farm, and in another shaft north of the road on the same property; and that extensive mining had been done by open pits and shafts on the Buchanan property, on Cove Creek, and in the small adjacent valley.

[1] Watson, T. L., op. cit., p. 214.

## PRESENT OPERATING MINES.

Two gypsum companies are operating in the area at the present time. The United States Gypsum Co., with offices in Chicago, leased the Robertson tract, adjoining the Mathieson Alkali Co.'s property on the southwest, from the Buena Vista Plaster Co. and has been operating for the last few years. This plant is located in a narrow extension of the broad flat at Saltville, separated from it by a low divide. Two shafts furnish access to the workings, which are reported to be about 100 feet below the surface, each set of workings seeming to be in a distinct body of gypsum. A third abandoned shaft leads to another mass of the deposit, and as other new bodies are located by drilling over the bottom land additional shafts will be sunk. Large deposits of gypsum on the eastern edge of the tract directly adjoining the Mathieson property were previously worked out by the owners.

As just mentioned, the gypsum in this mine seems to be in detached masses of great size and not in continuous beds, as might be expected. This will be referred to again later under the heading "Origin of the deposits." The gypsum is mostly a white to gray granocrystalline rock inclosed in clay, the gray variety streaked with fine dark argillaceous material. Numerous small anhydrite crystals are scattered through some of the gypsum from the old southernmost shaft, and these appear more prominently on weathered specimens. The gypsum is brought to the surface by elevators and conveyed by tram cars to the company's mill, where it is roasted and pulverized. The molding of plaster bricks, tiles, and hollow blocks in the company's shop is a new branch of the industry in this region.

The Southern Gypsum Co.'s plant and office are at North Holston, reached by the company's branch railroad from Saltville. The mine is on the old Pierson plaster-bank farm, in one of the embayments of lowland adjoining the North Fork of Holston River which is underlain by the soft shales of the Maccrady formation. The shaft in the lowland is connected by an aerial bucket tram with the main roasting and grinding plant at the railroad on the hillside. A large part of the crude product is ground for fertilizer at the lower mill near the shaft, much of the gypsiferous clay being of the right mixture to be used in this way for land plaster, effecting a great saving in the expense of mining. For wall and finishing plaster and cement retarder only the purer lump gypsum is employed.

The bulk of the gypsum here is much like that at the United States Co.'s plant, granular and crystalline. Some large sheets of pure selenite are encountered, and small veinlets of satin spar are common in the clay. Large masses of black argillaceous material called "black rock" occur in the midst of the gypsum, and apparent bedding of the gypsum is indicated by banding of black grains of the same material. The gypsum is reported to occur in beds of considerable thickness and extent and not in isolated masses, as at the United States Co.'s mine. The deposits have been tested by bore holes over all the river bottom of the embayment. The beds vary greatly in thickness, however, being somewhat lenticular in shape. The gypsum formerly outcropped at the river, where it was mined in open cuts in the early days for fertilizer. It is now mined from the shaft in the bottom land in all directions at a maximum depth of about 100 feet.

## OTHER PROSPECTS.

Old partly filled pits where gypsum, or "plaster," as it is commonly called, was mined from the surface in earlier days are still visible all along this belt from a point a mile west of Plasterco to the vicinity of Chatham Hill. Near Plasterco large pits, abandoned shafts, and caved-in ground abound, marking the places where the Buena Vista Co. and the Robertsons formerly operated extensively and removed much of the available gypsum that was close to the surface. Smaller openings were made in the embayment about 1 mile to the southwest, but the deposits there have been only slightly explored. They are all owned by the old Buena Vista Co. and are leased to the United States Gypsum Co. In the Saltville Valley thick deposits of gypsum are reported in all the wells drilled for salt, and some beds at the surface were formerly mined for the manufacture of a kind of cement. They are owned by the Mathieson Alkali Co. and are not now being worked.

At North Holston and in the embayment just east of it several old gypsum pits formerly worked on the Pierson and Miller farms are nearly obliterated. Several old pits are to be seen also near Broad Ford, some to the west but most of them in the broad embayment to the east. One is still open in the river bank on the Taylor farm, about a mile east of Broad Ford, where the gypsiferous shales have been dug out from beneath the overthrust Cambrian dolomite. Another pit on the Taylor farm is among the low hills to the northeast, beyond the point where the North Fork of Holston River leaves the belt of the Maccrady formation. A shaft on the adjacent Barnes place opened a large deposit by drifts but is now abandoned and filled with water.

Northeast of the Taylor farm conditions continue to appear favorable for the occurrence of gypsum, except that the exposed area of the Maccrady formation is narrow, but gypsum is not known to have been reported in the next 3 miles. Beyond, however, on the Buchanan property, important deposits occur and were mined on a large scale and crushed in the company's mill on the property, which was in operation three or four years ago and is still standing. The smaller holes have fallen in and been filled up, but some of the larger ones are full of water and are reported to be very deep. Pits are scattered over the broad embayment in the Maccrady formation, not only in the Locust Cove Creek bottom but also on the low divide and small valley to the west. Several pits were also located north of Chatham Hill, and the crude gypsum was crushed in a water-power mill on the river at Chatham Hill.

## ORIGIN OF THE DEPOSITS.

### FORMER VIEWS.

In his early description of these deposits W. B. Rogers correctly identifies the beds inclosing them as "Lower Carboniferous" and states further that they are at the fault contact between these beds and older limestones. As to their origin he adopts the explanation that oxidizing iron pyrites in the shales produced sulphuric acid, which, acting on limestone, converted it into calcium sulphate. He says:[1]

> In speculating upon the origin of the gypsum of this region, the readiest explanation that suggests itself is that which ascribes its production to similar causes with those which gave birth to the gypsum of the Tertiary strata of lower Virginia. It has been incidentally remarked above that pyritous slate occurs in fragments mingled with the gypsum and clay of the salt wells and other places. Supposing the valley to have once been filled with the débris of this slate and of the neighboring limestones, we would have all the materials brought together which are necessary for the production of the gypsum, while the slate after decomposition would become the clayey matrix in which the crystals would collect. This view is rendered more probable from the occurrence, even in the midst of the solid masses of plaster, of fragments of the siliceous rock which skirts the valley on the south. It is at least certain that the gypsum has not been deposited here, as in some other parts of the world, from the waters of thermal springs holding it in solution, since in that case it would be found disposed in layers as travertine and not in the irregular and scattered condition which has been described.

J. J. Stevenson,[2] in 1885, after describing the mining development, occurrence, and distribution of the gypsum and salt, arrives at somewhat similar conclusions, as follows:

> 1. The gypsum deposits are not beds of Carboniferous or Cambro-Silurian limestones changed into gypsum.
>
> 2. These deposits occupy deep basins, which have been eroded in Lower Carboniferous shale or limestone or in the hard, slightly calcareous sandstones of the Knox group. In at least two localities branches protrude from the main body into drains or ravines, so that the horizontal plan resembles somewhat the splash made by throwing soft mud against a wall.
>
> 3. The character of the deposit is wholly independent of the rocks on which it rests.

[1] Rogers, W. B., A reprint of annual reports * * * on the geology of the Virginias, 1884, pp. 141-142.
[2] Proc. Am. Philos. Soc., vol. 22, 1885, pp. 157-160.

4. The gypsum occurs in irregular masses, incased in red marly clay, which penetrates the gypsum to a variable distance; there is less of this clay in the eastern basins than at Saltville.

5. At a variable depth salt occurs with the gypsum, and this salt contains very little of iodides or bromides.

6. Blue clay overlies the gypsum at all localities yet examined.

7. No fossils of any sort have been found thus far in the gypsum, its incasing red clay, or in the overlying blue clay; but just west from Saltville a conglomerate cemented by gypsum occurs, in which remains of Mastodon have been found; this overlies the blue clay and incloses many fragments of both blue and red clay.

8. These gypsiferous deposits occur in the vicinity of the Saltville fault.

* * * * * * *

But the amount of the erosion and the general relation of the gypsum to the blue clay, with the relation of the latter to the Quaternary conglomerate, suggest that the gypsum is not older than the Tertiary; until some fossils have been discovered, however, the question of age must be regarded as undetermined.

* * * * * * *

Capellini ascribes the formation of this gypsum [at Castellina Marittima] to the action of sulphur springs on calcium carbonate held in solution; so that the carbonate was changed into sulphate and deposited as such in the littoral lakes of the middle Miocene. * * * The origin of the Holston gypsum is to be accounted for in some similar way. Several deep basins were occupied by lakes; that of the Saltville basin received not a little calcareous matter from the Lower Carboniferous beds forming its northerly shore, and some doubtless was received from the wash of the Knox beds on the southerly shore; in the basins farther east the calcareous matter derived from the wash should be far inferior to argillaceous matter. But the composition of the gypsum shows less of the red clay at Buchanan's than at Saltville. The principal source of the calcareous matter must be looked for not in the wash from the shores but in springs. That calcareous springs can produce deposits as extensive as those of this region is sufficiently shown by the extensive deposits around many of the springs at the far West. The calcium carbonate in solution would be converted into calcium sulphate by the sulphurous springs also issuing from the fault, and the gypsum would be deposited as such.

The red marly clays were derived from the wash and are more abundant at Saltville, where the soft red shales at the top of the Lower Carboniferous are fully exposed on the northerly side of the basin.

E. C. Eckel[1] in 1902 concluded that the deposits were interbedded as original sediments in the "Lower Carboniferous:"

Though the salt and gypsum deposits have been long known and worked and have been examined by many geologists, a wide range of opinion exists as to their age and origin, as will be seen on comparing the literature of the subject. It is sufficient in this place to note that, as to age, the deposits have been variously referred to the Silurian, Carboniferous, Triassic, Tertiary, and Pleistocene, while different authorities have considered them as originating from deposition from sea water, from deposition from lakes, by the decomposition of pyrite and resulting action on fragments of limestone, or by the action of sulphur springs on unweathered limestone.

The work of the last field season would seem to prove that both the salt and gypsum deposits originated from deposition, through the evaporation of sea water in a partly or entirely inclosed basin, and that they are of Lower Carboniferous age, being immediately overlain by the massive beds of the Greenbrier limestone and underlain by Lower Carboniferous sandstones.

---

[1] Bull. U. S. Geol. Survey No. 213, 1903, p. 406.

## OBSERVED RELATIONS.

The most striking fact in connection with the gypsum and salt deposits of this district is that they have been found in quantity only in the shales of the Maccrady formation along the Saltville fault. These shales also outcrop along the North Fork of the Holston southwest of Saltville, on the west side of the syncline, but so far as known neither gypsum nor salt has been observed in this area of the formation Stevenson reported gypsum on both sides of the fault on the Miller and Buchanan tracts northeast of Saltville, but these observations seem to be in error in that the fault was not accurately mapped, which is not strange, for the altered Carboniferous limestone very closely resembles the Cambrian dolomite, and some of the red shales of the Cambrian closely resemble those of the Carboniferous.

An effort has been made to obtain a carefully measured section of the Maccrady formation to determine the position of the gypsum and salt-bearing beds, but with scant success. In the broad flats where the gypsum occurs there are generally no outcrops except red clay and gypsum, and consequently there is little hope of solving the relation southwest of Saltville. Not even the base of the Maccrady, which is the most definite key horizon, is exposed there.

Northeast of Saltville there are a few good exposures, but generally where the gypsum occurs the inclosing rocks are soft clays and are hidden. The river cliff southwest of Maccrady is the best exposed section of these beds in the area, and the following details were measured there:

*Partial section of Maccrady formation west of Maccrady, Va.*

| | Thickness. | Distance above base. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Dark crumbly fossiliferous shale and earthy gray limestones | 50± | |
| Alternate thick earthy limestone, calcareous shale, and thin crystalline fossiliferous limestones | 60 | 558 |
| Massive-bedded bluish tough calcareous and argillaceous sandstone with fossiliferous calcareous layers | 25 | |
| Gray sandstone, weathering brown | 5 | |
| Shaly earthy contorted sandy limestone | 31 | |
| Hard thick-bedded bluish calcareous sandstone | 20 | |
| Softer shaly earthy sandstone | 30 | |
| Thick bed of earthy sandstone | 6 | |
| Hard impure limestone, with chert nodules | 8 | |
| Thick soft earthy sandstone | 10 | |
| Shaly earthy limestone | 60 | |
| Thick-bedded to shaly earthy sandstone | 45 | 318 |
| Covered, probably some red shale, shaly earthy limestone, and soft earthy sandstone | 225± | 93 |
| Red shaly sandstone and shale, mottled yellow | 10 | |
| Red shale in part, rest covered | 25 | |
| Red shaly sandstone, mottled yellow | 7 | |
| Shaly gray sandstone, with phosphatic fish plates | 10 | |
| Sandy shale, in part covered | 20 | |
| Soft shale, light buff to dark drab; light-gray fire clay with rootlets, leaves, and twigs at base | 20 | |
| Black coaly fissile shale | 1 | |
| Slabby blue even-grained irregular-bedded sandstone, weathering buff (top of Price sandstone). | | |

The next best partial section is just east of Watson Gap, 2 miles southwest of Broad Ford, which is as follows:

*Partial section of Maccrady formation east of Watson Gap, Va.*

| | Thickness. | Distance above base. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Thin-bedded earthy limestone, with some hard dense beds | 30 | 174 |
| Purple fissile shale, with some earthy limestones | 14 | |
| Fissile red shale | 10 | |
| Micaceous red sandstone, mottled yellow | 4 | |
| Fissile and crumbly red shale, mottled yellow | 37 | |
| Hard yellow and red agglomeratic shale | 1 | |
| Crumbly red sandstone and some yellow shale | 10 | 98 |
| Harder red sandstone, in part shaly | 4 | |
| Red argillite and shale, with drab sandy concretionary masses | 3 | |
| Greenish fire clay, with rootlets, red at surface | 2 | |
| Crumbly and fissile red and yellow shale | 30 | |
| Soft greenish micaceous sandstone, purplish at top | 20 | |
| Soft yellow shale | 4 | |
| Black fissile coaly shale | 3 | |
| Thin sandstone and fire clay, with rootlets | 1 | |
| Greenish fissile shale | 10 | |
| Thin irregular-bedded sandstone | 8 | |
| Sandy light-buff fire clay, with rootlets | 3 | |
| Covered, probably thin sandstone and shale | 10 | |
| Massive-bedded greenish-gray calcareous sandstone (top of Price sandstone). | | |

Just east of Broad Ford is another fair exposure that shows the relations of the gypsiferous shales to the rest of the formation:

*Partial section of Maccrady formation east of Broad Ford, Va.*

<table>
<tr><th colspan="2"></th><th>Thickness.</th><th>Distance above base.</th></tr>
<tr><td colspan="2"></td><td>Feet.</td><td>Feet.</td></tr>
<tr><td>Soft red and green shale and clay, with some soft thick brown sandstone and earthy limestone</td><td rowspan="6">Weather or change laterally into gypsum-bearing red plastic clays with secondary limestone layers</td><td rowspan="6">150</td><td rowspan="6"></td></tr>
<tr><td>Red and green shale</td></tr>
<tr><td>Red rippled sandstone</td></tr>
<tr><td>Gray shale with red sandstone bed</td></tr>
<tr><td>Red shale and sandstone</td></tr>
<tr><td>Gray shale</td></tr>
<tr><td colspan="2">Thin black fissile coaly shale</td><td>1</td><td>182±</td></tr>
<tr><td colspan="2">Earthy limestone and calcareous shale</td><td>12</td><td>170±</td></tr>
<tr><td colspan="2">Covered, probably in part soft earthy limestone</td><td>40+</td><td></td></tr>
<tr><td colspan="2">Red sandstone and sandy shale (with unexposed gray sandstone, shale, and carbonaceous seams to base of formation), estimated</td><td>130±</td><td></td></tr>
</table>

From the relations observed in the northeastern part of the area it may be stated that the gypsum does not occur in the lower red siliceous beds of the formation and probably not lower than 180 feet from the base; that thin-bedded argillaceous limestones which are characterized by a small spirifer resembling *S. bifurcata* generally occur near the top of this barren interval; that the gypsum seems to replace certain soft earthy sandstones, shales, and limestones in the overlying portion of the formation present in that part of the area.

Southwest of Saltville, where the surface exposures do not show the relations of the gypsum, the well records also do not aid much in their solution. From a glance at the records of the Mathieson Alkali Co.'s borings, kindly permitted by Mr. W. D. Mount, manager of the plant, no clue was gained as to the sequence of the gypsum and salt beds or of their relation to recognizable limestone, sandstone, or hard red sandy beds. The basal barren sandy beds were not observed, even in the deepest well. A generalized record of one of the typical wells of the Mathieson Co. illustrates the relative distribution of the gypsum and salt which prevails throughout most of the sections.

*Generalized section of a well at Saltville, Va.*

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Limestone and shale | 26 | 26 |
| Shale and gypsum | 195 | 221 |
| Mostly shale with gypsum and some rock salt | 359 | 580 |
| Mostly limestone with shale, gypsum, and rock salt | 215 | 795 |
| Mostly shale with gypsum and rock salt | 100 | 895 |
| Mostly rock salt with little shale | 197 | 1,092 |

The record of a well on the Buena Vista Plaster Co.'s property at Plasterco, as given by T. L. Watson, is as follows:

*Section of well at Plasterco, Va.*

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Red clay | 10 | 10 |
| Clay and plaster | 6 | 16 |
| Impure plaster | 34 | 50 |
| Pure plaster | 52 | 102 |
| Slate and plaster | 63 | 165 |
| Nearly all plaster | 45 | 210 |
| Blue slate | 110 | 320 |
| Blue slate and plaster | 70 | 390 |
| Yellow soapstone | 55 | 445 |
| Pure plaster | 45 | 490 |
| Red rock with little salt | 15 | 505 |

The distribution of gypsum throughout several hundred feet of strata in the wells at Saltville and Plasterco indicates that, even if the beds have a relatively steep dip, the gypsum has a wide vertical range in the southwestern part of the area and may replace higher beds in the formation than occur at the surface in the northeast.

## CONCLUSIONS.

It can not be determined positively from the well records whether the deposits are in thick continuous beds or, as has been found to be the condition in the mines at Plasterco, in detached segregated masses. The distinct interbedding, however, of the gypsum with limestone, shale, red clay, and rock salt in the Saltville wells precludes the idea that the deposits were formed in wash from the surrounding higher areas into a trough or lake, as suggested by Stevenson. The gypsum beds have nowhere been mined deep or far enough to determine how they change laterally into other sedimentary rocks. This must be inferred from such facts as can be gathered in the mines, on the surface, and in the well records.

The conclusion expressed by Eckel that the deposits are strictly sedimentary in origin, having been derived from the evaporation of confined bodies of water under salt-pan conditions, is believed by the writer to be only partly correct. The fact that the beds of almost solid gypsum 50 to 100 feet in thickness vary greatly, occurring at intervals along the belt of these rocks, with barren areas between, and, so far as known, not at all on the northwest side of the syncline away from the fault, does not harmonize with this view. That salt-pan conditions could be so local and still persist for so long a time as to form such thick beds of gypsum and that these conditions could be repeated over and over again in the same place while not occurring at all in intervening areas is highly improbable.

The facts that the gypsum is segregated in workable deposits in the Maccrady formation at intervals along a fault contact, with barren areas between, and that none occurs in the same formation, so far as known, where not adjacent to the fault, are more reasonably explained by assuming, first, that gypsum was originally deposited as disseminated grains and innumerable thin leaves with argillaceous and calcareous silt and earthy sand of the Maccrady formation in a partly inclosed arm of the sea, at times subjected to intense evaporation; second, that the gypsum was later concentrated in the same formation by ground waters, which, circulating along the fault, dissolved part of the disseminated calcium sulphate and redeposited it in adjacent gypsiferous beds, the gypsum being segregated by chemical selection. The calcium carbonate in the calcareous silt was likewise dissolved by the meteoric waters and the gypsum has taken its place, possibly by direct replacement, the waters, being carbonated, dissolving the calcium carbonate and depositing the calcium sulphate.

A sample of unaltered earthy limestone from the Maccrady formation at the horizon of the gypsum-bearing clays was analyzed for F. A. Wilder, president of the Southern Gypsum Co., and was reported to contain 4 per cent of $CaSO_4$, which would represent the disseminated gypsum in an original calcareous silt.

In addition to the facts mentioned above pointing to this conclusion, several other observations may be cited. The occurrence of large crystalline sheets of selenite in the granocrystalline mass and especially of small veinlets of satin spar in the otherwise barren inclosing clay, affords positive proof that solution and redeposition may have taken place to some extent. The massive gypsum has the appearance of bedding, due to the banding of gray impurities, but on close observation this is found to be not sedimentary banding parallel to the inclosing strata but concentric banding parallel to inclosed bodies of "black rock," fine particles of the argillaceous material producing the dark banding. These argillaceous masses may have resulted from less soluble clayey masses in an otherwise calcareous gypsiferous bed which was gradually encroached upon during the concentration of the gypsum and particles of it were left as banded impurities in the gypsum; similar drab argillaceous concretionary masses were observed in the red argillite 94 feet above the base of the Maccrady formation on the road east of Watson Gap. Or, on the other hand, the argillaceous impurities may have been segregated in the rounded masses by chemical repulsion during the concentration and purification of the gypsum. At least, both the banding of the gypsum and the rounded masses of argillaceous "black rock" appear to have resulted from the secondary segregation of the gypsum. The red plastic clay that generally incloses the gypsum is probably the fine argillaceous impurity of the earthy limestone left as a residuum, expelled by the crystalline segregation of the gypsum, and stained red by contained iron highly oxidized when set free during the process. Thin layers of fine-grained limestone in the gypsiferous clays were apparently redeposited from solution as another secondary mineral.

This theory as to the method of the concentration of gypsum is not new, for it has been proved beyond much doubt that the remarkable domes of salt and gypsum in Louisiana and Texas were formed by the deposition of these minerals along spring lines at the exposed intersection of fissures or faults,[1] having been dissolved and transported from some deeper-lying beds. Secondary limestone, apparently similar to the crackled layers in the clays of the Holston Valley area, also occur in the domes associated with the salt and gypsum. The fact that the Louisiana deposits were derived from lower beds suggests the possibility that the salt and gypsum in the Holston Valley area were also derived from beds at a lower horizon, that the solutions rose along the fault, and that these minerals were deposited at or near the surface in their present position. This explanation, however, is untenable, inasmuch as none of the older formations which outcrop to the west on the slopes of Clinch Mountain—not even the representative of the Salina, the great salt and gypsum bearing formation of New York—contain deposits from which these minerals could have been derived, and furthermore, as such strictly secondary deposits would be found only at or near the surface, whereas the Holston Valley deposits occur interbedded in the Maccrady formation to considerable depths.

[1] Harris, G. D., Rock salt: Bull. Louisiana Geol. Survey No. 7, 1907; Oil and gas in Louisiana: Bull. U. S. Geol. Survey No. 429, 1910.

If the theory of secondary concentration above suggested is the correct explanation of the origin of the gypsum in the Holston Valley area, it accounts for the absence of the mineral in quantity on the west side of the syncline away from the fault, the occurrence of natural outcrops of gypsum close to the fault, and the greater thickness of the deposits toward the southeast, as developed by borings in the Saltville, Plasterco, North Holston, and other tracts tested. In accordance with this theory it may be predicted that the gypsum will be found to extend under the overthrust Cambrian dolomite as far as the Maccrady formation is at the fault contact, and when the deposits near the surface are worked out deeper mining may be carried in this direction.

The beds of rock salt undoubtedly had the same origin as the gypsum and may be regarded as concentrations of somewhat saliferous beds, the associated calcium carbonate of the earthy limestone being dissolved out and its place taken by salt, segregated by solution and redeposition through chemical selection. Whether workable beds will be found associated with all the gypsum deposits can not at present be determined, but where salt has not been encountered in mining the gypsum there is still a prospect that it may be discovered at greater depth close to or under the overthrust dolomite. This is especially true southwest of Saltville, where the overriding Cambrian limestone conceals most of the Maccrady formation, as it is apparently turned under in a minor anticline next to the fault. Southwest of Plasterco both salt and gypsum may be expected along the fault some distance from its outcrop under the overthrust mass, where the Maccrady formation is probably at the fault contact. This may be proved by either drilling through an unknown thickness of tough dolomite southeast of the fault or boring diagonally under it in the soft rocks at the fault contact.

## SUMMARY.

The gypsum and salt deposits of southwestern Virginia described in this report are believed by the writer to have been derived from calcareous-argillaceous sediments which originally contained disseminated gypsum and salt precipitated in a partly inclosed arm of the sea during the deposition of the Maccrady formation, these minerals having been concentrated in the same formation by ground waters which circulated along the fault contact between the Carboniferous and Cambrian rocks, dissolved the calcium carbonate from the earthy limestones, and segregated the gypsum and salt in the gypsiferous and saline beds by chemical selection.

# 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: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 741–834.

Butts, Charles, Variegated marble southeast of Calera, Shelby County, Ala.: Bull. 470, 1911, pp. 237–239.

Coons, A. T., Slate: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 723–739.

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.

——— The granites of Maine: Bull. 313, 1907, 202 pp.

——— 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. 15c.

Darton, N. H., Marble of White Pine County, Nev., near Gandy, Utah: Bull. 340, 1908, pp. 377–380.

——— 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.

——— Brownstones of Pennsylvania: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1025–1043.

Hopkins, T. C., and Siebenthal, C. E., The Bedford oolitic limestone of Indiana: Eighteenth Ann. Rept., pt. 5, 1897, pp. 1050–1057.

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.

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.

——— 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, 1895, 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. 40c.

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 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.

BASSLER, R. S., Cement materials of the valley of Virginia: Bull. 260, 1905, pp. 531–544. 40c.

BURCHARD, E. F., Portland cement materials near Dubuque, Iowa: Bull. 315, 1907, pp. 225–231.

——— Concrete materials produced in the Chicago district: Bull. 340, 1908, pp. 383–410.

——— 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 1911: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 485–519.

BUTTS, CHARLES, Sand-lime brick making near Birmingham, Ala.: Bull. 315, 1907, pp. 256–258.

——— Ganister in Blair County, Pa.: Bull. 380, 1909, pp. 337–342.

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. 40c.

——— 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., The materials and manufacture of Portland cement: Senate Doc. 19, 58th Cong., 1st sess., 1903, pp. 2–11.

——— 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. Exhausted. Available for reference in larger public libraries.

——— The American cement industry: Bull. 260, 1905, pp. 496–505. 40c.

——— Portland cement resources of New York: Bull. 260, 1905, pp. 522–530. 40c.

——— 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 (in press).

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.

*——— 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.

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.

PEPPERBERG, L. J., Cement material near Havre, Mont.: Bull. 380, 1909, pp. 327–336.

RICHARDSON, G. B., Portland cement materials near El Paso, Tex.: Bull. 340, 1908, pp. 411–414.

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 Pittsburg 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.

TAFF, 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.

# SURVEY PUBLICATIONS ON CLAYS, ETC.

In addition to the papers named below, some of the publications listed on pages 258–259 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.


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. 15c.

——— The clays of Arkansas: Bull. 351, 1908, 247 pp.

BUTTS, CHARLES, 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.

——— Economic geology of Richmond, Va., and vicinity: Bull. 483, 1911, 48 pp.

DARTON, N. H., and SIEBENTHAL, C. E., Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report: Bull. 364, 1909, 81 pp.

DEUSSEN, ALEXANDER, Notes on some clays from Texas: Bull. 470, 1911, pp. 302–352.

ECKEL, E. C., Stoneware and brick clays of western Tennessee and northwestern Mississippi: Bull. 213, 1903, pp. 382–391. 25c.

——— Clays of Garland County, Ark.: Bull. 285, 1906, pp. 407–411. Exhausted.

FENNEMAN, N. M., Clay resources of the St. Louis district, Missouri: Bull. 315, 1907, pp. 315–321. 50c.

——— Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: Bull. 438, 1911, 73 pp.

FISHER, C. A., The bentonite deposits of Wyoming: Bull. 260, 1905, pp. 559–563. 40c.

——— Clays in the Kootenai formation near Belt, Mont.: Bull. 340, 1908, pp. 417–423.

FULLER, M. L., Clays of Cape Cod, Massachusetts: Bull. 285, 1906, pp. 432–441. Exhausted.

LANDES, HENRY, The clay deposits of Washington: Bull. 260, 1905, pp. 550–558. 40c.

LINES, E. F., Clays and shales of the Clarion quadrangle, Clarion County, Pa.: Bull. 315, 1907, pp. 335–343. 50c.

MATSON, G. C., Notes on the clays of Florida: Bull. 380, 1909, pp. 346–356.

MIDDLETON, JEFFERSON, Clay-working industries: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 521–584.[1]

——— Fuller's earth: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1031–1035.

PHALEN, W. C., Clay resources of northeastern Kentucky: Bull. 285, 1906, pp. 412–416. Exhausted.

——— Economic geology of the Kenova quadrangle, Kentucky, Ohio, and West Virginia: Bull. 349, 1908, pp. 112–122.

PHALEN, W. C., and MARTIN, LAWRENCE, Clays and shales of southwestern Cambria County, Pa.: Bull. 315, 1907, pp. 344–354. 50c.

——— ——— Mineral resources of Johnstown, Pa., and vicinity: Bull. 447, 1911, 140 pp.

PORTER, J. T., Properties and tests of fuller's earth: Bull. 315, 1907, pp. 268–290. 50c.

RICHARDSON, G. B., Clay near Calhan, El Paso County, Colo.: Bull. 470, 1911, pp. 293–296.

RIES, HEINRICH, Technology of the clay industry: Sixteenth Ann. Rept., pt. 4, 1895, pp. 523–575. $1.20.

——— The pottery industry of the United States: Seventeenth Ann. Rept., pt. 3, 1896, pp. 842–880.

——— The clays of the United States east of the Mississippi River: Prof. Paper 11, 1903, 298 pp. 40c.

SCHRADER, F. C., and HAWORTH, ERASMUS, Clay industries of the Independence quadrangle, Kansas: Bull. 260, 1905, pp. 546–549. 40c.

SHALER, M. K., and GARDNER, J. H., Clay deposits of the western part of the Durango-Gallup coal field of Colorado and New Mexico: Bull. 315, 1907, pp. 296–302. 50c.

SHALER, N. S., WOODWORTH, J. B., and MARBUT, C. F., The glacial brick clays of Rhode Island and southeastern Massachusetts: Seventeenth Ann. Rept., pt. 1, 1896, pp. 957–1004.

SHAW, E. W., Clay resources of the Murphysboro quadrangle, Illinois: Bull. 470, 1911, pp. 297–301.

SIEBENTHAL, C. E., Bentonite of the Laramie Basin, Wyoming: Bull. 285, 1906, pp. 445–447. Exhausted.

STOSE, G. W., White clays of South Mountain, Pennsylvania: Bull. 315, 1907, pp. 322–334. 50c.

UDDEN, J. A., Geology and mineral resources of the Peoria quadrangle, Illinois: Bull. 506, 1912, 103 pp.

VAN HORN, F. B., Fuller's earth: Mineral Resources U. S. for 1907, pt. 2, 1908, pp. 731–734. $1.

VAUGHAN, T. W., Fuller's earth of southwestern Georgia and Florida: Mineral Resources U. S. for 1901, 1902, pp. 922–934. 50c.

——— Fuller's earth deposits of Florida and Georgia: Bull. 213, 1903, pp. 392–399. 25c.

VEATCH, OTTO, Kaolins and fire clays of central Georgia: Bull. 315, 1907, pp. 303–314. 50c.

WOOLSEY, L. H., Clays of the Ohio Valley in Pennsylvania: Bull. 225, 1904, pp. 463–480. 35c.

[1] Previous volumes of the Mineral Resources of the United States contain chapters devoted to clay and the clay-working industries of the United States.

# SURVEY PUBLICATIONS ON GYPSUM AND PLASTERS.

The more important publications of the United States Geological Survey on gypsum and plasters are included in the following list. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. 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 others, Gypsum deposits of the United States: Bull. 223, 1904, 123 pp. 25c.

Boutwell, J. M., Rock gypsum at Nephi, Utah: Bull. 225, 1904, pp. 483–487. 35c.

Burchard, E. F., Gypsum deposits in Eagle County, Colo.: Bull. 470, 1911, pp. 354–366.

——— Gypsum: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 639–644.

Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report: Bull. 364, 1909, 81 pp.

Eckel, E. C., Gypsum and gypsum products: Mineral Resources U. S. for 1905, 1906, pp. 1105–1115. $1.

Harder, E. C., The gypsum deposits of the Palen Mountains, Riverside County, Cal.: Bull. 430, 1910, pp. 407–416.

Hess, F. L., A reconnaissance of the gypsum deposits of California: Bull. 413, 1910, 37 pp.

——— Gypsum deposits near Cane Springs, Kern County, Cal.: Bull. 430, 1910, pp. 417–418.

Richardson, G. B., Salt, gypsum, and petroleum in trans-Pecos Texas: Bull. 260, 1905, pp. 573–585. 40c.

Shaler, M. K., Gypsum in northwestern New Mexico: Bull. 315, 1907, pp. 260–265.

Siebenthal, C. E., Gypsum of the Uncompahgre region, Colorado: Bull. 285, 1906. pp. 401–403. Exhausted.

——— Gypsum deposits of the Laramie district, Wyoming: Bull. 285, 1906, pp. 404–405. Exhausted.

## SURVEY PUBLICATIONS ON GLASS SAND AND GLASS-MAKING MATERIALS.

The list below includes the important publications of the United States Geological Survey on glass sand and glass-making materials. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The publications marked "Exhausted" are no longer available for distribution but may be consulted at many public libraries.

BURCHARD, E. F., Requirements of sand and limestone for glass making: Bull. 285, 1906, pp. 452–458. Exhausted.

——— Glass sand of the middle Mississippi basin: Bull. 285, 1906, pp. 459–472. Exhausted.

——— Glass-sand industry of Indiana, Kentucky, and Ohio: Bull. 315, 1907, pp. 361–376.

——— Notes on glass sands from various localities, mainly undeveloped: Bull. 315, 1907, pp. 377–382.

——— Glass sand, other sand, and gravel: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 585–638.

FENNEMAN, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: Bull. 438, 1911, 73 pp.

PHALEN, W. C., and MARTIN, LAWRENCE, Mineral resources of Johnstown, Pa., and vicinity: Bull. 447, 1911, 140 pp.

STOSE, G. W., Glass-sand industry in eastern West Virginia: Bull. 285, 1906, pp. 473–475. Exhausted.

WEEKS, J. D., Glass materials: Mineral Resources U. S. for 1883–84, 1885, pp. 958–973, 60c.; idem for 1885, 1886, pp. 544–555, 40c.

## SURVEY PUBLICATIONS ON LIME AND MAGNESITE.

In addition to the papers listed below, which deal principally with lime, magnesite, etc., further references on limestones will be found in the lists given under the heads "Cement" and "Building stone." These publications, except the one marked "Exhausted," can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C.


Bastin, E. S., The lime industry of Knox County, Me.: Bull. 285, 1906, pp. 393–400. Exhausted. May be seen at many public libraries.

Burchard, E. F., Lime: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 645–718.

Burchard, E. F., Butts, Charles, and Eckel, E. C., Iron ores, fuels, and fluxes of the Birmingham district, Alabama: Bull. 400, 1910, 204 pp.

Butts, Charles, Limestone and dolomite in the Birmingham district, Alabama: Bull. 315, 1907, pp. 247–255.

Calkins, F. C., and MacDonald, D. F., A geologic reconnaissance in northern Idaho and northwestern Montana: Bull. 384, 1909, 112 pp.

Gale, H. S., Magnesite: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1113–1127.

Hess, F. L., Some magnesite deposits of California: Bull. 285, 1906, pp. 385–392. Exhausted. May be seen at many public libraries.

—— The magnesite deposits of California: Bull. 355, 1908, 67 pp.

Ries, Heinrich, The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut: Seventeenth Ann. Rept., pt. 3, 1896, pp. 795–811.

# ASPHALT.

## SURVEY PUBLICATIONS ON ASPHALT.

The following list comprises the more important papers relative to asphalt published by the United States Geological Survey or by members of its staff. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.


ANDERSON, ROBERT, An occurrence of asphaltite in northeastern Nevada: Bull. 380, 1909, pp. 283–285.

BOUTWELL, J. M., Oil and asphalt prospects in Salt Lake basin, Utah: Bull. 260, 1905, pp. 468–479. 40c.

DAY, D. T., Asphalt: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1003–1021.

DAY, W. C., The coal and pitch of the Newport mine, Oregon: Nineteenth Ann. Rept., pt. 3, 1899, pp. 370–376. $2.25.

ELDRIDGE, G. H., The uintaite (gilsonite) deposits of Utah: Seventeenth Ann. Rept., pt. 1, 1896, pp. 909–949. $2.

——— The asphalt and bituminous-rock deposits of the United States: Twenty-second Ann. Rept., pt. 1, 1901, pp. 209–452.

——— Origin and distribution of asphalt and bituminous-rock deposits in the United States: Bull. 213, 1903, pp. 296–305. 25c.

HAYES, C. W., Asphalt deposits of Pike County, Ark.: Bull. 213, 1903, pp. 353–355. 25c.

TAFF, J. A., Albertite-like asphalt in the Choctaw Nation, Indian Territory: Am. Jour. Sci., 4th ser., vol. 8, 1899, pp. 219–224.

——— Description of the unleased segregated asphalt lands in the Chickasaw Nation, Indian Territory: U. S. Dept. Interior, Circular 6, 1904, 14 pp.

——— Grahamite deposits of southeastern Oklahoma: Bull. 380, 1909, pp. 286–297.

TAFF, J. A., and SMITH, C. D., Ozokerite deposits in Utah: Bull. 285, 1906, pp. 369–372. Exhausted. May be consulted at the larger libraries of the country.

VAUGHAN, T. W., The asphalt deposits of western Texas: Eighteenth Ann. Rept., pt. 5, 1897, pp. 930–935

# ABRASIVES.

## SURVEY PUBLICATIONS ON ABRASIVE MATERIALS.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various abrasive materials. The Government publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.


ARNOLD, RALPH, and ANDERSON, ROBERT, Diatomaceous deposits of northern Santa Barbara County, Cal.: Bull. 315, 1907, pp. 438–447.

CHATARD, T. M., Corundum and emery: Mineral Resources U. S. for 1883–84, 1885, pp. 714–720. 60c.

ECKEL, E. C., The emery deposits of Westchester County, N. Y.: Mineral Industry, vol. 9, 1901, pp. 15–17.

HOLMES, J. A., Corundum deposits of the southern Appalachian region: Seventeenth Ann. Rept., pt. 3, 1896, pp. 935–943.

JENKS, C. N., The manufacture and use of corundum: Seventeenth Ann. Rept., pt. 3, 1896, pp. 943–947.

PARKER, E. W., Abrasive materials: Nineteenth Ann. Rept., pt. 6, 1898, pp. 515–533.

PHALEN, W. C., Abrasive materials: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 835–854.

PRATT, J. H., The occurrence and distribution of corundum in the United States: Bull. 180, 1901, 98 pp. 20c.

——— Corundum and its occurrence and distribution in the United States: Bull. 269, 1905, 175 pp. (Bulletin 269 is a revised edition of Bulletin 180.)

RABORG, W. A., Buhrstones: Mineral Resources U. S. for 1886, 1887, pp. 581–582. 50c.

——— Grindstones: Mineral Resources U. S. for 1886, 1887, pp. 582–585. 50c.

——— Corundum: Mineral Resources U. S. for 1886, 1887, pp. 585–586. 50c.

READ, M. C., Berea grit: Mineral Resources U. S. for 1882, 1883, pp. 478–479. 50c.

SIEBENTHAL, C. E., and MESLER, R. D., Tripoli deposits near Seneca, Mo.: Bull. 340, 1908, pp. 429–437.

TURNER, G. M., Novaculite: Mineral Resources U. S. for 1885, 1886, pp. 433–436. 40c.

——— Novaculites and other whetstones: Mineral Resources U. S. for 1886, 1887, pp. 589–594. 50c.

WOOLSEY, L. H., Volcanic ash near Durango, Colo.: Bull. 285, 1906, pp. 476–479. Exhausted. May be found at many libraries.

# PHOSPHATES.

## A GEOLOGIC RECONNAISSANCE IN SOUTHEASTERN IDAHO.

By A. R. SCHULTZ and R. W. RICHARDS.

### PURPOSE OF INVESTIGATION.

A reconnaissance examination of the part of southeastern Idaho located between the Wyoming boundary and meridian 112° and between parallels 42° 45′ and 43° 30′ was undertaken in 1911 with the purpose of collecting data for the elimination of nonphosphate lands from the phosphate reserves. After the close of the detailed field work in southeastern Idaho, the writers spent three weeks in the region south of Snake River and north of the areas examined in detail by Gale and Richards[1] in 1909, and by Richards and Mansfield[2] in 1910 and 1911. As a result of this reconnaissance examination 249,049 acres of withdrawn phosphate land has been restored to agricultural entry. The data collected during the examination indicate that not all of the phosphate land was included in the phosphate reserves as originally constituted by the withdrawals of December, 1908, and December, 1909. The old phosphate reserve boundary has been so modified and extended as to include all the known phosphate areas. Figure 32 shows the area examined in 1911 in detail (1911b), as well as the reconnaissance area (1911a), its relation to the areas surveyed in the preceding years (1909 and 1910) and described in Bulletins 430 and 470, and the extent of the phosphate reserve on July 1, 1912. Some of the land in the Caribou Range lying between Tincup and Garden creeks is probably underlain by phosphate beds at depths of less than 5,000 feet. These lands have not yet been included in the phosphate reserve, because it was found to be impossible during the short reconnaissance examination to determine the thickness of the overlying beds and to work out the necessary detailed structure to determine in what places the phos-

[1] Gale, H. S., and Richards, R. W., Bull. U. S. Geol. Survey No. 430, 1910, pp. 457–535.
[2] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, 1912, pp. 681–709.

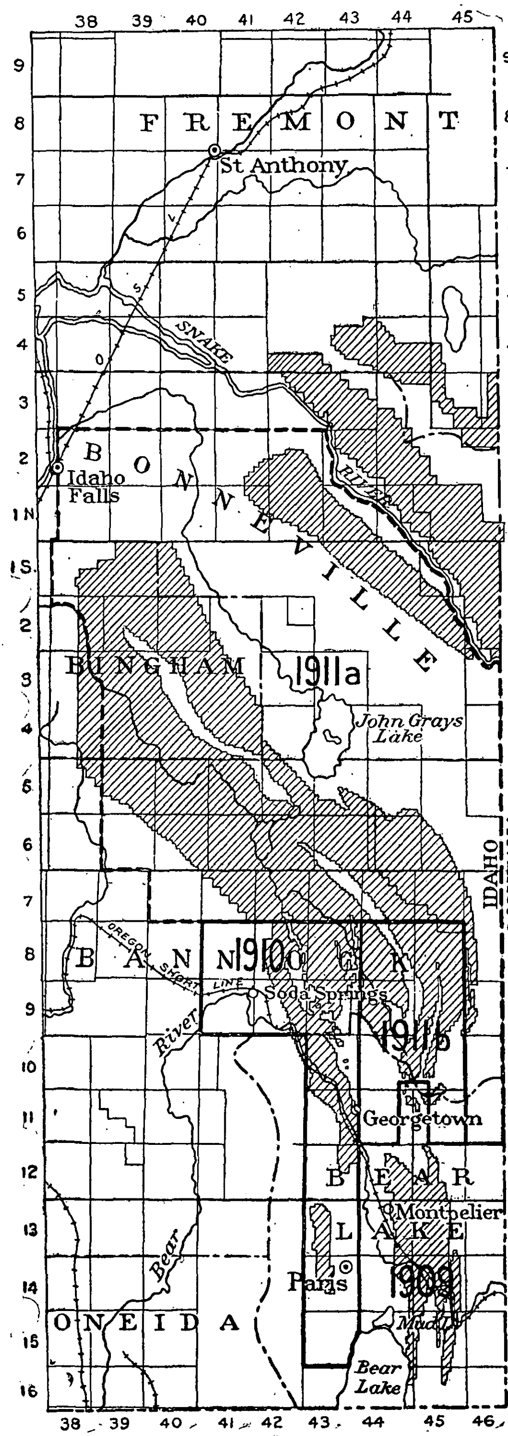



FIGURE 32.—Map showing phosphate reserve in Idaho July 1, 1912. Shaded areas indicate phosphate lands.

phate beds occur at depths less than 5,000 feet.

## EARLIER WORK.

The entire area was examined in 1877 by geologists of the Hayden Survey and described in the report for that year. North of the forty-third parallel the examination was conducted by Orestes St. John, and south of that line by A. C. Peale. The geologic reports by these men include a fund of accurate information and represent reconnaissance work of high standard. In accuracy and quantity, however, the data given in the text in both reports are well in advance of the geologic maps which accompany them. The errors of the maps are solely responsible for the mislocation of the phosphate reserves as originally constituted, and the main results of the present examination comprise corrections of the errors in these old maps.

## GEOGRAPHY.

The area examined includes about 2,000 square miles, all lying within the Snake River basin. The main drainage has a northwesterly trend and is carried by Blackfoot River, John Grays Lake and its outlet, Willow Creek, and Snake River. A large portion of the area is included within the Caribou National Forest and is mainly used for cattle and sheep grazing during the summer. A few ranchers control the greater part of the remainder of the area. Gray and Henry are the main trading points. Post offices are maintained at Alpine, Blowout, Glen, Gray, Henry, Herman, Irwin, Wayan, and Williamsburg.

Two main types of country are included in the area—the lava plains or plateaus and the rugged mountainous areas, which are made up of deformed sedimentary rocks, mainly sandstone and limestone.

## GEOLOGY.

### STRATIGRAPHY.

#### GENERALIZED SECTION.

The rocks of the region range in age from Cambrian to Quaternary. The stratigraphic column appears to be fully represented from the basal Carboniferous to the Cretaceous. At or near the end of Cretaceous time there was an interval of erosion which appears to have continued until the late Tertiary, and is indicated by a marked unconformity.

The following generalized section represents the range of conditions as they are now interpreted for this region:

*Generalized section of the formations in southeastern Idaho south of Snake River.*

| | Feet. |
|---|---|
| Quaternary: Alluvium, travertine, and lava flows | ? |
| Tertiary (Pliocene ?): Marls, marly limestones, and calcareous conglomerates; also lava flows | ? |
| Unconformity. | |
| Cretaceous: | |
| Coal-bearing shales and sandstones of the Colorado group | Not determined. |
| Bear River (?) formation (gray limestones, calcareous sandstones, and dark-colored shales) | Not determined. |
| Cretaceous and Jurassic: Beckwith formation (red shales, sandstones, and conglomerates, with some limestone) | 4,650 |
| Jurassic: Twin Creek limestone (shaly limestone) | 1,200–3,500 |
| Jurassic or Triassic: Nugget sandstone (dark-red to white sandstone and quartzite) | 1,000–1,900 |
| Triassic: | |
| Ankareh shale (red shale with intercalated mottled limestone) | 200– 670 |
| Thaynes limestone (thin and thick bedded platy limestones) | 700–2,000 |

| | Feet. |
|---|---|
| Triassic—Continued. | |
| Woodside shale (rusty-brown to olive-green calcareous shales intercalated with muddy limestone lentils) | 1,000-1,200 |
| Carboniferous: | |
| Permian (?): Phosphoria formation[1] (Rex chert member at top over yellow to brown sandstones, brown to black shales, phosphate rock) | 75- 627 |
| Pennsylvanian: Wells formation[1] (sandy limestones, calcareous sandstones, and variable quartzites) | 1,000-2,400 |
| Mississippian: | |
| Upper Mississippian limestone (light gray, thick bedded) | 1,130+ |
| Madison limestone, lower Mississippian (thin bedded, dark gray to bluish gray) | 1,000 |
| Pre-Carboniferous: White quartzite (probably Ordovician) underlain by Cambrian sediments (limestones and quartzites, with beds of shale). | |

### PRE-CARBONIFEROUS ROCKS.

In the extreme southwestern portion of the area examined a white quartzite was found overthrust upon limestones of Mississippian age. The quartzite is lithologically similar to a quartzite seen in 1910 in vicinity of Soda Springs and there interpreted to be of Ordovician age; it here occurs in a similar discordant relation with Carboniferous rocks. Associated with the Ordovician rocks is a series of limestones and quartzites of Cambrian age, but no attempt was made to map the separate formational units.

### CARBONIFEROUS AND TRIASSIC ROCKS.

*General features.*—In the course of these reconnoissance examinations it has been found advisable, for the small-scale mapping, to group the Madison limestone (lower Mississippian), the upper Mississippian limestone, and the Wells formation (Pennsylvanian) into one map unit, and the later Carboniferous (Permian ?) and Triassic formations into another map unit comprising the Phosphoria formation (Permian ?), the Woodside shale, Thaynes limestone, Ankareh shale (all of Lower Triassic age), and the Nugget sandstone (of either Triassic or early Jurassic age) and corresponding to the "Permo-Carboniferous" of the Fortieth Parallel Survey.

In the southern part of the region examined the area occupied by the Permian (?) and Triassic formations practically represents the extent of the lands which are regarded as containing phosphate in

[1] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, 1912, pp. 681-709.

such quantities as will eventually be suitable for economic development. The beds overlying the phosphate deposits become much thinner toward the north, and in the northern part of the region the area that contains phosphate deposits susceptible of economic development should probably include the Twin Creek limestone and the basal member of the Beckwith formation.

The general distribution of the Mississippian and Pennsylvanian rocks is shown on the accompanying map. In all the areas rocks of both series outcrop, the Pennsylvanian lying conformably on the Mississippian. Richards and Mansfield have made a detailed study of the Mississippian and Pennsylvanian formations in the area lying immediately to the south and summarize them briefly as follows:

*Madison limestone* (*lower Mississippian*).—The basal Carboniferous rocks are dark bluish gray, relatively thin bedded cliff-making limestones. The base of the formation is not exposed, but the thickness may amount to 1,000 feet. The fauna collected from these beds includes small cup corals, Syringopora, Loxonema, Productella, *Spirifer centronatus*, Chonetes, Euomphalus, etc., and, according to G. H. Girty, corresponds to the fauna of the basal portion of the "Wasatch limestone" of the Wasatch Mountains of Utah, as described by the early writers.

*Upper Mississippian limestone.*—Above the Madison limestone, apparently in conformable succession, though the base is not exposed, occur about 1,130 feet of massive light to dark-gray limestones weathering white to light gray. Locally there is a zone of dark shale about 15 feet thick near the top. In places also there are chert nodules in concentric and irregular forms, and streaks of chert. The limestones are here and there specked with siderite and seamed with calcite or aragonite and at some horizons are abundantly fossiliferous. The fauna includes large cup corals with many fine septa, Syringopora, Lithostrotion, Martinia, and *Productus giganteus*.

*Wells formation* (*Pennsylvanian*).—The upper Mississippian limestone is succeeded by about 2,400 feet of sandy limestones, calcareous sandstones, and quartzites of somewhat variable character. At the type locality in Wells Canyon, in T. 10 S., R. 45 E., the formation consists of three portions. The upper and lower portions are predominantly calcareous; the middle is mainly sandy. For these strata the name Wells formation has recently been introduced.[1]

The upper limestone, 75 feet thick, consists of dense gray siliceous limestone or calcareous sandstone, which weathers into white massive beds that are topographically conspicuous as cliff makers. Bluish-white chert occurs in bands 2 inches to 1 foot thick and locally in ovoid nodules. Toward the base the chert becomes more nodular and darker. Silicified fragments of brachiopods project in

[1] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, 1912, pp. 681–709.

little crescents from the weathered surfaces of the limestone. The most important fossils are Squamularia and a large Productus.

The middle portion comprises 1,700 to 1,800 feet of calcareous sandstone and quartzite, with a few thin beds of limestone, weathering white, red, or yellow and forming smooth slopes with few projecting ledges. This member is sparingly fossiliferous or nonfossiliferous. No fossils have yet been found in it.

The lower portion is from 100 to 800 feet thick. The rocks are cherty limestones with interbedded sandstones and are topographically important as cliff makers. They weather to gray or reddish colors. The base of the formation is marked by the Schizophoria horizon (Schizophoria, Marginifera, Composita, *Spirifer rockymontanus*, Bryozoa, etc.).

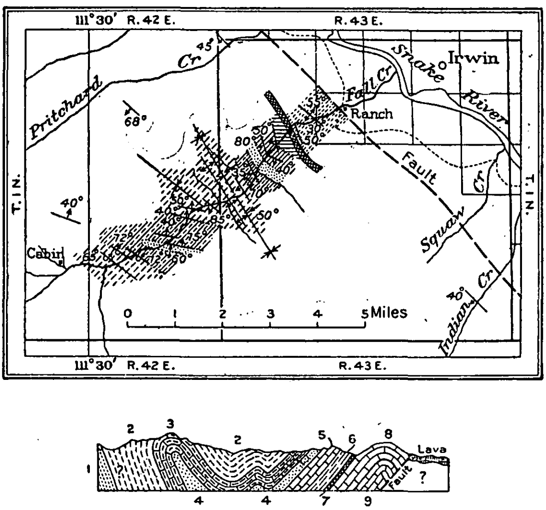



FIGURE 33.—Map and geologic section along Fall Creek, T. 1 N., Rs. 42 and 43 E., Idaho, made from a paced traverse along Fall Creek across part of the Caribou Range. 1, Bear River (?) formation (Cretaceous); 2, Beckwith formation (Cretaceous and Jurassic); 3, Twin Creek limestone (Upper Jurassic); 4, Nugget sandstone (Jurassic or Triassic); 5, Thaynes limestone and Ankareh shale (Lower Triassic); 6, Woodside shale (Lower Triassic); 7, Phosphoria formation (Permian?); 8, Wells formation (Pennsylvanian); 9, Madison limestone (Mississippian).

*Phosphoria formation (Permian?)*.—The Phosphoria formation,[1] which is regarded as of probable Permian age, although it may prove to be Pennsylvanian, overlies the Wells formation conformably, so far as observed in the course of this examination. Its stratigraphic relation to the overlying and underlying formations is shown in the section on Fall Creek (fig. 33).

The Phosphoria formation carries the economically valuable deposits of phosphate of this and the surrounding region.

In the region immediately south of the area covered in the course of this reconnaissance the formation consists of two portions. The upper part is mainly chert and cherty limestone and has been called the Rex chert member. This member ranges from a maximum thickness of about 450 feet to a feather edge but usually is from 100 to 240 feet thick. The basal portion of the formation consists of 75

[1] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, 1912, pp. 681–709.

to 627 feet of alternating brownish shales, brownish sandstones, compact fetid limestones, usually lenticular, with one, two, or three zones bearing beds of high-grade oolitic phosphate rock (containing 70 per cent or more of tricalcium phosphate), which range from 1 to 7 feet in thickness. The natural exposures within the area examined were not good enough to afford detailed sections, but in all the districts where its outcrop is indicated on the map the Phosphoria formation was noted as composed of ledge-making cherts at the top (Rex chert member) and softer rocks, shales and sandstones with phosphate rock, at the base. The upper portion locally, as on Pritchard Creek, includes a thin bed of high-grade rock phosphate. It is thought that careful measurements will show that the upper cherty portion of the formation occupies a relatively greater part of the entire section than it does to the south. The areal distribution of this formation is practically represented by the line of phosphate outcrop on Plate VI.

*Lower Triassic formations.*—The lower Triassic rocks, including the Woodside, Thaynes, and Ankareh formations, occur throughout the Caribou and Blackfoot ranges and were for the most part mapped by the Hayden Survey as part of the "Jura-Trias."

The Woodside shale conformably overlies the Phosphoria formation (Permian?) and is composed mainly of rusty brown to olive-green calcareous shales intercalated with muddy limestone lentils in which fossil shells are so closely matted that their specific characters are rarely discernible. Toward the top limestones become a prominent feature of the formation, and the distinction between this and the overlying Thaynes limestone depends mainly upon the recognition of a cephalopod zone containing Meekoceras at the base of the Thaynes.

The Thaynes limestone includes both thick-bedded and thin-bedded platy limestone. Lithologically it is usually characterized by a bluish-gray color on fresh fracture, but it weathers to light brown or buff and generally to an uneven sandy surface. The Meekoceras zone was noted in the Blackfoot Range at several places in the southeastern part of the field and in sec. 15, T. 4 S., R. 40 E., and secs. 6 and 11 T, 5 S., R. 40 E.

A red-bed series, composed of red shale and intercalated mottled limestone, overlies the Thaynes limestone and is known as the Ankareh shale. This formation and the two immediately underlying formations were originally described by Boutwell from observations in the Park City mining district, Utah. The similarity of the beds in the Idaho section to those around Park City has led to the use of the same formation names in this region. Red shales which are representative of the Ankareh shale were noted in T. 7 S., R. 44 E., and in the canyons of Pritchard and Fall creeks, in T. 1 N., Rs. 42 and 43 E.

*Nugget sandstone* (*Jurassic or Triassic*).—The Nugget sandstone overlies the Ankareh shale and consists of massive red sandstone, with white conglomeratic sandstone at the base and top of the formation, in places silicified to a quartzite. Owing to its massive and resistant character the Nugget sandstone forms high ridges with broad rounded slopes. The formation thins toward the north, and in the north end of the Caribou Range, south of Snake River, is approximately 1,000 feet thick. The Nugget sandstone was recognized throughout the area examined, along the Lander trail, Tincup Creek, Fall Creek, Pritchard Creek, Willow Creek near the mouth of John Grays Outlet, and at several places in the Caribou and Blackfoot ranges.

### JURASSIC AND CRETACEOUS ROCKS.

For convenience of mapping, the Jurassic and Cretaceous rocks overlying the Nugget sandstone in this region have been grouped together. These rocks, which correspond to the "Laramie" and in part to the "Jura Trias" of the Hayden Survey reports on this area, comprise the Twin Creek limestone (Upper Jurassic), the Beckwith formation (Jurassic and Cretaceous), the Bear River (?) formation (Upper Cretaceous), and the overlying coal-bearing sandstones and shales of the Colorado group. The later Cretaceous Bear River (?) formation and Colorado group do not occur in the areas studied in detail but were observed throughout the northern part of the region west of the Caribou Range. As all these beds occur at a considerable distance stratigraphically above the phosphate horizon, very little study was made of their distribution.

The Twin Creek limestone overlies the Nugget sandstone and, so far as observed in the course of this examination, is conformable to it. The beds consist principally of grayish-white shaly limestones and are readily recognized wherever exposed. The Twin Creek becomes thinner toward the north and is approximately 1,200 to 1,500 feet thick on Fall Creek, in the northern part of the Caribou Range. The beds of this formation are exposed in numerous parallel anticlines and synclines throughout the Caribou Range and are readily seen along Tincup and Fall creeks. They are also exposed on Willow Creek at the mouth of John Grays Outlet and in the northern part of the Blackfoot Range. In the northern part of the field they were for the most part mapped by the geologists of the Hayden Survey as a part of their Laramie formation.

The Beckwith formation overlies the Twin Creek limestone and is extensively exposed in the northeastern part of the area examined, particularly north and east of John Grays Lake. Extensive exposures of these beds were also seen in the north end of Little Gray

Ridge, west of John Grays Lake, and in the hills east of Willow Creek. Throughout the Caribou Range the Twin Creek and Beckwith formations are intimately associated with the numerous anticlines and synclines that cause the outcrops of these beds to parallel one another. The exposures of these beds and their relations to one another are indicated in the sections along Fall and Tincup creeks (figs. 33 and 34). The Beckwith formation consists of reddish or chocolate-colored sandstone and shale, associated with whitish to gray sandstone, limestone, and red conglomerates. The upper member consists of calcareous sandstone, red conglomerate, and massive gray limestone. Most of the Beckwith exposures were mapped by the geologists of the Hayden Survey as part of their Laramie formation.

Overlying the Beckwith formation, with apparent conformity, occurs a series of beds whose thickness was not determined. They consist of gray limestones, calcareous sandstones, dark-colored shales, brownish and gray sandstone, and light-drab calcareous deposits. Interbedded with these rocks are calcareous shales and thin beds of coal. The beds are very widely distributed north of the old Lander trail and east of Willow Creek, lying for the most part on the west flank of the Caribou Range or between that range and Willow Creek. A hurried examination was made of these beds in the Fall Creek basin and 2 miles northeast of Herman (northeast of John Grays Lake). About a quarter of a mile east of the east quarter corner of sec. 25, T. 3 S., R. 43 E., a few fragmentary fossils were collected by Mr. Schultz from beds that resemble lithologically the Bear River formation of western Wyoming. A similar fossil bed was seen in the Fall Creek basin, where the creek enters the canyon. It is more than likely that St. John correlated these beds, as well as the Beckwith and Twin Creek formations, as Laramie on the basis of similar fresh-water fossils.

T. W. Stanton, who examined the fossils collected in T. 3 S., R. 43 E., reports on them as follows:

I have examined the small lot of fresh-water fossils which you recently handed me from a locality northeast of John Grays Lake, on the west slope of the Caribou Range, about 2 miles east of Herman, Idaho. It has not been found practicable to develop the fossils by etching or otherwise, and the preservation of the specimens on weathered surfaces is not satisfactory. Fragments of Unio and casts of Viviparus or Campeloma are recognized, and Goniobasis and possibly other genera of fresh-water gastropods may be represented. In my opinion this fauna is Cretaceous, but on account of the absence of definitely characteristic forms I am unable to determine whether it belongs to the Bear River formation. Similar imperfect fossils have been collected in Montana in rocks that are provisionally referred to the Kootenai formation.

Additional good collections and accurate stratigraphic data concerning the rocks which were mapped as Laramie by St. John in this general region are greatly desired.

### TERTIARY AND QUATERNARY ROCKS.

On Snake River in T. 1 S., R. 45 E., near the mouth of Bear Creek, is a small area of calcareous conglomerates and inferior lithographic limestones which were provisionally mapped as Carboniferous by St. John,[1] but which appear in the light of the detailed studies that have been carried on farther to the south to be Tertiary lake beds, probably of Pliocene age. This correlation is made purely on lithologic and structural grounds.

On the north side of Indian Creek, near the southwest corner of sec. 5, T. 1 N., R. 45 E., at the north end of the Caribou Range, were seen some pinkish-gray clays and greenish, red, and drab sandstone and clays that resemble the beds of the Wasatch formation (Eocene) of western Wyoming and that may represent the northwestward extension of that formation.

The Tertiary beds on Indian Creek are overlain by igneous rocks or basalts similar to those which occur in the canyons farther west. South of Indian Creek the Tertiary sediments strike approximately east and west and dip about 45° S. The greater portion of the igneous rocks represent the southern lobes of the extensive lava flows of the Snake River Plains, which have been referred mainly to the Tertiary by Russell.[2] There are, however, within the area a number of subordinate cones, many of which are broken and shattered and undoubtedly served as the outlet for the later lavas surrounding them. Some of these are of Pleistocene or Recent age if the Tertiary beds are correctly determined as Pliocene.

Along all the large streams in this region occur considerable deposits of washed soil and gravels of Quaternary age. Some of the gravels along Snake River and McCoy Creek and its tributaries are washed for gold. For the most part the alluvial bottoms are small and are confined to narrow strips along the streams or are cut out entirely where the stream has entrenched itself in the lava beds. The largest of the alluvial bottoms occurs around John Grays Lake and marks in a way the former extent of this large inland lake.

### STRUCTURE.

The geologic structure of the area examined is rather complex, and no attempt was made to decipher any of the structure in detail. The tracing of the phosphate beds, however, permitted all the larger units to be worked out with considerable accuracy.

Three main mountain ranges, more or less parallel, extend in a southeast-northwest direction across the area examined. The one

---

[1] St. John, Orestes, Report on the geological field work of the Teton division: Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1879, pp. 325–508.

[2] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 1–192.

farthest to the northeast, south of Snake River, is the Caribou Range. Southwest of the Caribou Range lies the Blackfoot Range, and in the southwestern part of the area lies the northwest extension of the Soda Springs Hills.

The Caribou Range is by far the most complex of these ranges and consists of an anticlinorium, as indicated by the accompanying section, along Tincup Creek (fig. 34). A large thrust fault extends along the east flank of the Caribou Range and probably represents the northward continuation of the fault that lies for the most part in Snake and Salt River valleys, west of the Salt River Range. Minor faulting was observed at several places in the Caribou Range, but

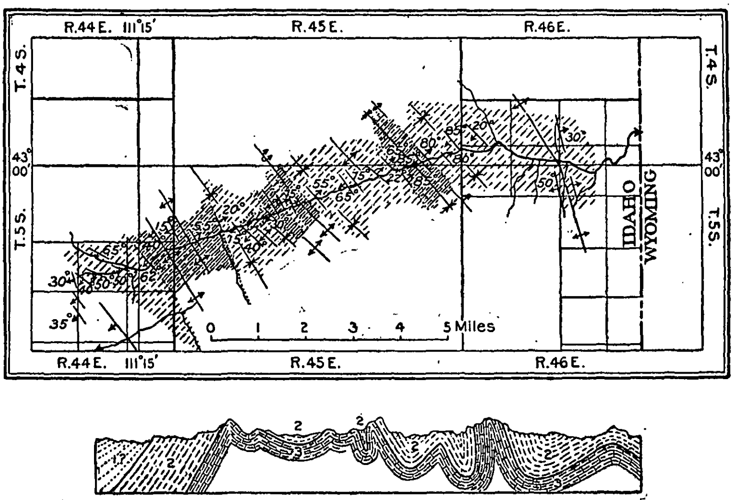



FIGURE 34.—Map and geologic section along Tincup Creek, T. 5 S., Rs. 44, 45, and 46 E., Idaho, made from a paced traverse along Tincup Creek across part of the Caribou Range. 1, Bear River (?) formation; 2, Beckwith formation; 3, Twin Creek limestone.

no attempt was made to study the relation of these faults to one another.

The Blackfoot Range consists chiefly of the crest of an anticline faulted along the northeast and southwest limbs. With these two major faults are associated numerous minor faults and folds that require considerable study before the history of the range can be worked out. It is believed that the fault along the northeast flank of the Blackfoot Range and south of John Grays Lake is the northward extension of the Bannock fault described by Richards and Mansfield.[1]

The Soda Springs Hills consist of a monoclinal uplift having a southeast-northwest trend and dipping toward the southwest. A large fault lies along the northeast side of the range and a similar fault occurs along the southwest. Both of these faults probably

[1] Richards, R. W., and Mansfield, G. R., Jour. Geology, vol. 20, 1912, pp. 681–709.

represent the northwest extension of the faults mapped by Richards and Mansfield[1] in the Soda Springs area and later correlated by them with the Bannock fault.[2]

## MINERAL DEPOSITS.

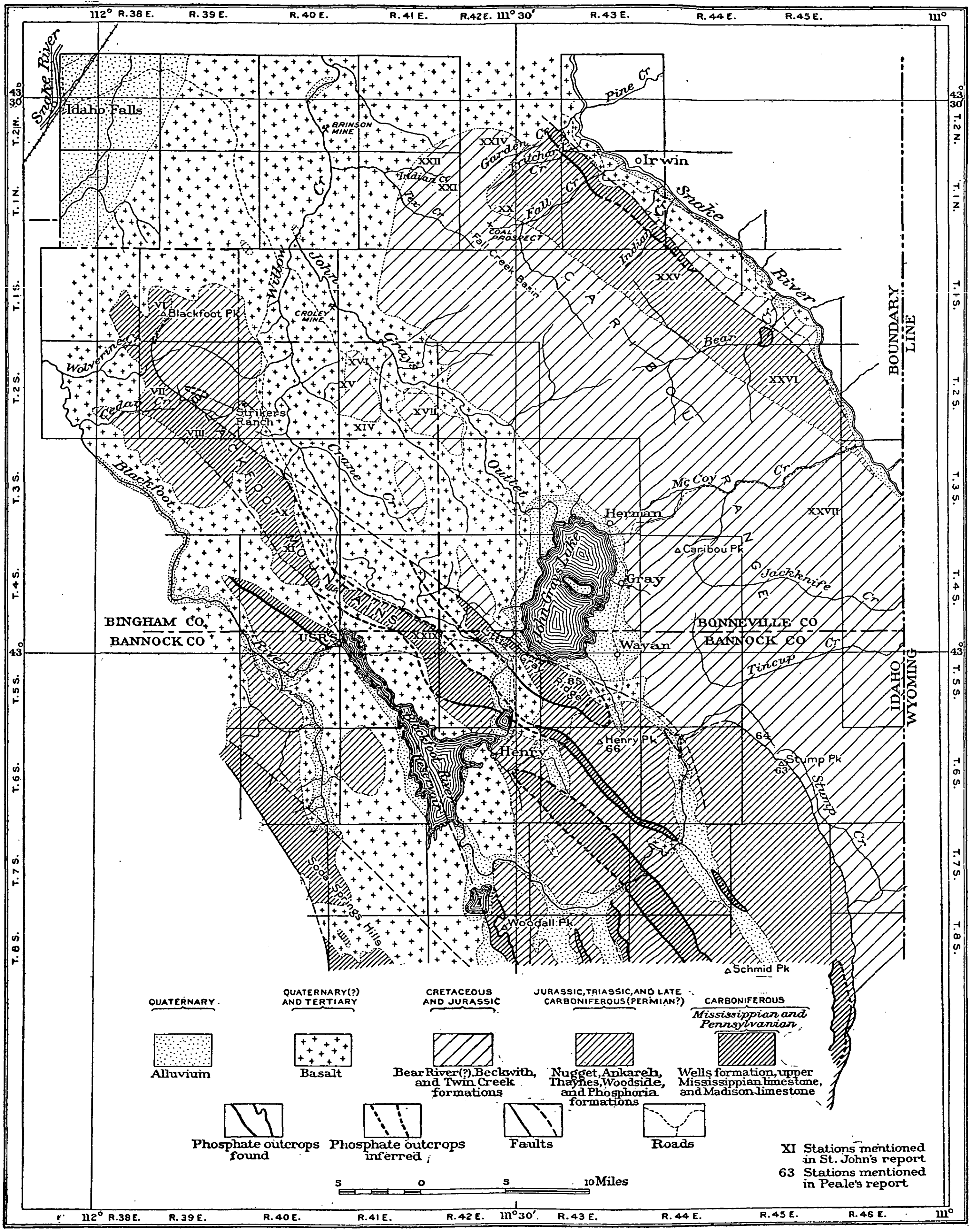
### PHOSPHATE.

The distribution of the phosphate beds or Phosphoria formation in the area examined can be best understood by referring to the map (Pl. VI) accompanying this report. The outcrops of the phosphate beds seen in the field are shown by heavy black lines; the inferred outcrops by dotted heavy lines. The distribution of the Phosphoria formation also indicates in a general way the structure of the region. The phosphate beds in this region are very similar to those described by Gale, Richards, and Mansfield in their reports on the areas to the south. No phosphate prospects have been opened in the area examined and no attempt was made in the reconnaissance examination to prospect the phosphate outcrops, and therefore detailed descriptions of the beds are lacking. Samples of float and fragments of rock in place picked up at several places show the presence of high-grade material, and workable beds similar to those prospected farther south are undoubtedly present. Samples of high-grade phosphate rock were found in the following localities:

Diamond Creek, in T. 7 S., R. 44 E.
Lanes Creek, in T. 6 S., R. 44 E.
Several places on the southwest flank of Little Gray Ridge southwest of John Grays Lake, in T. 5 S., R. 43 E.
Southwest and northeast flanks of Little Gray Ridge, or southeast extension of Blackfoot Range, in Tps. 4 to 7 S., Rs. 41 to 44 E.
Northeast flank of Blackfoot Range east and southeast of Blackfoot Peak, in T. 1 S., R. 39 E., and west of Striker's ranch, in T. 2 S., R. 39 E.
T. 4 S., R. 40 E., northwest of the United States Reclamation Service dam on Blackfoot River.
Sage Valley, Tps. 8 and 9 S., R. 46 E.
Caribou Range:
- Several places on Bear Creek.
- Indian Creek.
- Fall Creek.
- Pritchard Creek.
- Garden Creek.

Two sections of the phosphate shales in the areas to the south which have been examined in detail will give an idea of the range of phosphate content which may be expected within this area.

[1] Bull. U. S. Geol. Survey No. 470, 1911, Pls. X, XI.
[2] Jour. Geology, vol. 20, 1912, pp. 681–709.




MAP SHOWING THE DISTRIBUTION OF PHOSPHATE DEPOSITS IN A PORTION OF SOUTHEASTERN IDAHO, SOUTH OF SNAKE RIVER.

The following detailed section of the lower part of the Phosphoria formation was measured and sampled in 1909 under exceptionally favorable conditions of exposure in T. 11 S., R. 44 E., in the Georgetown district.

This section contains the maximum amount of high-grade phosphate rock and probably the highest average phosphoric acid content of all the sections which have been examined in detail in the western phosphate fields. It represents, then, presumably an upper limit of conditions which may be found upon prospecting within the area of this reconnaissance.

*Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho.*

| Field No. of specimen. | | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. | Thickness. | |
|---|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft.* | *in.* |
| 144-A | Shale, calcareous, or muddy limestone, brown, weathering into irregular chip fragments; effervesces vigorously | 3.5 | 7.7 | 25 | 6 |
| 144-B | Phosphate rock, oolitic, weathering brown or gray; effervesces slightly; lower 1½ inches somewhat cherty | 35.8 | 78.4 | | 6 |
| 144-C | Shale, hard, brown, calcareous at the top; effervesces vigorously | Trace. | | 1 | |
| 144-D | Phosphate rock, coarsely oolitic, gray; effervesces vigorously | 37.6 | 82.1 | 2 | 11 |
| 144-E | Shale, brownish, earthy, containing 6 inches of phosphate; effervesces considerably | 10.0 | 21.9 | 1 | |
| 144-F | Phosphate rock, including— Ft. in.<br>(a) Phosphate rock, oolitic, hard, gray, calcareous 7<br>(b) Phosphate rock, medium, gray, oolitic 6<br>(c) Shale, phosphatic, light brown 4<br>(Sample shows considerable effervescence.) | 21.9 | 48.0 | 1 | 5 |
| 144-G | Phosphate rock, including—<br>(a) Phosphate rock, coarsely oolitic, gray, brittle 1 2<br>(b) Phosphate rock, finely oolitic, brownish gray 4<br>(c) Phosphate rock, coarsely oolitic, dark gray 2<br>(d) Phosphate rock, finely oolitic, brownish gray 4<br>(e) Phosphate rock, coarsely oolitic, gray 7<br>(f) Phosphate rock, finely oolitic, thin bedded 3<br>(g) Phosphate rock, coarsely oolitic, gray 1 4<br>(Sample effervesces slightly.) | 33.3 | 72.7 | 4 | 2 |
| 144-H | Phosphate rock, including—<br>(a) Phosphate rock, medium to finely oolitic, brownish gray 7<br>(b) Shale, phosphatic, brownish, somewhat oolitic 10<br>(c) Phosphate rock, coarsely oolitic 2<br>(d) Phosphate rock, shaly, brown 3 | 29.3 | 65.8 | 1 | 10 |
| 144-I | Phosphate rock, including—<br>(a) Phosphate rock, coarsely oolitic, brownish-black streaks 1 1<br>(b) Phosphate rock, shale, brown, thin bedded 5<br>(c) Phosphate rock, coarsely oolitic, crumbly 4<br>(d) Phosphate rock, medium to coarsely oolitic 3<br>(Sample effervesces considerably.) | 34.7 | 75.8 | 4 | 10 |
| 144-K | Shale, brownish to black, earthy composition, thin bedded, with a few limestone lenses; effervesces slightly | 24.2 | 53.0 | 8 | 9 |
| | Limestone, dark, compact, fetid | | | 1 | 9 |
| 144-L | Shale, brownish to black, earthy; effervesces slightly | 11.7 | 25.6 | 12 | |
| 144-M | Shale, including— Ft. in.<br>(a) Shale, brownish-black, earthy 7<br>(b) Concealed, not included in sample (probably same as a and c) 4 7<br>(c) Shale, brownish black, earthy 5 5 | 15.1 | 33.1 | 17 | |
| 144-N | Shale, black, earthy; effervesces slightly | 19.9 | 43.6 | 12 | |

*Complete section of the phosphate-bearing strata in Georgetown Canyon, Idaho*—Continued.

| Field No. of speci-men. | | $P_2O_5$. | Equiva-lent to $Ca_3(PO_4)_2$. | Thick-ness. |
|---|---|---|---|---|
| | *Ft. in.* | *Per cent.* | *Per cent.* | *Ft. in.* |
| 144-O | 1. Shale, brownish black, earthy........ 4<br>2. Limestone, single stratum (not sampled)........ 2<br>3. Shale, brownish black, earthy........ 4<br>4. Limestone, single stratum (not sampled)........ 2 | 21.2 | 46.4 | 12 |
| 144-P | Shale, black and dark brown, calcareous, earthy; effervesces considerably | 25.8 | 56.3 | 6 2 |
| 144-Q | Shale, black and dark brown, calcareous, earthy; effervesces considerably | 24.6 | 53.9 | 12 |
| 144-R | Limestone, shaly, brownish gray; effervesces vigorously | 17.8 | 39.0 | 4 10 |
| | Limestone, single stratum | | | 11 |
| | Limestone ("cap lime"), fine, dark gray, fossiliferous | | | 2 3 |
| 144-S | Phosphate rock, main bed prospected, coarse to medium, oolitic, gray; contains two or three minor streaks of shaly material; effervesces slightly | 36.8 | 80.4 | 6 4 |
| 144-T | Shale, brown, earthy; effervesces slightly | 3.7 | 8.1 | 9 |
| | Limestone, massive, underlying the phosphatic series. Thickness not determined. | | | |
| | | | | 139 11 |

Another detailed section of the lower portion of the Phosphoria formation which was measured and sampled about 26 miles north of the locality of the above section will serve to illustrate the leanest conditions to be expected within the area of the reconnaissance. This section contains the minimum amount of high-grade phosphate rock and also the lowest average content of phosphoric acid yet found in the sections measured in the Idaho portion of the phosphate reserve.

*Complete section of the phosphate-bearing strata in the SW. ¼ SW. ¼ sec. 7, T. 8 S., R. 44 E. of the Boise meridian, Idaho.*

| Field No. of speci-men. | | $P_2O_5$. | Equiva-lent to $Ca_3(PO_4)_2$. | Thick-ness. |
|---|---|---|---|---|
| | | *Per cent.* | *Per cent.* | *Ft. in.* |
| | Sandstone, white, fine grained, weathers brown | | | 10 |
| R 378-6 | Shale, brown, sandy, with limestone lenses | | | 47 |
| | Limestone, grayish black, fine grained, compact, fetid | | | 5 |
| R 378-5 | Phosphatic rock, black, coarsely oolitic | 26.3 | 57.4 | 1 |
| | Limestone, grayish black, fine grained, compact, fetid | | | 6 |
| | Shale, brown, with some oolitic streaks | | | 1 |
| | Limestone, grayish black, fine grained, compact, fetid | | | 1½ 6 |
| | Shale, brown, with some oolitic streaks | | | 1 |
| R 378-4 | Phosphate rock, grayish black, medium oolitic | 33.5 | 73.2 | 6 |
| | Shale, brown, thin-bedded, slightly oolitic | | | 1 |
| R 378-3 | Shale, brown, finely oolitic | | | 10 |
| | Shale, brownish black | 6.6 | 14.4 | 8 |
| | Limestone, gray, fine grained, fetid | | | 2 |
| | Shale, brownish black | | | 4 |
| R 378-2 | Phosphatic rock, brownish black, finely to coarsely oolitic | 29.4 | 64.2 | 1 1 |
| R 378-1a | Phosphate rock, brownish black, shaly | 17.2 | 37.6 | 1 4 |
| R 378-1 | Phosphate rock, brownish black, finely oolitic | 27.5 | 60.1 | 1 4 |
| | | | | 76½ 7 |

As many of the formations overlying the phosphate beds thin greatly toward the north, and the numerous parallel anticlines in the Caribou Range expose rocks varying in age from Beckwith to Nugget, it is very probable that detailed work will show that phosphate beds underlie at depths less than 5,000 feet much of the area in the Caribou Range not at present included in the phosphate reserve. The same is probably true of much of the territory northeast and southwest of the Blackfoot Range. The general relations of the Phosphoria formation to the underlying and overlying beds in the Caribou Range are shown in the section measured along Pritchard Creek (fig. 35).

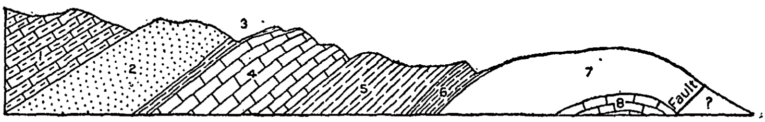



FIGURE 35.—Geologic section on Pritchard Creek, T. 1 N., R. 42 E., Idaho. 1, Twin Creek limestone; 2, Nugget sandstone; 3, Ankareh shale; 4, Thaynes limestone; 5, Woodside shale; 6, Phosphoria formation; 7, Wells formation; 8, Mississippian.

## COAL.

Coal has been reported at several localities in the region covered by the reconnaissance examination and is believed to occur in beds of Cretaceous age. A coal prospect was opened several years ago in the Fall Creek basin, approximately in sec. 29, T. 1 N., R. 42 E. According to reports a coal of good grade was encountered, but on account of the distance from settlements no extensive development work was done. Owing to lack of time and the heavy fall of snow during the encampment of the reconnaissance party in this vicinity, it was impossible to make an examination of the coal prospect or of the beds in which the coal occurs.

According to reports, coal was discovered on Willow Creek in sec. 27, T. 2 N., R. 40 E. No examination was made of the beds in which the coal occurs. Ranchers on Willow Creek report that a Mr. Brinson was installing machinery and expected to mine coal during the winter of 1911–12. This prospect is known locally as the Brinson mine.

A somewhat similar occurrence of coal was reported on the west side of John Grays Outlet in sec. 24, T. 1 S., R. 40 E. The plat of this township shows a coal tunnel in the SE. ¼ sec. 24. This prospect has been opened for some time and is locally known as the Croley mine. No examination was made of the beds in this immediate vicinity or of the mine itself, and it is not known whether the reported coal occurs in Cretaceous beds or at some other horizon.

## GOLD.

Placer mining has been carried on along Snake River, Tincup Creek, and McCoy Creek and its tributaries since 1860. The gold on these streams occurs in the gravels forming the terraces along the streams and in the deposits of bowlders, gravel, and sand filling the channels or forming the beds of the streams.

The bars of Snake River above the mouth of McCoy Creek are worked occasionally with fair results. No work was being done when the present party passed this part of the river. Placer sluicing on a small scale was being undertaken on the bench gravels at the junction of McCoy Creek and Snake River. The operators had just completed the sluice boxes and burlap tables preparatory for sluicing. Panning tests of the gravels made by the operators are reported to have proved to them that sluicing operations here can be successfully conducted. Sluice boxes and separating tables were seen at several points on Snake River above and below the mouth of McCoy Creek. Owing to lack of time and the fact that the ground was covered with 2 feet of snow when the party passed along Snake River these placer workings were not examined. For a more complete statement regarding the Snake River placers the reader is referred to a report on gold developments in central Uinta County, Wyo., and at other points on Snake River.[1]

Gold placers have been extensively worked near the headwaters of McCoy Creek in the vicinity of Caribou Peak and on the small streams heading on the east, south, and north slopes of the mountain. The largest of the hydraulic placers in the Caribou Peak region occurs on Iowa Gulch, where, it is asserted, a good clean-up is made each year. Hydraulic placer mining on a smaller scale is being done on the headwaters of Tincup Creek and on Ketchen Creek, a tributary of McCoy Creek. In 1911 a Mr. Barnes was engaged in placer work on Ketchen Creek and said that he had made over $1,000 during the months of August and September.

The placer mines on Iowa Gulch were discovered in 1870, and since that time the Caribou district has had a fluctuating population. Although perhaps never remarkable for extraordinary yields in gold, the placers are said to give fair returns from year to year. The operators report that the chief difficulty in extracting the placer gold in the Caribou region is the scantiness of the supply of water, which lasts only about three months after the snow melts.

The auriferous gravels are reported to occur most abundantly in Bilks Gulch, which heads immediately east of the summit of Caribou Peak, and to be distributed all along Bilks Gulch and Iowa Gulch as far as McCoy Creek, a distance of about 5 miles. The gravels consist of abraded volcanic and sedimentary materials largely mixed

[1] Schultz, A. R., Bull. U. S. Geol. Survey No. 315, 1910, pp. 71–88.

with red and maroon shales, sandstones, and conglomerates of the Beckwith formation and with limestone from the Twin Creek or possibly the Thaynes limestone.

It is quite evident that the gold in these stream gravels is derived from the rocks in the vicinity of Caribou Peak. In an attempt to locate the lodes from which the gold is derived the entire region about Caribou Peak has been pretty thoroughly prospected. Tunnels and shallow excavations may be seen in the most extraordinary and unexpected places. Most of the old prospect cabins were abandoned at the time of the writers' visit, but a number of them showed evidence of recent occupancy. As the tops of the mountain slopes were covered by 2 feet of snow at the time it may be that operations were merely suspended for the winter. Numerous shafts and tunnels have been opened on supposed parent lodes, but so far as could be learned none of them have proved successful. It is reported that sufficient gold was found in a vein on the southeast side of Caribou Peak to justify the building of a 40-stamp mill. The mill was constructed and a tramway built between it and the mine. From all indications at the stamp mill very little rock has been handled. Samples were gathered from some of the rock in the tramcar, but no assays have been made of the material. A representative of the company could not be found at the mine or at the mill on the day the writers were at this locality, but prospectors in the vicinity reported that the mill was forced to close for lack of water.

The major part of Caribou Peak is composed of sedimentary Jurassic and Triassic rocks which have been affected by volcanic phenomena of great interest. The sedimentary beds have been metamorphosed to a greater or less extent by intrusive volcanic material and the shales in places seem to have been permeated by mineral vapors or solutions, to which may be attributed the "mineral pockets" found in these sedimentary beds. No attempt was made to work out the relation between the igneous and sedimentary rocks, to ascertain the extent of the influence of the intrusive rocks on the mineral deposits, or to map the productive placer ground or locate any of the veins or prospected lodes in this vicinity. It would require a more extended examination than it was possible to make in order to determine the variable character of the eruptive rocks, their relation to the sedimentary beds, and their influence as a cause for ore deposition.

## COPPER.

Copper deposits[1] in the vicinity of Montpelier, Idaho, in the "Red Beds" of Triassic age, have been prospected for some time,

[1] Gale, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: Bull. U. S. Geol. Survey No. 430, 1910, pp. 112–121.

but their character or value below the surface has not been revealed. Prospecting of a similar nature has been carried on in the southern and eastern parts of the field on the same beds without apparent success. Some prospecting for copper has also been carried on in the Caribou Mountain region, presumably in beds of Beckwith age. It is reported that considerable quantities of copper were found in some of the prospects in this region, but from the abandoned workings it appears doubtful whether any of them yielded paying returns.

## SALT.

Salt deposits in the form of rock salt and brine springs occur in Crow and Stump creek valleys, in the southeastern part of the area covered by the reconnaissance survey. Several of these springs were visited, but no study was made of the salt deposits. All the salt springs visited have been abandoned for years and the old cabins are nearly destroyed. These salt deposits have been described by Breger.[1]

[1] Breger, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: Bull. U. S. Geol. Survey No. 430, 1910, pp. 555–569.

# SOME FURTHER DISCOVERIES OF ROCK PHOSPHATE IN MONTANA.

By J. T. PARDEE.

## INTRODUCTION.

High-grade phosphate rock was discovered by the writer in the season of 1911 at three localities in western Montana from which it has not hitherto been reported. These are (1) in the Garnet Range, 6 miles north of Garrison; (2) at Philipsburg, on the south slope of Flagstaff Hill; and (3) half a mile east of Elliston, north of Little Blackfoot River. Rock phosphate was also discovered by R. W. Stone, of the Geological Survey, about 2 miles east of Cardwell (formerly known as Jefferson Island), on the Northern Pacific Railway, at the summit of the cliffy slope rising to the west from Jefferson River. As these discoveries were merely incidental to the prosecution of other geologic work, the deposits were not studied in any great detail nor their limits found. Enough was learned, however, to make certain that they are commercially valuable and of the same type as the phosphate found by Gale[1] near Melrose, Mont., in 1910, and that of the extensive Idaho-Wyoming field.[2]

The first three localities mentioned lie from 60 to 70 miles north and the fourth 40 miles northeast of Melrose; hence these discoveries may be said to extend the limits of the known phosphate field for those distances. (See fig. 36.)

Although the phosphate bed was probably once continuous over much of this general region, it is now found only in more or less detached areas as a result chiefly of deformation, igneous intrusions, and erosion that caused tilting, elevation, and in some places complete removal of the deposit or in other places its burial to a depth beyond that permitting commercial exploitation under present conditions. The location of the areas in which workable phosphate may be

[1] Gale, H. S., Rock phosphate near Melrose, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 440–451.

[2] Gale, H. S., and Richards, R. W., Phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 457–535. Richards, R. W., and Mansfield, G. R., Preliminary report on a portion of the Idaho phosphate reserve: Bull. U. S. Geol. Survey No. 470, 1911, pp. 371–439.

expected is usually indicated with certainty by the bold outcrops of certain strata of the series that incloses the phosphate-bearing beds.

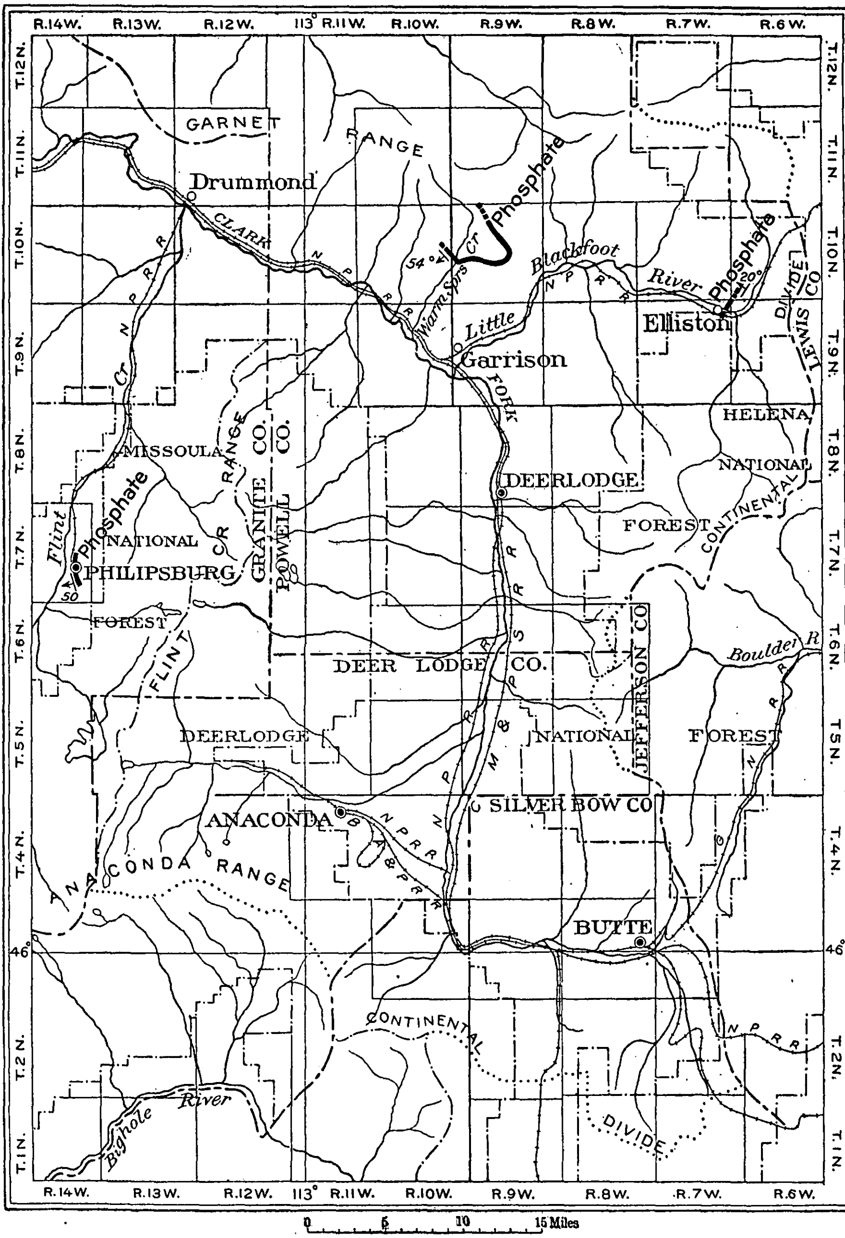



FIGURE 36.—Map showing location of recent discoveries of phosphate rock in Montana.

## STRATIGRAPHY AND STRUCTURE.

### GENERAL OUTLINE.

The phosphate bed is found in rocks of Carboniferous age. In this region these strata vary somewhat from place to place, but certain of them are persistent, outcrop boldly, and if the upper members are present almost always serve to mark phosphate localities. These key strata are:

1. Beds of chert, usually limy or sandy and variable in thickness, but always closely associated with the phosphate and usually lying just above it.

2. A rather pure and massive quartzite of moderate thickness (a member of the Quadrant formation) that lies beneath the phosphate, separated usually from it by a few feet of limy shale.

3. A thick, massive limestone, known as the Madison limestone, that underlies the quartzite, from which it is separated usually by some red shale that also belongs to the Quadrant formation.

These beds are, as a rule, steeply tilted and their major structural lines trend in general northwest and southeast.

## LOCAL DESCRIPTIONS.

*Garnet Range area.*—The lower part of the following section was measured along the canyon of Warm Spring Creek, north of Garrison, and the upper part in the foothills north of Drummond.

*Section showing stratigraphic succession of beds in the Garnet Range area, Mont.*

| Geologic age. | Formation. | Description. | Thickness (feet). |
|---|---|---|---|
| Lower Cretaceous | Kootenai formation | Gray-blue limestone; abundant small gastropods. | 100 |
| | | Mostly purple shale; some beds of gray-greenish and buff sandstone. | 1,050 |
| Lower Cretaceous(?) | Kootenai(?) formation. | Mostly gray buff-weathering limestone with a thin bed of greenish sandstone. | 300 |
| | | Flinty gray to dull-colored argillite, obscurely variegated; thin bed of blue limestone at base. | 725 |
| Upper Jurassic(?) | Ellis(?) formation | Gray sandstone containing grains of black that give it a peppered appearance; conglomeratic at base. | 500 |
| Upper Jurassic | Ellis formation | Buff-weathering shales and limestones; some purplish and greenish layers. | 75 |
| Pennsylvanian | Quadrant formation. | Chert and quartzite | 150 |
| | | Phosphate | 8 |
| | | Pure quartzite, massive, yellow stained | 250 |
| | | Red shale, locally mottled with cream-colored spots. | 300 |
| Mississippian | Madison limestone | Gray to blue limestone; abundant crinoid fragments, etc. | 1,000 |

The main structural feature of this area is an anticline whose axis coincides nearly with the northwest-southeast diagonal of the township (T. 10 N., R. 9 W. Montana principal meridian). This fold ends like an upturned boat keel near the southeast corner of the township. It brings to the surface a series of rocks extending from the upper portion of the Cretaceous on its outer flanks to the Madison limestone at its crest. The outcrops of these beds, including that of the phosphate, trace a series of U-shaped curves open to the northwest. The approximate position of the phosphate outcrop is shown on the map (fig. 36). Dips on this bed vary from 54° in the canyon of Warm Spring Creek to 30° or less at the rounding of the "keel." The anticline is cut transversely by a number of small faults with downthrow to the northwest, the aggregate result of which is to

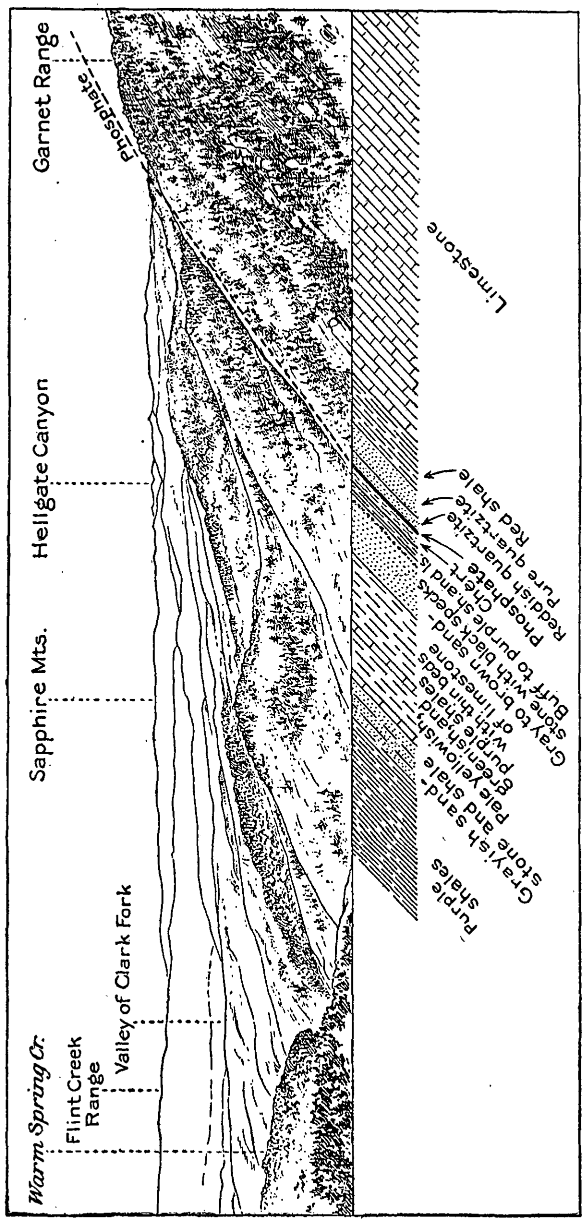



FIGURE 37.—View looking westward across Warm Spring Creek canyon from point 6 miles north of Garrison, Mont., in the western part of T. 10 N., R. 9 W.

narrow the U traced by the phosphate outcrop. Figure 37 is a view looking westward across the canyon of Warm Spring Creek.

*Philipsburg.*—The following section, shown at Flagstaff Hill, is from measurements by F. C. Calkins,[1] supplemented by the writer.

---

[1] Unpublished field notes, 1908.

*Section at Philipsburg, Mont.*

| Geologic age. | Formation. | Description. | Thickness (feet). |
|---|---|---|---|
| Upper Jurassic | Ellis formation | Buff-weathering limestone and shale | 100 |
| Pennsylvanian | Quadrant formation | Brownish sandstone, quartzitic | 120 |
| | | Cherty limestone and shale | 35 |
| | | Phosphate bed | ([a]) |
| | | Siliceous limestone | 35 |
| | | Quartzite | 220 |
| Mississippian | Madison limestone | Massive white to gray limestone | 1,000 |

[a] Not measured.

The strike here is a little west of north and the dip about 50° W.

*Elliston.*—The section along Little Blackfoot River at Elliston is as follows:

*Section at Elliston.*

| Geologic age. | Formation. | Description. | Thickness (feet). |
|---|---|---|---|
| Upper Jurassic(?) | Ellis(?) formation | Gray sandstone, cross-bedded, specked with black. | 500 |
| Upper Jurassic | Ellis formation | Buff-weathering limestone and shale | 75 |
| Pennsylvanian | Quadrant formation | Cherty limestone and quartzite | 100 |
| | | Phosphate | ([a]) |
| | | Pure quartzite | 200 |
| Mississippian | Madison limestone | Gray to blue limestone, crinoid fragments, etc. | ([a]) |

[a] Not measured.

The average strike of these beds is N. 30° E. and the dip 20° W.

*Cardwell.*—The section exposed by the steep slope west of Jefferson River [1] is as follows:

*Section at Cardwell.*

| Geologic age. | Formation. | Description. | Thickness. |
|---|---|---|---|
| | | | *Ft. in.* |
| Upper Jurassic | Ellis formation | Quartzite sandstone | 50 |
| Pennsylvanian | Quadrant formation | Cherty limestone | 50 |
| | | Phosphate | 6 |
| | | Brown shaly limestone | 1 |
| | | Phosphate | 6 |
| | | Brown shaly limestone | 8 |
| | | Phosphate | 6 |
| | | Cherty limestone | 100 |
| | | Red limestone | 150 |
| Mississippian | Madison limestone | Massive gray limestone | 1,000 |

These beds dip northwest and across the river to the northeast are cut off by a fault.

## THE PHOSPHATE.

*Physical character.*—Float rock phosphate is but moderately abundant in the vicinity of outcrops of the phosphate bed. The fragments are small, blocks as large as a foot through being rare. Because of a closely spaced parting or fissility parallel to the bedding the phosphate rock readily splits into thin slabs and blocks, and the

[1] Stone, R. W., unpublished field notes, 1911.

absence of large fragments in the surface mantle is thus explained. The float can be most readily distinguished from other rocks by means of its finely oolitic texture, thin bluish-white coating on weathered surfaces, and greater heaviness. The fresh fracture is usually black to brownish.

*Thickness and assay value.*—The section of the bed exposed by Warm Spring Creek, in sec. 19, T. 10 N., R. 9 W., as determined from a small artificial exposure, is shown below. The analyses were made in the laboratory of the United States Geological Survey by J. G. Fairchild. They show the presence of a bed of high-grade phosphate more than 4 feet thick and some leaner beds.

*Section and analyses of phosphate bed in the Garnet Range.*

| Section. | Analyses. | |
|---|---|---|
| | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. |
| | *Per cent.* | *Per cent.* |
| Cherty sandstone | | |
| Cherty phosphate (3 feet 3 inches) | 17.3 | 37.7 |
| Black phosphate (4 feet 4 inches) | 32.4 | 70.7 |
| Cherty phosphate (3 feet 3 inches) | 22.7 | 49.5 |
| Cherty quartzite | | |

The formula $Ca_3(PO_4)_2$ represents tricalcium phosphate, or, as it is more commonly termed, "bone phosphate." Material containing 60 per cent or more of tricalcium phosphate is considered high grade. Analyses of float from other portions of this township show a phosphoric acid content equivalent to 57.6 to 79 per cent of bone phosphate. The following analyses of samples from Flagstaff Hill, Philipsburg, from the slope north of Little Blackfoot River just east of Elliston, and from the locality near Cardwell were made by Mr. Fairchild.

*Analyses of phosphate rock from western Montana.*

| Description. | $P_2O_5$. | Equivalent to $Ca_3(PO_4)_2$. |
|---|---|---|
| *Cardwell.* | *Per cent.* | *Per cent.* |
| Loose fragment below outcrop; dark in color, finely oolitic | 23.9 | 52.2 |
| Loose fragment below outcrop; light in color, coarsely oolitic | 27.6 | 60.3 |
| Loose fragment below outcrop; dark in color, oolitic texture inconspicuous. | 18.0 | 39.3 |
| Loose fragment below outcrop; light brownish color, coarsely oolitic | 24.5 | 53.6 |
| *Philipsburg.* | | |
| Float, black phosphate | 30.9 | 67.5 |
| Cherty phosphate from ledge | 23.5 | 51.3 |
| Brownish phosphate from ledge | 12.3 | 26.9 |
| *Elliston.* | | |
| Float, grayish-black phosphate | 30.0 | 65.5 |

At neither Philipsburg nor Elliston was the thickness of the bed determined. The outcrops show that in each place it is at least 1 foot and the distribution of float indicates that it is probably more, about the same as in the Garnet Range locality.

*Amount, accessibility, and uses.*—Although detailed work upon which to base a tonnage estimate has not yet been done, it is apparent from the examination made that in the Garnet Range at least a large amount of phosphate is present. For instance, 14,000 tons would be the yield of an acre underlain by a flat bed of phosphate 4 feet thick. Where the phosphate bed is steeply tilted the amount beneath an acre is much greater.

The phosphate at both Philipsburg and Elliston is near the tracks of the Northern Pacific Railway; that at Cardwell lies near the Chicago, Milwaukee & Puget Sound and Northern Pacific railways; and that north of Garrison is readily accessible by two wagon roads, one going directly north from that place, the other up the valley of Warm Spring Creek. The latter route is one that offers no unusual difficulties for the construction of a railroad that would, with a haul of about 6 miles, place the phosphate on the main line of either the Northern Pacific or the Chicago, Milwaukee & Puget Sound Railway.

The principal use of phosphate rock is to fertilize farm lands that are deficient in phosphorus, one of the three essential mineral plant foods, the other two being potash and nitrates. The need for it will become more apparent with the deterioration of western grain lands. There is also the possibility that some virgin lands may be deficient in this material and would be improved by its application. The rock phosphate is largely used as a fertilizer, both in finely ground form applied to the soil without chemical treatment, when it is known as "floats," and also after treatment with sulphuric acid, which makes the fertilizing constituents of the rock readily available as plant food.

That the phosphate beds may, by thus creating a demand for sulphuric acid, aid in the solution of the smelter smoke problem is suggested by Gale.[1] That great quantities of sulphurous acids are daily escaping at Anaconda is a matter of common knowledge. Nowhere does this fact appear more impressive than from a viewpoint situated on the phosphate outcrop north of Garrison, from which the vast column of smoke pouring out of the smelter stack 35 miles away, at times clouding the whole Deer Lodge Valley, can be plainly seen.

[1] Gale, H. S., Rock phosphate near Melrose, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 448–450.

# SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relating to phosphates and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum."

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


Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Bull. 430, 1910, pp. 536–551.

——— A reconnaissance of the phosphate deposits in western Wyoming: Bull. 470, 1911, pp. 452–481.

Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report: Bull. 364, 1909, 81 pp.

Eckel, E. C., Recently discovered extension of Tennessee white-phosphate field: Mineral Resources U. S. for 1900, 1901, pp. 812–813. 70c.

——— Utilization of iron and steel slags: Bull. 213, 1903, pp. 221–231. 25c.

——— The white phosphates of Decatur County, Tenn.: Bull. 213, 1903, pp. 424-425. 25c.

Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 196–231.

Gale, H. S., Rock phosphate near Melrose, Mont.: Bull. 470, 1911, pp. 440–451.

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. 430, 1910, pp. 457–535.

Girty, G. H., The fauna of the phosphate beds of the Park City formation of Idaho, Utah, and Wyoming: Bull. 436, 1910, 82 pp.

Hayes, C. W., The Tennessee phosphates: Sixteenth Ann. Rept., pt. 4, 1895, pp. 610–630. $1.20. Also Seventeenth Ann. Rept., pt. 2, 1896, pp. 519–550. $2.35.

——— The white phosphates of Tennessee: Trans. Am. Inst. Min. Eng., vol. 25, 1896, pp. 19–28.

——— A brief reconnaissance of the Tennessee phosphate field: Twentieth Ann. Rept., pt. 6, 1899, pp. 633–638.

——— The geological relations of the Tennessee brown phosphates: Science, vol. 12, 1900, p. 1005.

——— Tennessee white phosphate: Twenty-first Ann. Rept., pt. 3, 1901, pp. 473–485.

——— Origin and extent of the Tennessee white phosphates: Bull. 213, 1903, pp. 418–423. 25c.

IHLSENG, M. C., A phosphate prospect in Pennsylvania: Seventeenth Ann. Rept., pt. 3, 1896, pp. 955–957.

MEMMINGER, C. G., Commercial development of the Tennessee phosphates: Sixteenth Ann. Rept., pt. 4, 1895, pp. 631–635. $1.20.

MOSES, O. A., The phosphate deposits of South Carolina: Mineral Resources U. S. for 1882, 1883, pp. 504–521. 50c.

ORTON, EDWARD, Gypsum or land plaster in Ohio: Mineral Resources U. S. for 1887, 1888, pp. 596–601. 50c.

PENROSE, R. A. F., Nature and origin of deposits of phosphate of lime: Bull. 46, 1888, 143 pp. Exhausted.

PURDUE, A. H., Developed phosphate deposits of northern Arkansas: Bull. 315, 1907, pp. 463–473. 50c.

RICHARDS, R. W., and MANSFIELD, G. R., Preliminary report on a portion of the Idaho phosphate reserve: Bull. 470, 1911, pp. 371–439.

STOSE, G. W., Phosphorus ore at Mount Holly Springs, Pennsylvania: Bull. 315, 1907, 474–483. 50c.

——— Phosphorus: Mineral Resources U. S. for 1906, 1907, pp. 1084–1090. 50c.

STUBBS, W. C., Phosphates of Alabama: Mineral Resources U. S. for 1883-84, 1885, pp. 794–803. 60c.

VAN HORN, F. B., The phosphate deposits of the United States: Bull. 394, 1909, pp. 157–171.

——— Phosphate rock: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 877–888.

WEEKS, F. B., Phosphate deposits in the western United States: Bull. 340, 1908, pp. 441–447.

WEEKS, F. B., and FERRIER, W. F., Phosphate deposits in western United States: Bull. 315, 1907, pp. 449–462. 50c.

WILBER, F. A., Greensand marls in the United States: Mineral Resources U. S. for 1882, 1883, pp. 522–526. 50c.

# MINERAL PAINT.

## SURVEY PUBLICATIONS ON MINERAL PAINT.

The following 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.


AGTHE, F. T., and DYNAN, J. L., Paint-ore deposits near Lehigh Gap, Pennsylvania: Bull. 430, 1910, pp. 440–454.

BURCHARD, E. F., Southern red hematite as an ingredient of metallic paint: Bull. 315, 1907, pp. 430–434.

——— Barytes and strontium: Mineral Resources U. S. for 1910, pt. 2, 1911, pp. 799–802.

ECKEL, E. C., The mineral-paint ores of Lehigh Gap, Pennsylvania: Bull. 315, 1907, pp. 435–437.

——— Metallic paints of the Lehigh Gap district, Pennsylvania: Mineral Resources U. S. for 1906, 1907, pp. 1120–1122. 50c.

HAYES, C. W., and ECKEL, E. C., Occurrence and development of ocher deposits in the Cartersville district, Georgia: Bull. 213, 1903, pp. 427–432. 25c.

MILLER, B. L., Paint shales of Pennsylvania: Bull. 470, 1911, pp. 485–497.

PHALEN, W. C., Mineral paints: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 971–993.

STODDARD, J. C., and CALLEN, A. C., Ocher deposits of eastern Pennsylvania: Bull. 430, 1910, pp. 424–439.

# SALINES.

## THE SEARCH FOR POTASH IN THE DESERT BASIN REGION.[1]

By Hoyt S. Gale.

### AUTHORITY FOR INVESTIGATIONS RELATING TO POTASH.

Acts authorizing investigations looking to the possible development of commercial sources of potash salts in the United States were passed by Congress as follows (Stat. L., vol. 36, pt. 1, pp. 1256, 1418):

Chapter 285. An act making appropriations for sundry civil expenses for the fiscal year ending June thirtieth, nineteen hundred and twelve, and for other purposes.

*  *  *  *  *  *  *

*United States Geological Survey.*—For chemical and physical researches relating to the geology of the United States, including researches with a view of determining geological conditions favorable to the presence of deposits of potash salts, forty thousand dollars. * * * [Approved Mar. 4, 1911.]

Chapter 238.—An act making appropriations for the Department of Agriculture for the fiscal year ending June thirtieth, nineteen hundred and twelve.

*  *  *  *  *  *  *

*Bureau of Soils.*—For exploration and investigation within the United States to determine a possible source of supply of potash, nitrates, and other natural fertilizers, twelve thousand five hundred dollars, two thousand five hundred dollars of which shall be immediately available. * * * [Approved Mar. 4, 1911.]

Field and laboratory investigations to be conducted by both the Geological Survey and the Bureau of Soils are thus provided for. In recent years the annual appropriation for the work of the chemical and physical laboratories of the Geological Survey has been $20,000, so that the addition of $20,000 to this item in the current appropriation was made with an understanding that the amount of the increase should be devoted to the geologic investigations relating to potash in this country.

[1] Revision of report published Dec. 11, 1911, as Bulletin 530-A.

## SCOPE OF POTASH INVESTIGATIONS.

The investigations of the Geological Survey with a view of determining geologic conditions favorable to the presence of deposits of potash salts have been concentrated during the fiscal year 1911–12 along the followng lines:

1. The exploration by deep boring for deposits of buried salines in Nevada and in other localities in the western public-land States, by a drilling party in charge of James H. Hance, under the direction of Hoyt S. Gale.
2. The investigations of the salt deposits and the brines and bitterns in the United States east of the Rocky Mountains, carried on by W. C. Phalen, under the supervision of David T. Day.
3. The investigation of the occurrence of certain rich potash-bearing rocks and minerals, described in short reports.
4. A small amount of general field investigation in the Western States by Hoyt S. Gale.
5. Prospecting with a hand-drilling apparatus for the purpose of testing the salt and upper ground waters or brines to a depth of 50 feet or more in the Silver Peak Marsh, Nevada, by a party in charge of R. B. Dole, assisted by Charles E. Watson.

Naturally work on such a subject as this has not been concluded within a single year, but the following preliminary reports have been issued:

The search for potash in the United States; a report of progress, by Hoyt S. Gale: Advance chapter A of Bull. 530, issued in December, 1911.

The occurrence of potash in the bitterns of the eastern United States, by W. C. Phalen: Advance chapter B of Bull. 530, issued in December, 1911.

Alunite, a newly discovered deposit near Marysvale, Utah, by B. S. Butler and Hoyt S. Gale: Bull. 511, issued in January, 1912.

Potash-bearing rocks of the Leucite Hills, Sweetwater County, Wyo., by A. R. Schultz and Whitman Cross: Bull. 512, issued in January, 1912.

Alunite in the San Cristobal quadrangle, Colo., by E. S. Larsen: Advance chapter F of Bull. 530, issued in January, 1912.

Potash salts, summary for 1911, by W. C. Phalen:. Advance chapter from Mineral Resources of the United States for 1911, issued in March, 1912.

Nitrate deposits, by Hoyt S. Gale: Bull. 523, issued in October, 1912.

It is the main purpose of the present report to review briefly the evidence on which the project of drilling for potash in the desert basins is based and the reason for the selection of the preliminary site in the Carson Sink, Nevada. This is the hypothesis which assumes that soluble potassium salts may be found segregated in layers or in mother-liquor solutions in the Carson Desert and elsewhere in the desert-basin region.

The discovery of one important example of such segregation of potash salts in the brines of Searles Lake, in San Bernardino County, Cal., is considered as an important confirmation of this hypothesis. It remains to test the hypothesis in other practicable situations, and it is believed that this will generally have to be accomplished by borings.

## SALINES IN THE GREAT BASIN.

### SURFACE SALTS.

The surface accumulations of salines in the Great Basin are among the most characteristic features of the deserts. These deposits include the so-called dry lakes, playas or mud flats, alkali flats, salt marshes, and alkaline efflorescences in various forms. There are also alkaline lakes whose waters carry saline material in greater or lesser amounts. Springs charged with mineral matter are rather common in certain parts of the deserts.

Salt, sodium carbonate and bicarbonate, sodium sulphate, and borax have been more or less profitably worked in many parts of the region. Nitrate salts in soils and in caves and ledges have been found at a number of places, but these are not conspicuous in form and are of more exceptional occurrence.

Numerous chemical data concerning the nature of the alkaline salts in the Great Basin deserts are already available. Some of these are to be found in published form, and perhaps a larger number consist of commercial analyses so scattered that they will be difficult to assemble. Experience has shown, however, that in the general run of such analyses potash determinations on natural waters are extremely likely to be in error, often to a serious degree, even when the work has been done by an experienced chemist. The determination of potash in alkaline and saline waters is difficult and rather expensive and is subject to considerable inaccuracies unless made by a chemist who has had much experience with that particular determination and who has therefore worked out the special difficulties involved and the methods of avoiding them.

Among the first and most natural suggestions made in connection with the idea of searching for sources of soluble potash salts was that this substance would probably occur in association with other desiccated saline and alkaline-water deposits, such as are known to be abundant in the desert-basin region. The likelihood that such deposits on the surface might yield workable potash salts was pointed out, and an offer for free tests for soluble potash in samples of the desert salts was published early in the progress of the present investigations. Moreover, it was suggested that as the desert surface deposits are plainly to be seen and readily accessible to the prospector, this phase of the search might well be trusted to his activity with the expectation that he would develop anything of evident value.

### BURIED SALTS.

No better statement of the reasons for assuming that immense quantities of saline material are included in the strata underlying the desert sinks of the Great Basin can here be made than by direct quotation from the writings of Russell[1] and Gilbert,[2] chiefly from the monograph on the history of Lake Lahontan. Russell does not suggest that such buried deposits will be found in commercially workable form but rather infers that the saline material is for the most part probably disseminated in the desert sands and clays. Nevertheless, the evidence that he presents is believed to be a very strong argument favoring the possible existence of such deposits, as will be seen by a review of the following quotations. It is also evident as a result of the drilling that has now been done that such salts are not disseminated to any important extent in the uppermost 800 feet or more of the Lahontan lake deposits, a result which tends rather to strengthen than otherwise the hope of ultimate success of the test in this locality.

## THE DESICCATION HYPOTHESIS TO ACCOUNT FOR BURIED SALTS IN THE DESERT BASINS, WITH SPECIAL REFERENCE TO LAKE LAHONTAN.

### DEFINITION OF THE GREAT BASIN.

The major part of the North American continent is drained by streams flowing to the ocean, but there are a few restricted areas having no outward drainage. The largest of these was called by Frémont, who first achieved an adequate conception of its character and extent, the "Great Basin," and is still universally known by that name. It is not, as the title might suggest, a single cup-shaped depression gathering its waters at a common center, but a broad area of varied surface, naturally divided into a large number of independent drainage districts. It lies near the western margin of the continent and is embraced by rivers tributary to the Pacific Ocean. * * *

The region is occupied by a number of mountain ridges which betray system by their parallelism and by their agreement in a peculiar structure. Their general trend is northerly, inclining eastward in the northern part of the basin and westward at the south. The individual ridges are usually not of great length, and they are so disposed en échelon that the traveler winding among them may traverse the basin from east to west without crossing a mountain pass. The type of structure is that of the faulted monocline, in which the mountain ridge is produced by the uptilting of an orogenic block from one side of a line of fracture, and it has been named (from the region) the Basin Range type. Its distribution, however, does not coincide perfectly with the district of interior drainage. On the one hand the Great Basin includes along its eastern margin a portion of the Plateau province, with its peculiar structural type, and on the other the Basin Range province extends southward through Arizona to New Mexico and Mexico.

Between the ranges are smooth valleys, whose alluvial slopes and floors are built of the débris washed through many ages from the mountains. In general, they are troughlike, but in places they coalesce and assume the character of plains. The plains occupy in general the less elevated regions, where an exceptional amount of detritus has been accumulated. In the local terminology they are called deserts. The largest are the Great Salt Lake and Carson deserts at the north and the Mojave and Colorado deserts at the south. The Escalante, the Sevier, the Amargosa, and the Ralston are of subordinate importance.

* * * * * * *

[1] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: Mon. U. S. Geol. Survey, vol. 11, 1885.

[2] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

The southern portions of Arizona and New Mexico and the western part of Texas resemble the Great Basin in climate, and they contain a number of small interior basins. These are not so fully determined in extent as the Great Basin, but several of them may be approximately indicated.

## LAKE LAHONTAN DEFINED.

[The monograph on Lake Lahontan] records the history of a large lake which flooded a number of the valleys of northwestern Nevada at a very recent geological date but has now passed away. This ancient water body is known as Lake Lahontan—named in honor of Baron La Hontan, one of the early explorers of the headwaters of the

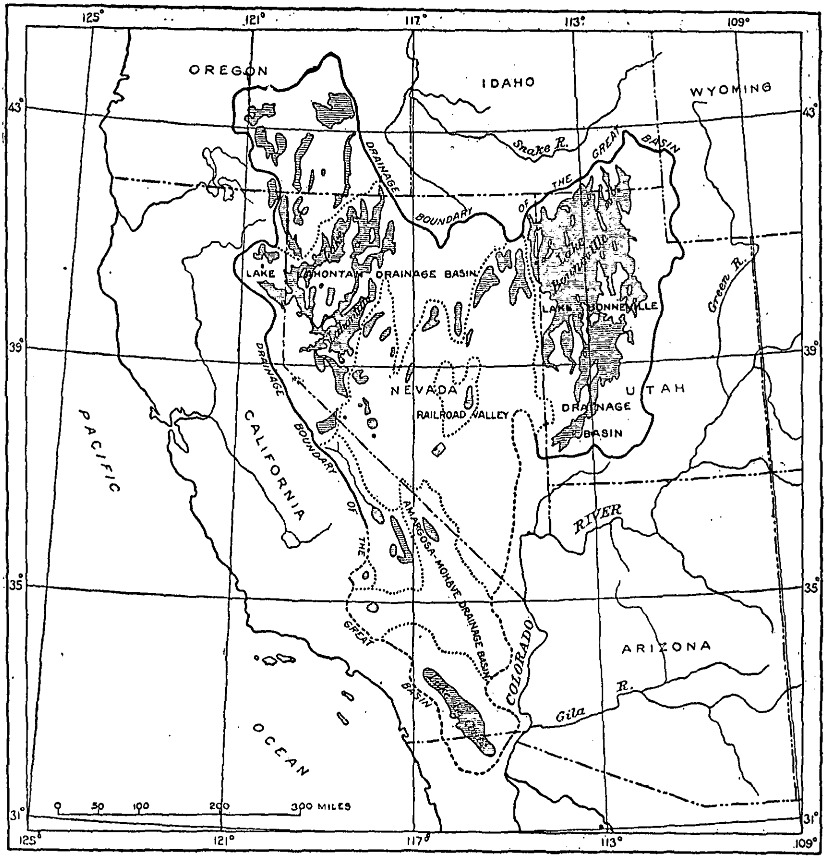



FIGURE 38.—Quaternary lakes of the Great Basin. (Revised from Pl. I of the Lake Lahontan monograph and Pl. II of the Lake Bonneville monograph.)

Mississippi—and was the complement of Lake Bonneville. The former, situated mostly within the area now forming the State of Nevada, filled a depression along the western border of the Great Basin at the base of the Sierra Nevada; the latter, embraced almost entirely in the present Territory of Utah, occupied a corresponding position on the east side of the Great Basin, at the foot of the Wasatch Mountains. The hydrographic basins of these two water bodies embraced the entire width of the Great Basin in latitude 41°. Lake Bonneville was 19,750 square miles in area and had a maximum depth of about 1,000 feet. Lake Lahontan covered 8,422 square miles of surface and in the deepest part, the present site of Pyramid Lake, was 886 feet in depth. The ancient lake of Utah overflowed northward and cut down its channel of discharge 370 feet. The ancient lake of Nevada did not overflow. Each of these lakes had two high-water stages separated by a time of desiccation. In the Lahontan Basin, as in the Bonneville, the first great rise was preceded by a long period of desiccation and was followed by a second dry epoch, during which the valleys of Nevada were even more completely desert than at present. During the second flood stage the lake rose higher than at the time of the first high water and then evaporated to complete desiccation. The present lakes of the basin are of comparatively recent date and are nearly fresh, for the reason that the salts deposited when the Quaternary lake evaporated were buried or absorbed by the clays and marls that occupy the bottom of the basin.

### ACCUMULATION OF SALINE MATERIAL.

It may be taken as a rule that all lakes which overflow are fresh and all lakes which do not find outlet become in time charged with mineral salts. River water is never absolutely pure but contains a small percentage of mineral matter, which is left behind when the water is evaporated. Should this process continue long enough it is evident that a lake without an outlet would in time become a saturated solution from which the less soluble mineral salts would begin to crystallize. * * *

Instances of the deposition of salts by the evaporation of inclosed lakes are common and may be illustrated by many examples in the Great Basin. The salt fields in Osobb Valley, the saline deposits left by the evaporation of the Middle Lake in Surprise Valley, Cal., in 1872, and by the broad salt field now covering the desiccated basin of Sevier Lake, in Utah, are all cases in point.

In the Lahontan Basin deposits of this character which have resulted directly from the evaporation of the former lake are nowhere to be found. The accumulations of common salt, sulphate of soda, etc., occurring in considerable quantities at certain localities have in all cases been deposited since the evaporation of the former lake. In some instances these accumulations are due to the leaching of saline clays and the evaporation of the resultant brine in restricted areas, as in the case of the salt fields in Alkali Valley; at other times saline deposits of considerable thickness have resulted from the evaporation of spring waters. Over very large areas the Lahontan beds are frequently whitened with a saline efflorescence, which also owes its accumulation to secondary causes, as will be described a few pages in advance.

Wherever the Lahontan sediments have been examined they have been found more or less highly charged with salts of the same character as those that were most common in the waters of the former lake. The total quantity of saline matter thus imprisoned is certainly very great and is assumed to represent the more soluble substances contributed to Lake Lahontan.

### DISAPPEARANCE OF SALINES FROM THE SURFACE.

The apparently anomalous phenomena of the desiccation of a great lake without leaving a surface deposit of salt seems explicable in only one way. Adopting the suggestion advanced by Mr. Gilbert in explanation of some portion of the history of Lake Bonneville, the absence of saline deposits is accounted for by the hypothesis that they were buried and absorbed by lacustral clays and playa deposits during periods of desiccation.

The freshening of a lake by desiccation may be illustrated in all its stages in the various basins that have been examined in the far West. A lake after a long period of concentration becomes strongly saline and finally evaporates to dryness, leaving a deposit of various salts over its bed. During the rainy season the bottom of the basin is converted into a shallow lake of brine which deposits a layer of sediment; on evaporating to dryness, during the succeeding arid season, a stratum of salt is deposited, which is, in its turn, covered by sediment during the succeeding rainy season. This process taking place year after year results in the formation of a stratified deposit consisting of salts and saline clays in alternating layers. The saline deposits may thus become more and more earthy until the entire annual accumulation consists of clays. The site of the former lake then becomes a playa. A return of humid conditions would refill a basin of this character and might form a fresh-water lake, the bottom of which would be the level surface of the submerged playa.

The larger lakes of the Lahontan Basin, as well as a number of less importance in eastern Nevada and southern Oregon, are without outlet. They occur in basins that in almost all cases were occupied by much larger water bodies during the Quaternary, which, like their modern representatives, never overflowed. From the long period of evaporation that has taken place one would expect the existing lakes to be dense mother liquors. The fact is, however, that they are but slightly charged with saline matter and in some instances are sweet to the taste and sufficiently fresh for all culinary purposes. In many localities the lacustral beds surrounding and underlying the present lakes are highly charged with soda salts, which rise to the surface during the dry season as efflorescences. As these lake basins were never filled to overflowing, we are forced to conclude that influx was counterbalanced solely by evaporation, and that during periods of extreme desiccation the saline deposits became buried and absorbed by the marls and clays which accumulated in the valleys. * * *

### POSSIBILITY OF BURIED SALINE DEPOSITS.[1]

As shown by the average composition of river water, about one-half of the total solids carried in solution by surface streams is calcium carbonate. This is the most difficult of solution of any of the salts ordinarily found in such waters, and the first to be precipitated when concentration by evaporation takes place. The more soluble salts consist mainly of sodium sulphate, sodium carbonate or bicarbonate, sodium chloride, magnesium, potash, iron, etc.

*The amount of these more soluble substances carried into Lake Lahontan must therefore have been about equal to the amount of calcareous tufa precipitated.*[2] As the lake never overflowed, these salts must still exist in its now nearly desiccated basin; yet in riding through the valleys that were formerly flooded no deposits of the salts referred to can be found at all commensurate with the vast quantity of calcium carbonate that attracts one's attention. The disappearance of the salts referred to seems to be satisfactorily explained in the following hypothesis:

After the last great rise of Lake Lahontan there was a long-continued episode during which its basin was more arid than at present. Evaporation during that time is thought to have been equal to precipitation, and the residual lakes were reduced to the playa condition—that is, the remnants of the great lake gathered in the lowest depressions of its basin were annually or occasionally evaporated to dryness, and their contained salts were precipitated and either absorbed by the clays, etc., deposited at the same time, or buried beneath such mechanical deposits. This process may be observed in action in many of the valleys of Nevada in which ephemeral lakes occur. The broad, naked playas of Black Rock, Smoke Creek, and Carson deserts, as well as the level floors of the basins occupied by Pyramid, Winnemucca, and Walker lakes, are in support of this hypothesis. Should the lakes just mentioned be evaporated to dryness, playas would be left similar to those in neighboring valleys of less depth.

*It is beneath the level floors of these valleys and lake basins that the more soluble salts once dissolved in the waters of Lake Lahontan are buried.*[2] Borings at certain localities might reveal the presence of strata of various salts, but in most cases they are probably disseminated through great thicknesses of clay, sand, and other mechanical sediments.

---

[1] Russell, I. C., Present and extinct lakes of Nevada: Mon. Nat. Geog. Soc., vol. 1, No. 4, 1895, pp. 101-132.

[2] The italics are added.

## SELECTION OF CARSON SINK FOR PRELIMINARY TEST BY DRILLING.

The physiographic history of the basins of Lakes Bonneville and Lahontan is thus probably more completely studied than that of any other part of the Great Basin. The monographs from which the foregoing quotations are made afford a wealth of maturely digested data on which to base the proposed plan of operation. A review of this material and the maps that accompany the reports leads to the conclusion that no better test of the hypothesis of possible buried salines in concentrated form could be made than to drill somewhere in the low portions of the Lahontan and Bonneville basins. Accordingly it was decided to make a practical test of this hypothesis by the selection of a drill site in one of these two basins.

For two reasons the Lahontan Basin was thought to offer the more favorable opportunity. First, it has been shown that Lake Lahontan never overflowed. This is important, as lake waters are freshened by overflow and the more soluble constituents of their waters are drained away. Lake Bonneville is known to have overflowed at least during a portion of its history, though there may have been desiccation periods preceding the overflowing. However, another factor appears to favor Lake Lahontan as a source of potash-bearing salt deposits, and this is concisely stated by Russell:[1]

> Surface waters derive their chemical impurities mainly from the rocks over which they flow and consequently vary in composition with the geological character of their hydrographic basins. When draining a granitic or volcanic area they are usually rich in potash and soda; when flowing over limestone they are frequently saturated with calcium carbonate. This is illustrated in the far West by the streams entering the Bonneville and Lahontan basins. In the former they have their sources in the Wasatch Mountains, where limestones occur, and are usually rich in calcium carbonate; potash is commonly absent, and soda, if present, is comparatively small in amount. In the Lahontan Basin volcanic rocks predominate and the streams contain a higher percentage of potash and soda than is usual in a region underlain by sedimentary rocks.

A summary of the low points in the Lahontan Basin narrows the selection of the drill site to a relatively small number of localities. The most extensive drainage is probably accumulated in the present Carson Sink. Humboldt Lake is really tributary to Carson Sink and, in effect, possibly always has been. The deep parts of Pyramid and Winnemucca lakes are lower in altitude, but they are water covered and so not as accessible, and their narrow, rock-walled valleys do not afford much opportunity for a satisfactory drill site. The Black Rock Desert and possibly also the Smoke Creek Desert lie at

[1] Mon. U. S. Geol. Survey, vol. 11, 1885, p. 173.

approximately the same elevation as the Carson Desert, and the Lahontan Lake waters stood at approximately the same depth over them. There are perhaps no good criteria by which to judge between the Black Rock Desert and the Carson Sink as promising fields in which to prospect. The existence of nearly saturated solutions of sodium chloride, containing large percentages of sodium sulphate and sodium carbonate, in the Soda Lakes near Fallon may be of some significance as to the derivation of these salts from buried salines that may exist beneath.

However, the selection of the general locality for the first trial was determined, other things appearing approximately equal, by accessibility to water, fuel, and other supplies. Carson Sink being selected, the particular site was picked, first, on vacant public land; second, as near the center on the assumed axis of lowest depression of the sink as feasible; and third, along as convenient a road for transportation of outfit and supplies as could be found within the limits of the other two controlling factors.

## THE TIMBER LAKE WELL NEAR FALLON, NEV.

The site selected is in sec. 30, T. 21 N., R. 30 E. The well is situated at the north end of Timber Lake, on the bank of Old Carson River near the point where that stream joins the standing water in Carson Sink. Timber Lake, now a dry basin covering an area of about 100 acres in the SE. ¼ sec. 30, was formerly filled by overflow from the main channel of Carson River. This lake has been drained by the cutting of a ditch for the purpose of straightening the course of the main river channel and is now growing up into a jungle of willows and small cottonwood trees.

The successful completion of a well on this site may prove, within the limit of depth attained, the existence and depth of any accessible saline deposits, and even if potash is not found in this first attempt, this boring will be a valuable guide in the selection of a site for further work.

The record of drilling for the year ending July 1, 1912, includes two periods of drilling amounting to a total of 135 days, or about 4½ months. The funds provided for this part of the work did not permit continuous operation and consequently the work was taken up during such periods as best conformed to the other arrangements involved in the general plans of the investigation. As stated in the preliminary report of progress on the Timber Lake well,[1] the drilling equipment

[1] Bull. U. S. Geol. Survey No. 530-A, 1911.

was delivered at Fallon, Nev., on September 19, 1911. A summary of the periods and rate of progress attained is as follows:

*Progress in drilling Timber Lake well, near Fallon, Nev.*

| | Time. | Amount drilled. | Average rate drilled. |
|---|---|---|---|
| | *Days.* | *Feet.* | *Feet per day.* |
| Oct. 6, 1911, to Jan. 11, 1912, inclusive | 98 | 555 | 5.6 |
| Jan. 12 to Apr. 19, inclusive | 99 | Drilling suspended. | |
| Apr. 20 to May 26, inclusive | 37 | 280 | 7.6 |
| May 27 to June 30, inclusive | 35 | Drilling suspended. | |
| | | 835 | 6.2 |

These unconsolidated caving and flowing sands and beds of sticky clay are perhaps as difficult to drill with standard drilling tools as any other materials that might be encountered. It is possible that by other methods of drilling, such as the use of the rotary, a more rapid rate of boring might be attained, but some factors of these other methods seem to prohibit their use for the purpose of obtaining the desired samples of soluble salts.

The work at the Timber Lake well has been under the general management and supervision of James H. Hance, who has kept the log of the well and taken the samples and made qualitative and approximate quantitative tests of the amount of potassium contained in the samples. The chemical record to date is negative so far as showing anything like commercially extractable percentages of soluble potash. The log shows an alternating series of unconsolidated sands, bearing much water and generally yielding artesian flows intercalated with beds of more or less compact clay that is impervious to the flow of water. The artesian waters are comparatively fresh and, although they have a smell and taste of hydrogen sulphide, are sufficiently good for use in camp. Analyses of these waters are in progress. As greater depth is reached, however, the volume of the lower flows encountered has diminished, or it may be that they have been in part cut off by the continuous heavy driving on the casing required to keep the hole from caving.

The negative tests for potash to the present depth (835 feet) in no way indicate the failure of the project nor invalidate the assumptions of the hypothesis on which the project is based. The very existence of large bodies of relatively fresh waters in the uppermost strata of the Lake Lahontan sediments serves to set at rest the chief doubt that has been seriously entertained concerning the probability of concentrated deposits of buried salines at greater depth in these beds. There can be little doubt that vast quantities of saline material exist within these desert basins and that a great part of this material has been carried by water in solution and concentrated in the lower parts of the basins. It has been argued that these salts may not be concentrated in well-defined stratified beds. Russell himself has already been quoted as preferring to believe that in most localities the salts are probably disseminated through great thicknesses of clay, sand, and other mechanical sediments. However, it has now been shown that for a depth of 835 feet near the lowest part of the sink of the Carson Desert these salts are not disseminated in much more than normal soil conditions or amounts for this general region. It remains to be seen whether drilling can be carried to a sufficient depth in this particular basin to strike the concentrated salines that are even more probable now that the saline material has not been found disseminated throughout this overlying thickness of the lake-bed deposits.

The log of the well at the Timber Lake site, in sec. 30, T. 21 N., R. 30 E., is shown in figures 39 to 44.

The record of progress on the boring now being made as a private enterprise in Railroad Valley, Nev., in the search for buried salines is interesting for comparison with that of the Timber Lake well. Although Railroad Valley is a narrower and smaller basin, the strata encountered are similar, being alternating layers of clay and sand or quicksand, and many of the latter bear large artesian flows of relatively fresh water.

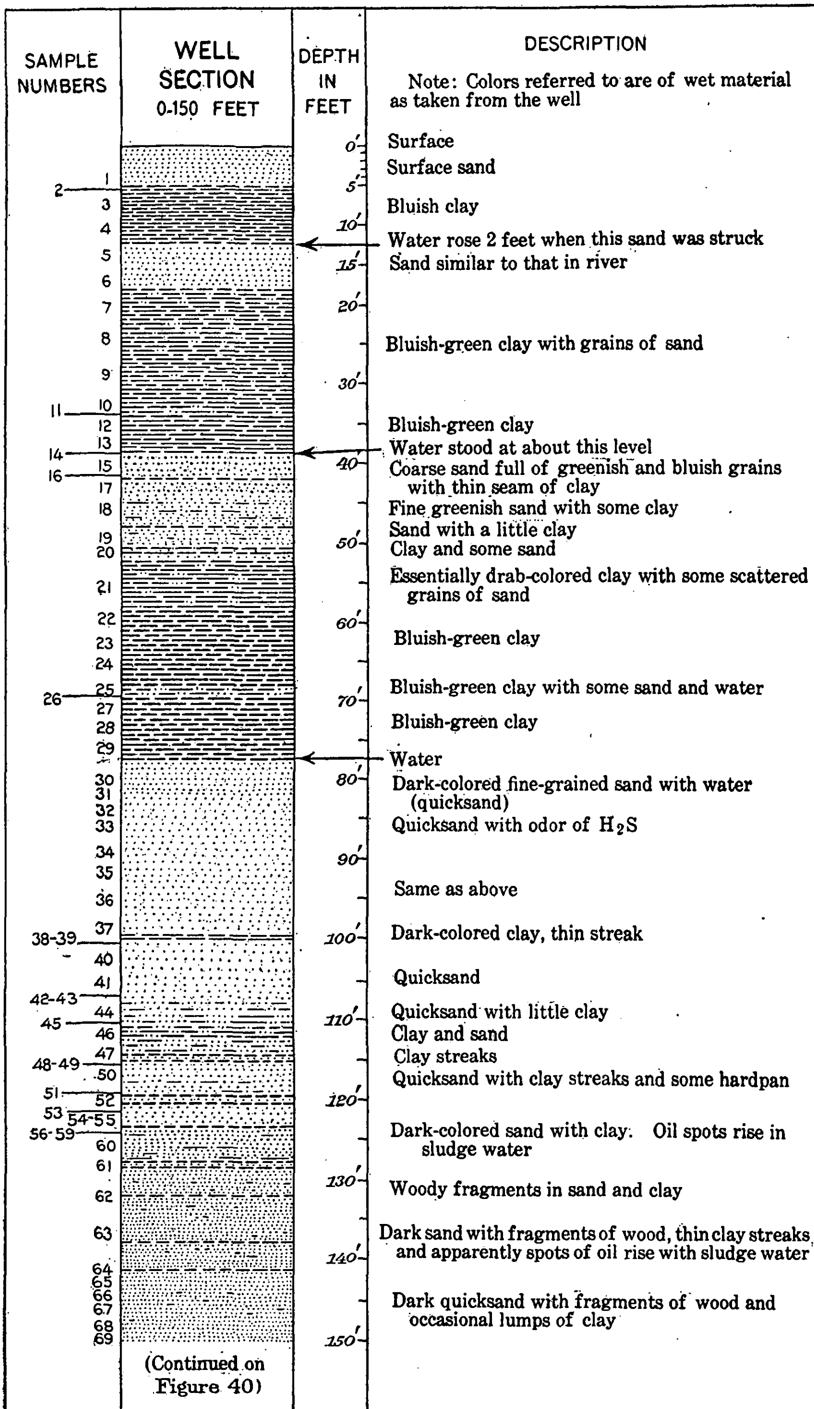
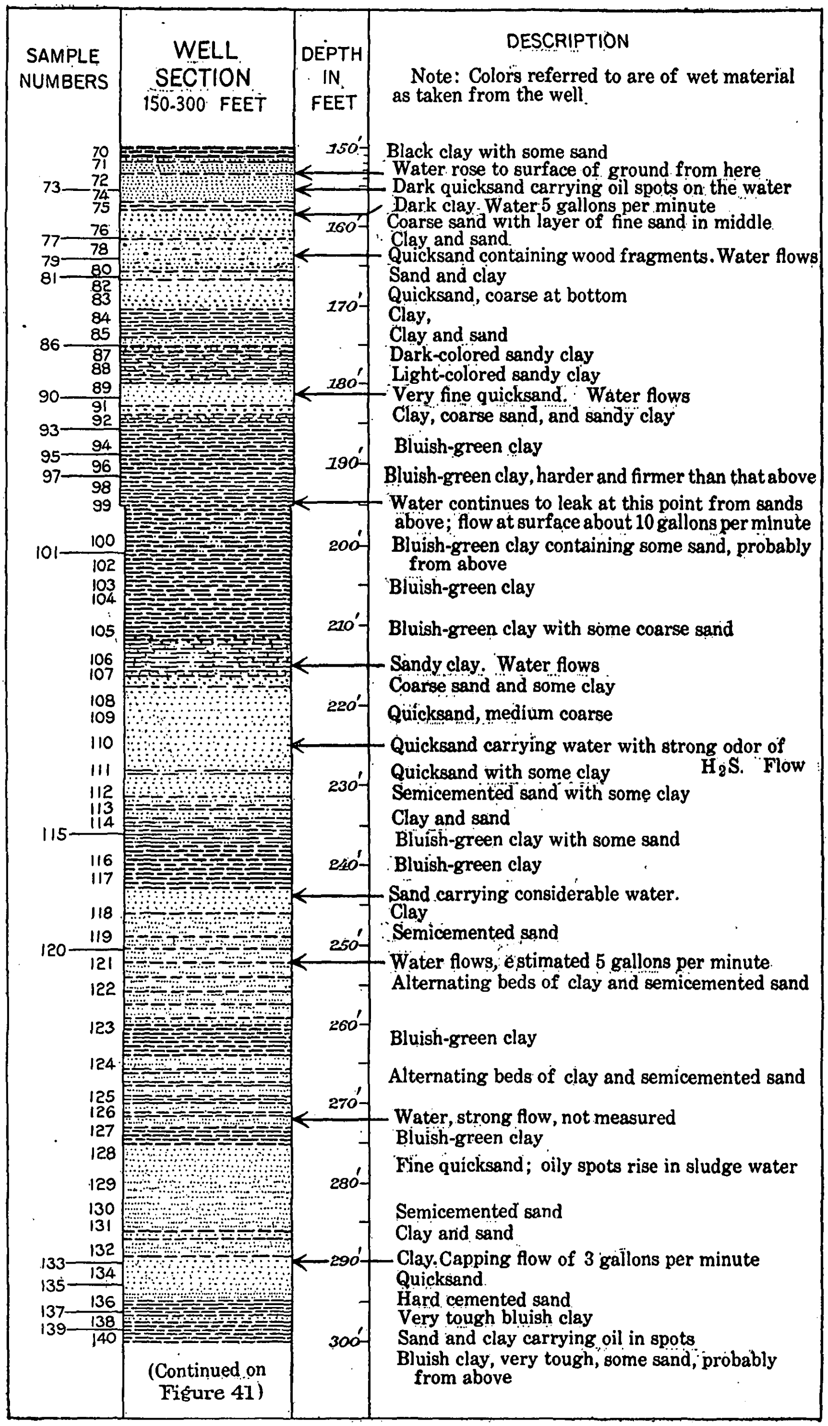



FIGURE 39.—Section of strata in Timber Lake well, near Fallon, Nev.—I.



(Continued on Figure 41)

FIGURE 40.—Section of strata in Timber Lake well, near Fallon, Nev.—II.

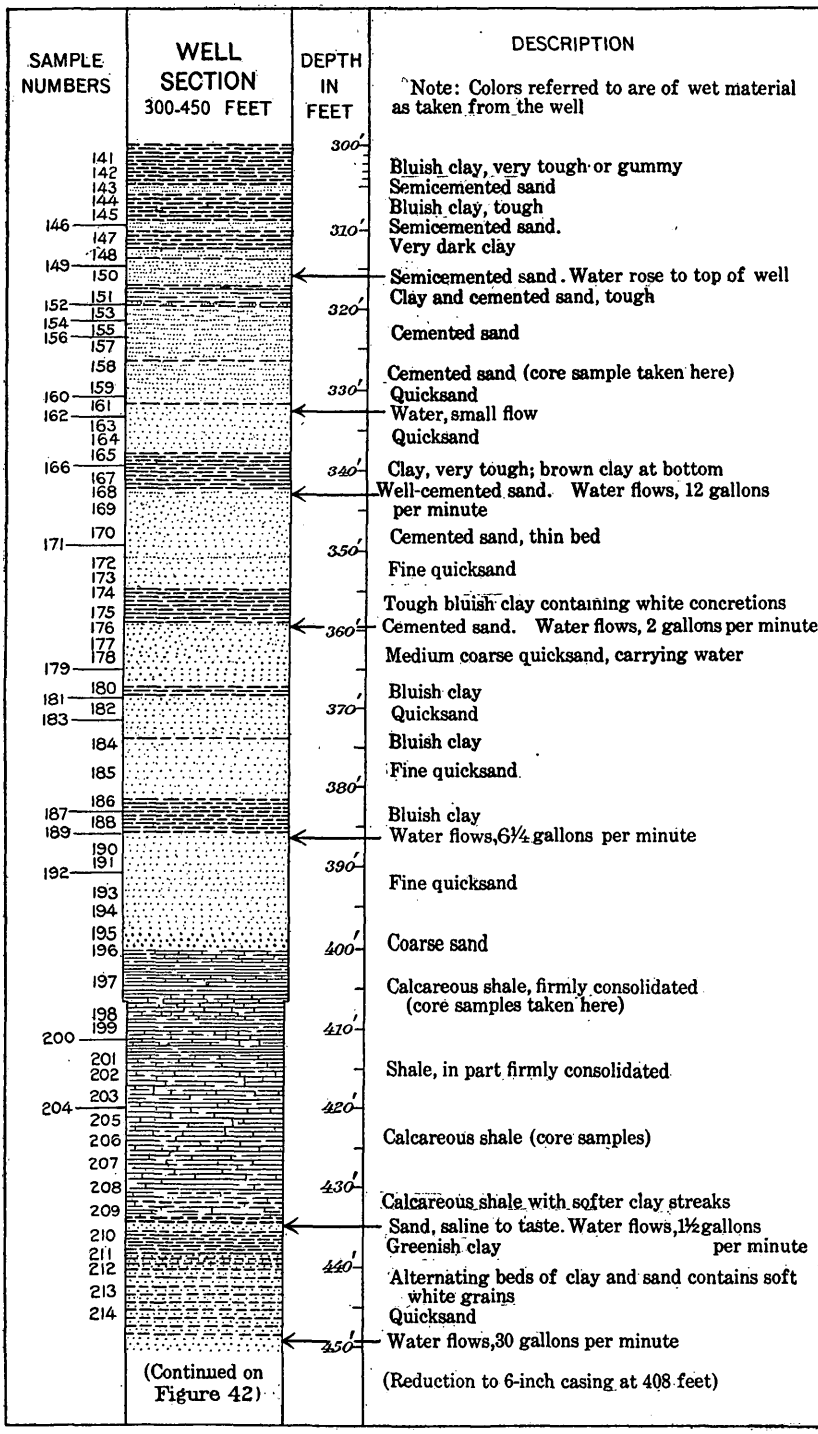



FIGURE 41.—Section of strata in Timber Lake well, near Fallon, Nev.—III.

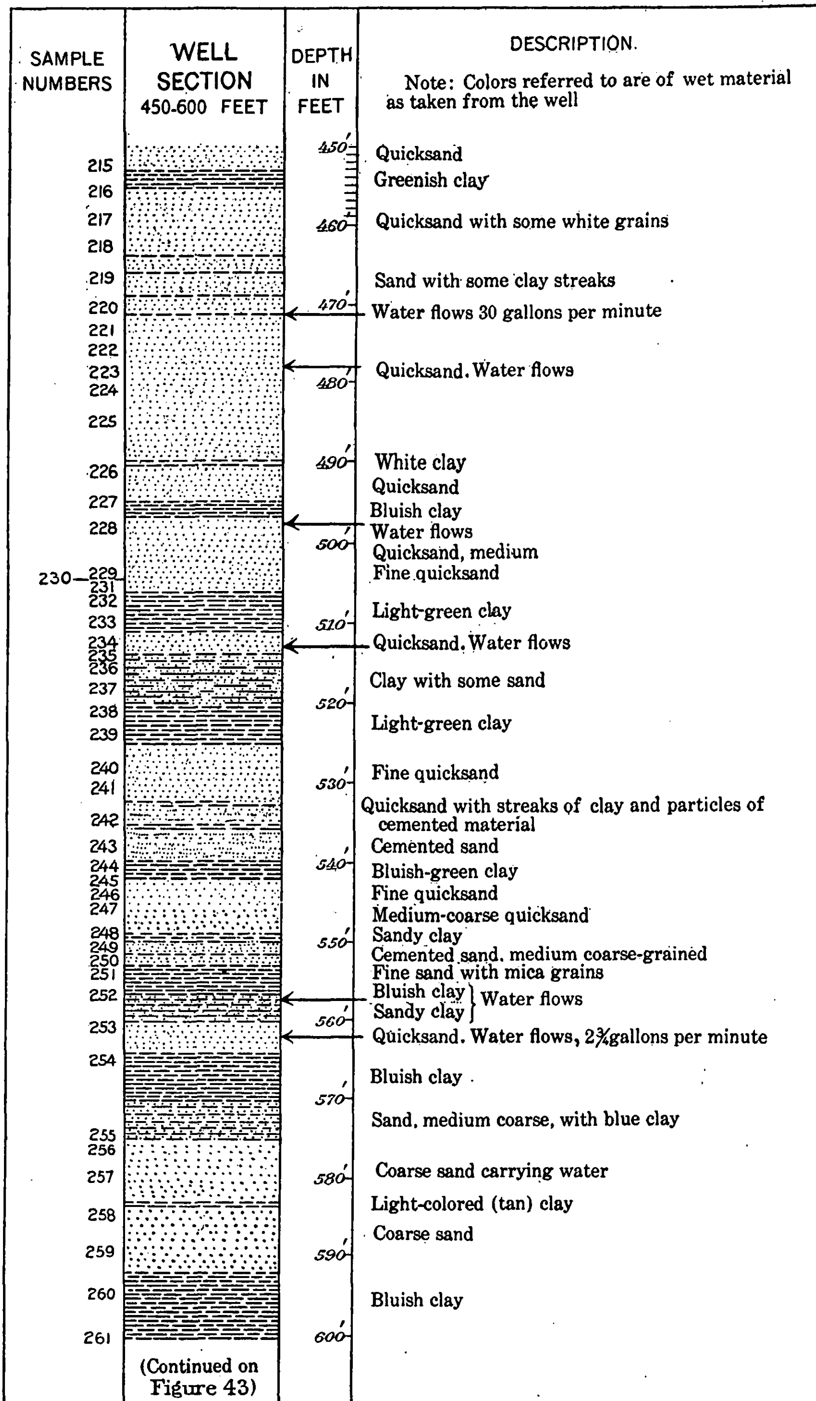



FIGURE 42.—Section of strata in Timber Lake well, near Fallon, Nev.—IV.

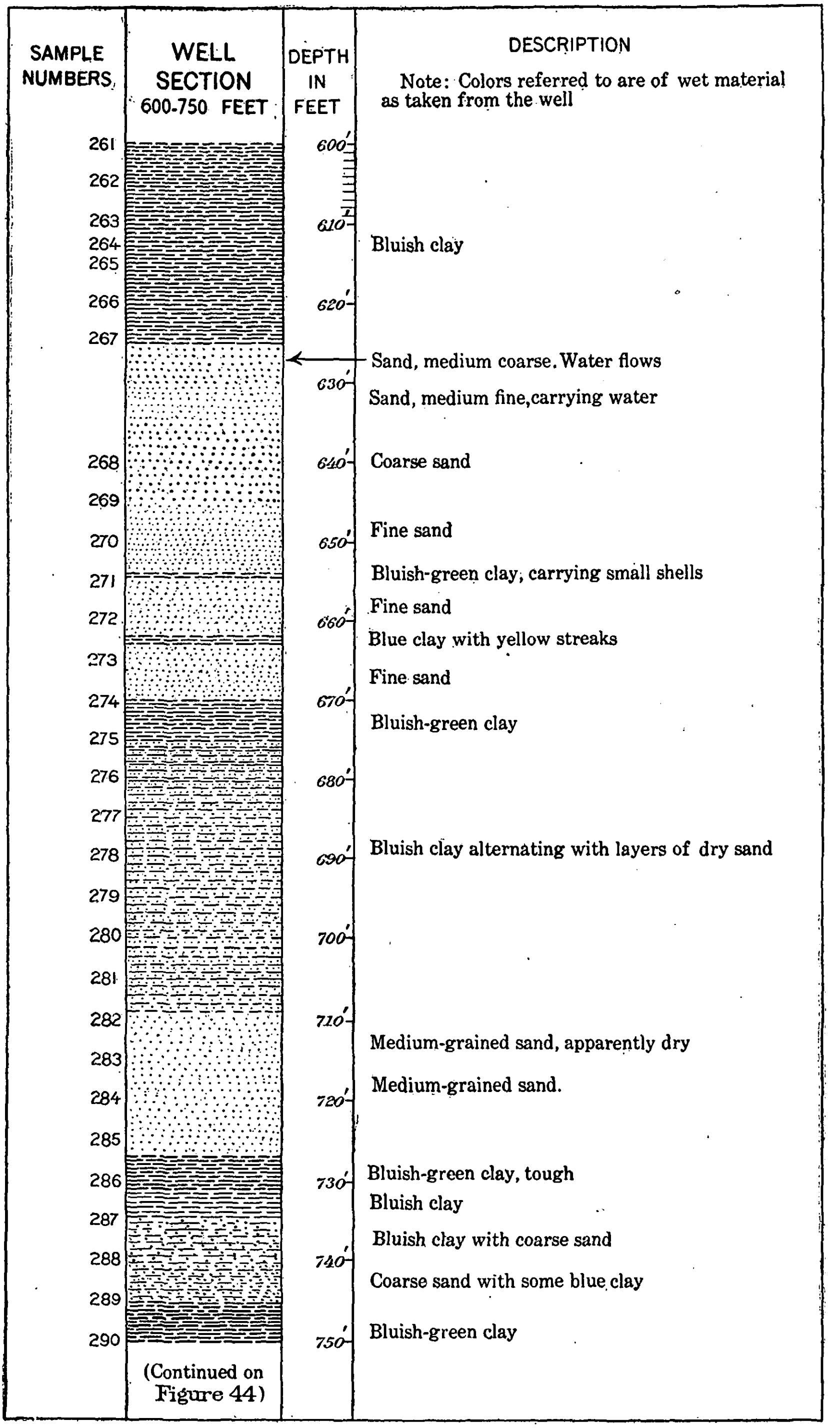



FIGURE 43.—Section of strata in Timber Lake well, near Fallon, Nev.—V.

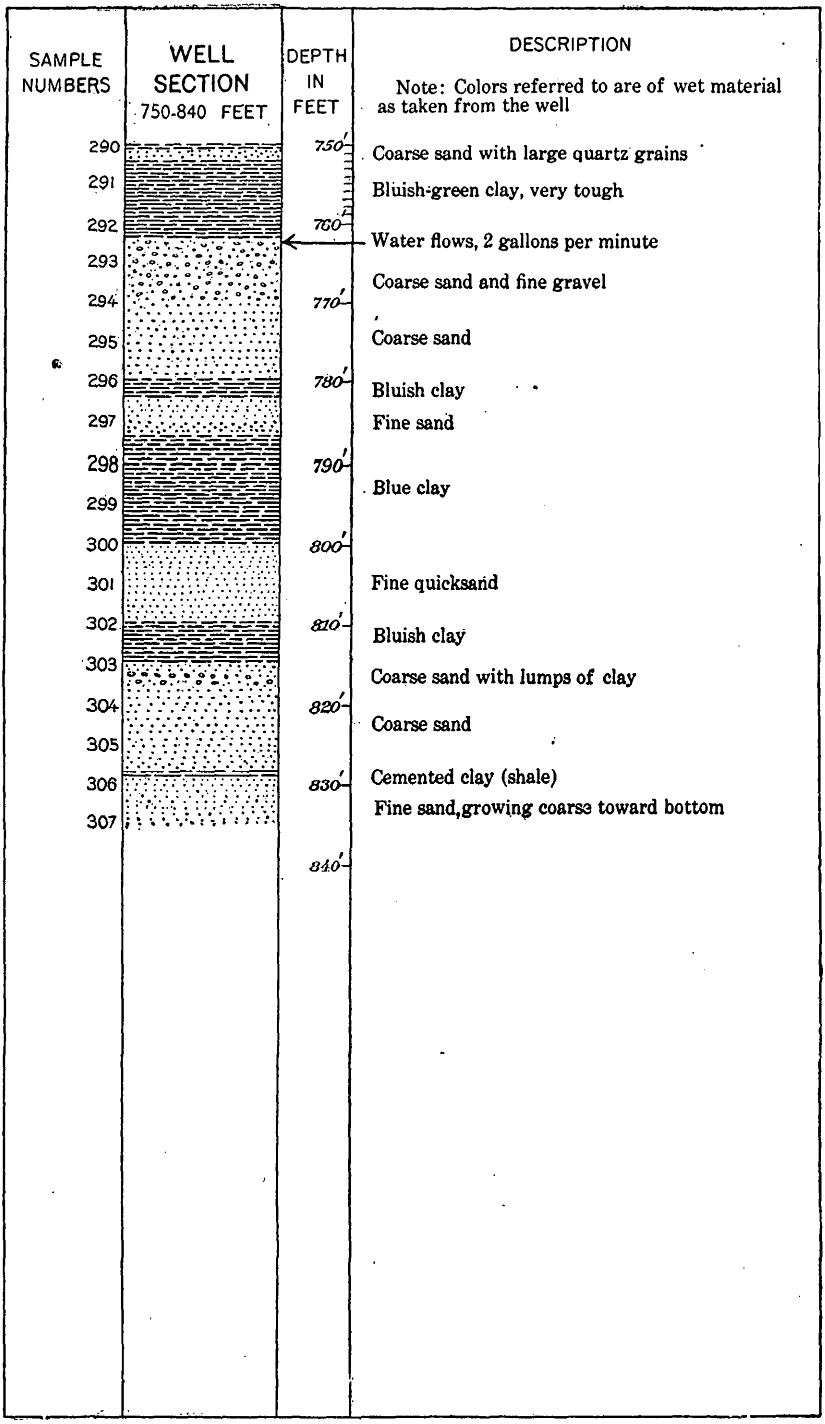



FIGURE 44.—Section of strata in Timber Lake well, near Fallon, Nev.—VI.

## SUMMARY OF EXPLORATION FOR THE GERMAN SALT DEPOSITS.

In this connection it is also of interest to note the history of the explorations which resulted in the discovery of the great deposits about Stassfurt, in Germany. Possibly the analogy between that search and our own should not be urged too strongly as bearing on the present situation, but it is nevertheless significant.

For centuries brine springs were known in the vicinity of Stassfurt, Prussia, and it is recorded that from at least as early as the thirteenth century salt was regularly produced or manufactured from these springs. When the demand for salt began to exceed the supply that could be obtained from the springs alone, attention was directed to the opinions expressed by the mining authorities of the times, who held that these springs must derive their salt from rich saline beds below and that these beds might be reached by boring.

The first boring was done by order of the Prussian Government, commencing in 1839. The saline bed was reached in 1843 at a depth of 768 feet. The boring was continued 975 feet deeper, a total of 1,743 feet, passing through the salt beds. At first the material sought was sodium chloride, or common salt, and the presence of magnesium and potassium compounds in the salts encountered was considered an unfortunate feature.

In 1851 a shaft was begun near one of the bore holes, still in the search for beds of common salt. The success attained in these experiments aroused many private undertakings, and when the value of the associated potash salts was also recognized, the industry became of great importance.

One authoritative account relates that from 1890 to 1902 more than 150 companies were organized for prospecting these deposits by boring, and that many of them drilled several holes, while others were liquidated without accomplishing anything; also that enormous sums of money were and are still being expended in such enterprises. The total amount of such drilling was estimated to be at least 500,000 feet in 1902 and must exceed that figure many times over at the present time.

The productive mines are worked by means of shafts and are supplied with very extensive equipment.

The problems relating to the method of extraction and refining of the potassium or other salts from the crude material as it is found at Stassfurt have been very successfully worked out.

# THE OCCURRENCE OF POTASH SALTS IN THE BITTERNS OF THE EASTERN UNITED STATES.

By W. C. PHALEN.

## INTRODUCTION.

In connection with the potash investigations carried on by the Geological Survey in the summer of 1911, as authorized by the act of March 4, 1911 (Stat. L., vol. 36, pt. 1, p. 1256), a systematic and fairly complete study of the brines, bitterns, and rock-salt deposits of the States east of the Rocky Mountains was attempted. The study was confined to the localities that were considered the most promising with reference to the occurrence of potash salts. The investigation has but recently been completed and many of the data collected have yet to be assembled and classified before being presented in final form. Moreover, most of the samples submitted for chemical examination are yet to be analyzed, and the analyses presented below constitute but a small fraction of those to be published later. It is hoped that the complete analyses will serve for many years as positive data on the occurrence or nonoccurrence of potash salts in connection with many of the salt deposits east of the Rocky Mountains. It will be understood, therefore, that this report is purely of a preliminary nature.

In connection with the study approximately 175 samples of brines, bitterns, and calcium chloride were collected. This does not include the large number of brine samples procured through correspondence, chiefly from oil drillers throughout the country, earlier in the year. The geology of the occurrences of the brine and the salt was investigated and to this end many records of deep wells were obtained. Where possible, actual samples of the rocks passed through in making the deep drillings were collected and will be studied microscopically and chemically during the coming winter. Because so few of the samples (less than 25) collected or received by the Survey have been analyzed, a general statement of results at this time is impossible. By reference to the analyses given further on it will be seen that many bitterns supposed to be devoid of potash salts in fact contain small amounts of them. Particular attention is called to a natural bittern from northern Ohio which is known to occur over a large area and which in its content of potash salts stands out from the rest.

## EXPLANATION OF THE TERM "POTASH."

To meet the numerous inquiries that have been addressed to the Geological Survey regarding the exact meaning of the terms "potash," "actual potash," "potassium," etc., the following explanation is given:

The element potassium, represented by the symbol K, is the basis of all potash salts or compounds. This substance is a metal—that is, it possesses metallic properties. To prevent rapid change it must be kept from air and water, with both of which it combines with great avidity. Combined with oxygen it forms potassium oxide, represented by the symbol $K_2O$, known among scientists as potassa but popularly as potash. In estimating the quantity of potassium in the different products of the Stassfurt deposits this compound, $K_2O$, is employed as a standard, the object being to establish a basis of comparison for all potassium salts. Among chemists as well as laymen there has grown up the practice of using for this standard the term "potash." When only the term "potash" is used in speaking of potash products, it is understood to refer to the potassium oxide ($K_2O$) present. As a matter of fact, potash salts are not sold in the form of $K_2O$, but as the sulphate or chloride,[1] etc. By the term "potassium sulphate" is meant potassium (K) combined with the acid radicle of sulphuric acid ($SO_4$), or potassium oxide ($K_2O$) combined with sulphur trioxide ($SO_3$), making the compound $K_2SO_4$. By "potassium chloride" is meant potassium (K) combined with another element, chlorine (Cl).

In the following table are given the percentages of the element potassium and the combination known as potash in or obtainable from the common potassium compounds and minerals:

*Potassium and "potash" in potassium compounds.*

| Name. | Symbol. | Percentage of potassium (K). | Chemical equivalent in terms of "potash" ($K_2O$). |
|---|---|---|---|
| *Element.* | | | |
| Potassium | K | 100 | |
| *Potassium salts or "potash salts."* | | | |
| Potassium chloride (mineral sylvite) | KCl | 52 | 63 |
| Potassium muriate (same as chloride). | | | |
| Potassium sulphate | $K_2SO_4$ | 45 | 54 |
| Potassium nitrate (saltpeter) | $KNO_3$ | 39 | 47 |
| Potassium carbonate[2] | $K_2CO_3$ | 57 | 68 |
| Potassium hydrate or caustic potash | KOH | 70 | 84 |
| Potassium cyanide | KCN | 60 | 72 |
| *Stassfurt minerals.* | | | |
| Carnallite | $KMgCl_3.6H_2O$ | 14 | 17 |
| Kainite | $MgSO_4.KCl.3H_2O$ | 16 | 19 |
| Sylvite (potassium chloride) | KCl | 52 | 63 |

[1] The chloride is also known in the trade by the chemically obsolete term, "muriate of potash."
[2] The term "potash" is often applied to this compound.

Other potash-bearing minerals that are found at Stassfurt are, among the chlorides, douglasite ($K_2FeCl_4 2H_2O$ ?); among the sulphates, polyhalite ($2CaSO_4.MgSO_4.K_2SO_4.2H_2O$), krugite ($4CaSO_4.MgSO_4.K_2SO_4.2H_2O$), langbeinite ($2MgSO_4.K_2SO_4$), leonite ($MgSO_4.K_2SO_4.4H_2O$), picromerite ($MgSO_4.K_2SO_4.6H_2O$), and aphthitalite ($K_3Na(SO_4)_2$). All these are of rare occurrence.

Some of the more common potash-bearing materials produced at Stassfurt consist of mixtures of potash-bearing minerals and others which do not contain potash. Among the latter may be noted common rock salt (sodium chloride) and kieserite (hydrous magnesium sulphate). Trade names have been applied to these mixtures, to which obviously no definite chemical symbol can be given. Among the trade names in common use are "sylvinite," "hartsalz," "manure salts," and "double manure salts." In a pamphlet issued by the German potash syndicate[1] these products are defined in part as follows:

Sylvinite is, in the main, a mixture of rock salt or sodium chloride ($NaCl$) and sylvite or potassium chloride ($KCl$), with a little kainite ($MgSO_4.KCl.3H_2O$).

Hartsalz is a mixture of sylvite or potassium chloride ($KCl$), rock salt or sodium chloride ($NaCl$), and kieserite ($MgSO_4.H_2O$).

Manure salts apparently consist chiefly of sodium chloride ($NaCl$) and potassium chloride with variable but small amounts of other salts.

Double manure salts consist essentially of the double sulphate of potassium and magnesium.

The table below gives the "potash" ($K_2O$) content and the minimum guaranteed "potash" in the products turned out by the German potash syndicate, as stated in the pamphlet just cited.

*"Potash" in products of German potash syndicate.*

| | Crude salts (natural products). | | | Sulphates (nearly free from chlorides). | | |
|---|---|---|---|---|---|---|
| | | | | Sulphate of potassium. | | Sulphate of potassium and magnesium (double manure salts). |
| | Kainite. | Carnallite. | "Sylvinite." | 90 per cent grade. | 96 per cent grade. | |
| Potash | 12.8 | 9.8 | 17.4 | 49.9 | 52.7 | 27.2 |
| Minimum guaranty | 12.4 | 9.0 | 12.4 | 48.6 | 51.8 | 25.9 |

[1] Stassfurt industry, published by the German Kali Works.

*"Potash" in products of German potash syndicate*—Continued.

| | Salts containing chlorides. | | | | |
|---|---|---|---|---|---|
| | Chloride of potassium. | | | Manure salts. | |
| | 90 to 95 per cent grade. | 80 to 85 per cent grade. | 70 to 75 per cent grade. | | |
| Potash | 57.9 | 52.7 | 46.7 | 21.0 | 30.6 |
| Minimum guaranty | 56.8 | 50.5 | 44.1 | 20.0 | 30.0 |

## STATEMENT OF THE GERMAN POTASH SYNDICATE.

In a pamphlet entitled "The potash controversy," dated at New York January 20, 1911, A. Vogel, general representative of the German potash syndicate for the United States and Canada, makes a statement on behalf of that syndicate. This statement is the same as that submitted to President Taft and Secretary Knox later in the year, except that certain matter not of general interest has been omitted.

Certain parts of this pamphlet will be quoted here in order to convey to American readers who have not had access to the subject matter contained in it some authoritative idea of the present status of the world's potash industry from the German side and the relations of the United States to it. In this brief summary will be shown (1) Germany's monopoly of the production of potash salts; (2) the consumption of potash salts in the United States; (3) the trade in potash salts with the United States, including a classification of importers. The discussion of these different topics will at once indicate the reasons why an investigation of potash resources has been undertaken by the United States Government.

*Germany's monopoly of the potash industry.*—The German Empire has a natural monopoly of potash salts. Practically all of the world's known potash resources are within its territory and under its control, and substantially the whole of the world's potash consumption has always been supplied from the German mines. There are in operation in Germany at present about 69 mines, and new mines are being developed from time to time. A number of them have long been owned and operated by different German States. One of the oldest and largest of the deposits has from the outset been owned and managed by the State of Prussia, and from time to time further deposits have been acquired by the Prussian Government. Another of the largest mines has from the outset been owned and operated by the Grand Duchy of Anhalt. Another large mine has for a long time been owned and operated by the State of Brunswick. Partial ownership of three further mines has for a number of years been in the State of Sachsen-Weimar.

*Consumption of potash salts in the United States.*—The world's consumption of potash salts during 1909 was about 670,000 tons of pure potash,[1] of which more than half was consumed in Germany. Of the balance exported, about 150,000 tons were shipped to the United States. In 1910 the total consumption considerably increased,

[1] Presumably reckoned as the oxide of potassium, or potassa, $K_2O$. The kind of ton is not stated.—W. C. P.

while the quantity exported to the United States is estimated at over 200,000 tons. These exportations by the German mines to the United States embrace various potash salts in both crude and concentrated form. The principal grades of concentrated salts are:

Muriate (or chloride) 80 per cent strength, containing 50 per cent of pure potash.
Sulphate, 90 per cent strength, containing 50 per cent of pure potash.
Sulphate magnesia, 48 per cent strength (known as "double manure salt"), containing 26 per cent of pure potash.

The principal grades of crude salts are:

Manure salt, containing not less than 20 per cent of pure potash.
Hard salt, containing not less than 16 per cent of pure potash.
Kainit, containing not less than 12.4 per cent of pure potash.

Speaking in terms of pure potash, the consumption in the United States is fairly evenly divided between the crude and concentrated salts. Muriate constitutes the great bulk of the trade in concentrated salts, kainit of the trade in crude salts.

*Trade with the United States, including a classification of importers.*—Practically all the potash consumed in the United States is imported from Germany, and it is devoted almost exclusively to the fertilization of farm land, either directly or else indirectly as one of the most essential ingredients of manufactured fertilizer.

Potash importers in the United States may be roughly divided into four principal classes, namely:

(1) The two large corporations engaged in the business of making fertilizers—the American Agricultural Chemical Co. in the North and the Virginia-Carolina Chemical Co. in the South. Their joint annual consumption is now, say, 70,000 tons, divided about equally between them.

(2) The less important established fertilizer manufacturers (including Armour & Co. and Swift & Co.), probably over 100 in number, known as the "independents," whose annual joint consumption is perhaps 70,000 or 80,000 tons. Most of these concerns, for their common protection, voluntarily act in harmony according to trade policies recommended by an informal association in which they are represented.

(3) Some ten or a dozen manufacturers of chemicals, whose annual joint consumption is about 10,000 tons.

(4) A very large number of smaller purchasers, including some 600 dry mixers and jobbers, hundreds of cotton-oil manufacturers who also make fertilizers, numerous farmers' unions and cooperative societies, and thousands of local dealers who distribute unmixed potash direct to the farmers for home mixing or for use unmixed on the soil. The importations to these purchasers have rapidly increased within the last year. In 1909 the quantity was comparatively insignificant. In 1910 it was probably more than 40,000 tons. The increase in the total consumption within the United States, from 150,000 tons in 1909 to 200,000 tons in 1910, is to be accounted for very largely by the additional importations of this class.

## PREVIOUS WORK ON POTASH SALTS BY THE UNITED STATES GEOLOGICAL SURVEY.

Early in 1911 the Geological Survey published a summary of the latest information on the domestic potash industry and the possibilities for its future development.[1] This summary, which is still available for free distribution, contained (1) a discussion of the various uses of potash salts aside from their application to the fer-

[1] Potash salts, their uses and occurrence in the United States: Advance chapter from Mineral Resources U. S. for 1910.

tilizer industry; (2) statistics showing the magnitude of the importation of potash salts, compiled from figures in possession of the Bureau of Statistics, Department of Commerce and Labor; (3) an account of the chemical manufactures in the United States dependent on imported potash salts and figures showing the magnitude of these industries, which include, aside from the fertilizer industry, the manufacture of potash salts for use in the soap, glass, and explosives industries, of alum, the cyanides, bleaching powder, dyestuffs, and a long list of general chemicals; (4) a section on the deposits of potash salts near Stassfurt, Germany, including an account of their discovery, the theory of their occurrence, and a list of the salts deposited; (5) notes on the German potash salts in the United States; (6) a statement of the financial results of German potash mining; (7) a discussion of the occurrence of potash compounds in the United States, including the igneous rocks, the marls of New Jersey,[1] the salines, and alunite, a mineral known to contain potash; (8) a sketch of the organic sources of potash salts, including wood ashes, beet-sugar molasses and residues, wool scourings or suint, and seaweed; (9) notes on the possible occurrence of potash salts in the United States.

## IMPORTS OF POTASH SALTS.

In order to bring before the reader the magnitude of the importation of potash salts into the United States, the following table is given, the figures having been obtained from the Bureau of Statistics.

*Imports of potash salts for the nine months ending September, 1909, 1910, and 1911, in pounds.*

[Figures from Bureau of Statistics.]

| | 1909 | | 1910 | | 1911 | |
|---|---|---|---|---|---|---|
| | Quantity. | Value. | Quantity. | Value. | Quantity. | Value. |
| Carbonate of potash | 16,512,865 | $545,317 | 12,997,618 | $415,686 | 16,711,935 | $503,828 |
| Caustic or hydrate of potash, not in sticks or rolls | 6,163,852 | 258,053 | 6,233,583 | 257,250 | 5,332,926 | 216,171 |
| Cyanide of potash [a] | | | | | [b] 1,385,275 | [b] 206,348 |
| Muriate of potash | 200,045,284 | 3,207,214 | 305,108,932 | 4,126,955 | [b]372,909,953 | 5,598,420 |
| Nitrate of potash, or saltpeter, crude | 12,261,105 | 361,331 | 9,874,717 | 297,158 | 6,780,382 | 225,280 |
| Sulphate of potash | 37,731,363 | 716,431 | 62,769,061 | 983,470 | 90,310,434 | 1,666,102 |
| All other potash [c] | [b] 375,758 | [b] 51,349 | 2,044,188 | 228,238 | 3,760,472 | 377,153 |
| | 273,090,227 | 5,139,695 | 399,028,099 | 6,308,757 | 497,191,377 | 8,793,302 |

[a] Included in "All other chemicals" prior to July 1, 1911.
[b] Figures cover period since July 1.
[c] Included in "All other chemicals" prior to July 1, 1909.

The imports of kainite and manure salts for the nine months ending September, 1911, amounted to 493,066 long tons, or 1,104,467,840 pounds, valued at $2,872,065, making a total importation of potash salts for the nine months ending September, 1911, of 1,601,659,217

[1] The Leitchfield marls (Shaler) of Kentucky, which contain appreciable amounts of potash and phosphoric acid, deserve to be mentioned in this connection.

pounds, valued at $11,665,367. In this connection the following recent statement prepared by the Bureau of Statistics is of interest:

The importation of potash salts is now running at the rate of over a million dollars a month, and has aggregated since 1900 approximately $75,000,000. While these potash salts enter the country in various forms and thus under various titles, including muriate of potash, sulphate of potash, carbonate of potash, kainit, etc., their aggregate import value in the nine months ending with September, 1911, was $11,500,000, against about $7,000,000 in the corresponding months of 1910 and a little over $5,000,000 in the corresponding months of 1909, thus indicating a steady and rapid growth in the importation of this class of products. Taking the figures for fiscal years, the total for 1911 was $14,000,000, compared with less than $12,000,000 in 1910, less than $4,000,000 in 1900, and less than $2,000,000 in 1890.

## PRESENT WORK OF THE GEOLOGICAL SURVEY.

### SCOPE OF THE WORK.

In view of the obvious and urgent necessity, as indicated in the general and specific ways mentioned above, to determine if possible a source of potash salts in the United States, and thus to conserve the vast sum of American money shipped abroad for potash salts each year, the United States Geological Survey, of the Department of the Interior, and the Bureau of Soils, of the Department of Agriculture, were commissioned by the Sixty-first Congress to search for potash salts.

In the previous publication of the Geological Survey alluded to above, it was stated in general, with reference to the possible occurrence of potash salts in the United States, that to make a thorough and complete investigation of the occurrence of potash salts, every known salt deposit should be tested, for ordinary rock salt may overlie soluble potash salts as well as underlie them. Both these conditions exist at Stassfurt. The normal occurrence of salt is, however, at the base of a series of soluble salines deposited from the evaporation of sea water. The brines of Midland, Saginaw, Bay, and Isabella counties, Mich., are of interest in this connection, inasmuch as they contain bromine in commercial quantity, a fact which indicates partial desiccation of sea water and the occurrence of mother liquors. The brines of Malden, Kanawha County, and of Mason and Hartford, Mason County, W. Va., and across Ohio River from Mason, in Meigs County, Ohio, likewise contain and are worked for bromine. Bromine is also obtained from brine in Pittsburgh, Pa.

The "Red Beds" of the southwestern part of the United States, in Texas, Oklahoma, Kansas, Colorado, New Mexico, and possibly other States, contain deposits of gypsum and salt and are worth notice as possible sources of potash salts. These beds might profitably be explored in those places where structural conditions seem to favor the accumulation and retention of the salines.

The Geological Survey has concentrated its investigations of the possibilities of finding potash salts in commercial quantities along the following lines: (1) The exploration by actual deep drilling for deposits of potash salts in Nevada and in other localities in the far West, to be selected later, under the direction of Hoyt S. Gale, whose report of progress has already been published; (2) the investigation of the occurrence of certain rich potash-bearing rocks and minerals, to be described in short reports; and (3) the investigation of the salt deposits and the brines and bitterns in the United States east of the Rocky Mountains, carried on by the writer under the supervision of David T. Day.

## INVESTIGATION OF THE BRINES.

### COLLECTION OF SAMPLES.

The work in connection with the investigation of the brines, primarily, was begun in April, 1911, by sending a circular letter to all the salt producers in the United States and to many drillers of oil wells, to procure samples of brine. This circular letter is in part as follows:

> The Geological Survey is desirous of making a comparative study of the different brines characteristic of the different salt-producing regions of the States east of the Missouri River. I shall be very glad if you will therefore send a sample of your brine and a sample of the mother liquor in as concentrated a form as possible, and also give an idea as to the amount of original brine which the mother liquor represents. These will be examined, and a copy of the final report will be sent to you as promptly as possible. In this examination particular account will be taken of the occurrence of potash in these brines. I am sending, under separate cover, cans in which these samples may be sent. These cans are labeled ready to be returned. * * *

Accompanying each bottle sent out was another circular letter describing the objects of the work and giving explicit directions as to the brine samples. The form of this circular letter addressed to oil producers is as follows:

> The United States Geological Survey is making a systematic examination of crude petroleum from all the pools in the United States. In connection with this investigation it is advisable to make comparative analyses of the salt water found in each pool. This feature of the investigation is receiving particular attention at this time on account of the demand for potash salts and in the hope that these analyses may lead to the discovery of salt deposits containing potash in commercially valuable quantities.
>
> Accompanying this circular you will receive a bottle or can, which you are requested to fill with brine from your well and send by mail to the United States Geological Survey.
>
> In filling the bottle please observe the following precautions:
>
> 1. Remove the bottle from the mailing case and take care not to stain the mailing case with oil.
> 2. Rinse the bottle with the brine before filling.
> 3. Fill the bottle with the brine as it issues from the well, if possible. If this is not practicable, take it from the settling tank. A slight amount of oil in the sample will do no harm.

4. Wipe the bottle dry, close it tightly, and fill out each item of the label legibly and as carefully as possible.

5. Replace in mailing case, screw on the cap tightly, see that the mailing case is clean, and place it in any post office. The mailing case is properly labeled and does not require postage.

A copy of the analysis will be furnished you if asked for.

The responses received were very satisfactory, and many brines from all parts of the United States have been received. These will be investigated by the Bureau of Soils, as a result of a cooperative agreement between that bureau and the Geological Survey.

## FIELD WORK.

At the beginning of the field season the writer was detailed to make a systematic examination of all the salt deposits and the salt industry in the United States east of the Rocky Mountains, with special reference to the occurrence of potash salts.

Accordingly, visits were made to practically all the salt plants in the eastern United States where there seemed any likelihood of procuring material that would prove of value in the present investigation. During the early part of 1911 it was rumored that potash salts had been found near Goderich, Canada, and this locality also was visited and samples obtained. The age of the beds near Goderich in which salt occurs, it is thought, will prove identical with that of the beds around Detroit and along St. Clair River, and there is no more reason to suspect the occurrence of potash salts in western Ontario than in the State of Michigan. The rumor proved to be entirely unfounded.

During the early part of the work the writer was accompanied by J. W. Turrentine, of the Bureau of Soils. The field work extended over the western portion of New York and included visits to the operating plants in Wyoming, Livingston, and Genesee counties, by the writer, and to points in Tompkins County, by Dr. Turrentine. Every active salt plant in the Lower Peninsula of Michigan, in northern and southern Ohio, West Virginia, and western Pennsylvania was visited. The Kansas field was gone over, and a trip was made to Louisiana. Samples of rock salt were carefully collected in the mines visited, and where the evaporative process was used samples of the brine and of as old a bittern as possible were collected in order to secure the maximum concentration of the mother liquor salts—that is, those salts remaining in the brine after the removal of the sodium chloride. In every case care was taken to obtain a bittern from which the maximum amount of salt had been removed, for there, if anywhere, would potash salts occur, if any were present in the original brine. The amount of bittern going to waste daily from the different plants was ascertained where practicable, for these data, together with a knowledge of the composition of the bittern, would show the amount of potash salts now going to waste in different parts of the country. In addition to collecting samples of rock salt, brines, and bitterns, the investigators obtained samples of calcium chloride, which represents the final concentrated product from the evaporation of the bittern after the sodium chloride and bromine have been removed. The geology of the brines was also studied, and to this end records of deep drillings were collected. In Michigan, both in the eastern part of the State near Detroit and in the western part near Manistee and Ludington, samples of these drillings were obtained. They will not only serve as a guide to the stratigraphy of the regions whence they come, but, when examined both microscopically and chemically, they may show the presence of potash salts. A bulletin on the salt industry is planned for issue in the spring of 1912, which will summarize the results of the last season's work and include sections on the geology of the brines, the chemistry of brine in general, the salt-making processes in the United States, the occurrence of potash salts in the brines, together with a quantitative statement of the aggregate amount going to waste at the plants visited, and a bibliography of the most important publications relating to the occurrence of salt and the salt industries in general.

It is believed that there is need of such a publication at the present time, for the results of work along this line in the United States are scattered and inaccessible. Moreover, the chemical work connected with the present investigation is being done with extreme detail and care on samples that have been collected under circumstances as closely similar as possible. The results should be strictly comparable.

## GEOLOGY OF THE BRINES.

### NEW YORK.[1]

The salt beds of the State of New York occur almost exclusively in the Salina formation, or, as it has sometimes been called, the "Onondaga Salt group" of the Silurian system. According to Vanuxem,[2] this important formation contains all the gypsum masses of western New York and furnishes all the salines of Onondaga and Cayuga counties.

The Salina formation was described by James Hall[3] as follows:

> Succeeding the Niagara group is an immense development of shales and marls with shaly limestones, including veins and beds of gypsum. The general color is ashy, approaching drab, with some portions of dark bluish green. The lower part is of deep red, with spots of green. Succeeding this, where protected from atmospheric influences, the rock is blue like ordinary blue clays, with bands of red or brown. This portion

[1] See also Merrill, F. J. H., Bull. New York State Mus. No. 11, 1893.
[2] Report on the geology of the third district of New York, 1842.
[3] Geology of the fourth district of New York, 1843.

and that succeeding it are often green and spotted and contain seams of fibrous gypsum and small masses of reddish selenite and compact gypsum. From this it becomes gradually more gray, with a thin stratum of clayey limestone, which is sometimes dark, though generally of the same color as the surrounding mass. The formation terminates upward with a gray or drab limestone called by Vanuxem the "magnesian deposit." The red shale forming the lower division of the group is well developed, but in the third district has not been found west of the Genesee River. It appears in the eastern part of Wayne County, as indicated by the deep-red color of the soil which overlies it.

In their studies of the surface Hall and Vanuxem found no rock salt, because this mineral, being soluble, can not remain at the surface; but from various wells put down since their time sections of the Salina formation have been obtained, showing the position and relation of the salt beds.

Throughout the Oatka-Genesee district, which was visited by the writer, the salt is usually found at levels varying from 550 to 750 feet below the surface of the Onondaga limestone. Exceptions to this are few in number. The upper surface of the Onondaga has been taken as the datum plane to determine the relative position of the salt beds, because it is invariably recognized by the driller. Its persistent character and the abundance of chert scattered through it contrast strongly with the overlying soft shales and thin limestones.

The dip of the strata in western New York is approximately southeast, at the rate of about 60 feet to the mile, and the section between Le Roy, in eastern Genesee County, and Gainesville Creek shows that the beds do not slope uniformly to the south, but undulate in that direction. Extraneous evidence seems to point to the fact that many of the wells and shafts of New York have penetrated only little more than halfway through the salt masses.

#### MICHIGAN.

The rock salt of Michigan is found in the Monroe formation, consisting of Silurian rocks, which have sometimes been called "Salina," but which are not known to be the same as the Salina formation of New York. The brines in the Saginaw Valley occur in the sandstones of the Marshall formation (lower Carboniferous), whose base lies from 750 to 1,000 feet below the surface along Saginaw River. It is these sandstones that yield the brines which are utilized so extensively in the manufacture of salt, bromine, and calcium chloride.

#### OHIO.[1]

The salt produced in Ohio comes from two distinct districts—the northeastern district, comprising Cuyahoga, Medina, Summit, and Wayne counties, and the southeastern district, comprising Meigs and Morgan counties. In southeastern Ohio Meigs County is by far the

[1] Bownocker, J. A., Salt deposits and the salt industry in Ohio: Bull. Geol. Survey Ohio, 4th ser., No. 8, 1906.

larger producer, and Pomeroy is the center of the industry. The salt horizon of the northeastern part of the State is in the Monroe formation of the Silurian. The surface rocks in the Ohio Valley near Pomeroy, Ohio, and Mason, W. Va., lie near the top of the Conemaugh formation, formerly known as the "Lower Barren Coal Measures." The depths of the wells in this region have undergone great variation. At first the wells were very shallow, but later they were extended to greater depths as the supply of brine near the surface became exhausted. When the supply from these deeper wells became inadequate they were sunk to still greater depths. At present salt works both in Ohio and in West Virginia are pumping brine from depths of 1,100 to 1,350 feet. The brine-bearing strata dip toward Pomeroy from the northwest, and as the brine has been removed from the wells the supply has been renewed from the rocks lying at higher levels in that direction. The brine was doubtless once a part of the ocean, and as the sand or gravel now constituting the salt-bearing rocks was deposited on the ocean floor, sea water filled the spaces between the grains and pebbles and has since remained in that position. It must be borne in mind that the Pomeroy brines were formed very near the shore, probably within a landlocked sea, and hence might vary considerably from those in the open ocean. This fact explains the presence of the relatively large quantities of bromides and iodides, as these substances are contained in certain marine plants. It is possible that the conditions were very favorable for these plants in the early sea in the vicinity of Pomeroy. The wells along Ohio River procure their brine chiefly from a horizon approximately near the base of the Salt sand of the Carboniferous.

## WEST VIRGINIA.

The geology of the brine beds at Mason, W. Va., is similar to that at Pomeroy, on the opposite side of Ohio River. On the Ohio side the geology has been worked out by J. A. Bownocker and published in Bulletin 8 of the Ohio Geological Survey and in "Mineral resources of the United States" for 1907. It has been given above under Ohio and will not be repeated here.

Brines occur near Malden, W. Va., which is located on Kanawha River a few miles above Charleston. The record of a gas well on Cool Spring Branch of Burning Springs Hollow, about 3 miles from Malden, throws some light on the geology of the beds from which the brine is obtained. The record of the well, which is known as the Edwards well No. 1, has been published in a report by I. C. White.[1] According to White, the sandstone known to the oil men as the Salt sand furnishes the brine in the Kanawha Valley. This sandstone belongs to the Pottsville formation and lies very near the base of the coal measures.

[1] West Virginia Geol. Survey, vol. 1, p. 272.

### KANSAS.

The salt industry in Kansas depends on the rock salt found in Permian strata and includes the mining of this salt and the evaporation of artificial brines from wells drilled to it. By far the larger part of the salt is obtained by evaporation. The subject of salt mining in Kansas is very fully described in two papers, one by Samuel Ainsworth and the other by C. M. Young, referred to in the chapter on salt and bromine in "Mineral resources of the United States" for 1909.

In 1887 and 1888 the important salt beds of Kansas were found while wells were being drilled for oil and gas. They have been developed in an area located in the south-central part of the State, in Rice, Reno, Kingman, and parts of the adjoining counties, including Ellsworth, Saline, McPherson, Harvey, Sedgwick, Sumner, Harper, Barber, Pratt, Stafford, Barton, and Russell. In the early history of the industry numerous shafts were sunk to the salt deposits, but from lack of experience and of funds to carry on the work many of them proved failures. Only four important operations may be listed among the plants mining rock salt in recent years, and one of these plants was destroyed by fire late in 1908 and has never been rebuilt. Only three other salt mines in Kansas have ever produced salt to any extent and these have been described by Ainsworth.[1]

Young[2] discusses the evaporated-salt industry, which has its center at Hutchinson. He describes the manner of obtaining the brines from the wells, the various processes—direct heat, grainer, vacuum pan—of converting the brine into salt, the methods of handling the salt, and the productive capacity of the district.

### LOUISIANA.

In Louisiana the salt mined on Weeks and Avery islands, so called, belongs in Quaternary strata. Weeks Island is on the east shore of Weeks Bay, an eastern lobe of Vermilion Bay. It is sometimes called Grande Côte on account of its size, though it is scarcely 2 miles in diameter. Salt is also mined on Avery Island, in Iberia Parish, 10 miles southwest of New Iberia. The details connected with the mining of salt in Louisiana have been published in the chapter on salt and bromine in "Mineral resources of the United States" for 1909, as obtained from a recent publication by G. D. Harris, State geologist of Louisiana.[3]

---

[1] Ainsworth, Samuel, Eng. and Min. Jour., Sept. 4, 1909, pp. 454-456.

[2] Young, C. M., Eng. and Min. Jour., Sept. 18, 1909, pp. 558-561.

[3] Rock salt; its origin, geology, occurrence, and importance in the State of Louisiana: Bull. Geol. Survey Louisiana No. 7, 1908, p. 259.

## ANALYSES OF THE BRINE.

The samples whose analyses are given below represent only a very small part of those submitted for examination. The care with which the work is being done requires a great deal of time, consequently the work has to proceed slowly. The chemical work thus far has been done by R. F. Gardner and A. R. Merz, of the Bureau of Soils, Department of Agriculture.

*Composition of certain of the New York bitterns.* [a]

| Sample No. | Source. | Description of sample. | Constituents, in grams per liter. | | | | | | | | Percentage of KCl in total solids. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K. | Na. | Ca. | Mg. | Cl. | $SO_4$. | Total. | Content of KCl. | |
| 2 | Worcester Salt Co., Silver Springs. | Bittern from grainer | 2.8 | 100.3 | 19.9 | 1.8 | 197.2 | 0.5 | 322.5 | 5.34 | 1.7 |
| [b] 4 | Remington Salt Co., Ithaca. | Bittern from vacuum pan. | 1.0 | 109.1 | 10.3 | 1.6 | 191.1 | .6 | 313.7 | 1.91 | .6 |
| 5 | Rock Glen Salt Co., Rock Glen. | Bittern 10 days old. | 1.9 | 106.7 | 13.5 | 1.5 | 193.5 | .8 | 317.9 | 3.62 | 1.1 |
| 7 | Star & Crescent Salt Co., Salt Vale. | Bittern from grainer | 1.8 | 93.7 | 25.2 | 2.6 | 197.5 | .4 | 321.2 | 3.43 | 1.06 |
| 11 | Genesee Salt Co., Pifford. | Bittern, 36 hours old, from grainer. | 1.3 | 114.2 | 6.4 | 1.9 | 192.8 | 1.2 | 317.8 | 2.48 | .8 |
| 18 | Le Roy Salt Co., Le Roy. | Bittern going to waste outside plant. | .2 | 72.7 | 5.3 | .7 | 122.8 | 1.1 | [c]202.8 | .38 | .2 |

[a] These analyses constitute but a fractional part of those to be submitted in the final report.
[b] Collected by J. W. Turrentine.
[c] Diluted with water.

Except sample 18, the bitterns analyzed thus far from western New York show a close similarity. Sample 18, collected from the salt plant of the Le Roy Salt Co., can not be regarded as representative, as it is contaminated with considerable fresh water. It was collected from a steady flow from a pipe outside the plant and represents waste fresh water from various sources plus bittern from the grainers.

The results given above are not strictly comparable, for most of the bitterns were taken from grainers which had been running different lengths of time. In some places salt was crystallizing rapidly and in others, where the temperature was somewhat lower, salt was making slowly. Thus the bitterns represent variable amounts of original brine and consequently some variation in the amount of total solids is to be expected. Considering the fact that the amount of total solids has not been reduced to a common standard of time and volume, the close agreement in total grams of salt per liter is somewhat remarkable. The original brines, which came from beds at the same geologic horizon, must be very closely related in chemical composition. The amount of potassium chloride in the New York brines is very small and not of commercial importance. These brines may be considered as solutions of sodium chloride (common salt) and calcium chloride, with small amounts of calcium sulphate (gypsum), potassium chloride, and magnesium chloride.

*Composition of certain of the Michigan bitterns.*[a]

| Sample No. | Source. | Description of sample. | Constituents, in grams per liter. | | | | | | | | Per cent of KCl in total solids |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K. | Na. | Ca. | Mg. | Cl. | $SO_4$. | Total. | Content of KCl. | |
| 23 | Delray Salt Co., Delray (Detroit). | Bittern from grainer. | .... | 121.1 | 1.9 | 0.2 | 187.5 | 3.4 | 314.1 | ........ | ........ |
| 98 | Worcester Salt Co., Ecorse (Detroit). | Bittern, 11 days old. | .... | 119.5 | 3.0 | .3 | 189.9 | .2 | 312.9 | ........ | ........ |
| 53 | Peters Salt & Lumber Co., East Lake (Manistee). | Bittern, 19 days old, from grainer. | 0.5 | 115.1 | 3.9 | 3.0 | 191.4 | 2.3 | 316.2 | 0.95 | 0.3 |
| 56 | Buckley & Douglas Lumber Co., Manistee. | Bittern from grainer, 4 weeks old. | .2 | 119.1 | 2.4 | 1.6 | 189.8 | 3.4 | 316.5 | .38 | .1 |
| 59 | Louis Sands Lum- Co., Manistee. | Bittern from grainer, 3 weeks old. | .7 | 111.1 | 3.5 | 4.6 | 189.8 | 2.3 | 312.0 | 1.33 | .4 |
| 61 | Stearns Salt & Lumber Co., Ludington. | Bittern from grainer. | .... | 121.4 | 2.8 | .3 | 190.4 | 2.4 | 317.3 | ........ | ........ |
| 63 | Hine & Co., Bay City. | Bittern from grainer, 5 days old. | 1.3 | 66.1 | 40.6 | 11.5 | 207.7 | .4 | 327.6 | 2.48 | .8 |
| 96 | Michigan Salt Works, Marine City. | Bittern, 6 weeks old, from grainer. | 2.0 | 104.6 | 13.8 | 2.7 | 194.6 | .6 | 318.3 | 3.81 | 1.2 |

[a] These analyses constitute but a fractional part of those to be submitted in the final report.

The samples of bittern collected from the Delray Salt Co., the Worcester Salt Co., and the Michigan Salt Co. came from the southeastern part of Michigan and from the same geologic formation, though not necessarily from the same salt bed within that formation. In total constituents they show close agreement not only around Detroit, along Detroit and St. Clair rivers, but also with those representing brine from presumably the same group of rocks near Manistee and Ludington, in the western part of the State. Considering the fact that the two bitterns obtained near Detroit do not show even a trace of potash, the bittern from Marine City, Mich., with 1.2 per cent of potassium chloride, is rather remarkable. The bitterns from Manistee contain extremely small quantities of potash salts, that from Ludington showing none whatever.

The brines and bitterns from Saginaw Valley come from rocks very much higher in the geologic column, as indicated in the section on the geology of the Michigan brines. It is to be regretted that an analysis of an older and hence more concentrated bittern than that given in the table (No. 63) is at present not available, nor that of a sample of calcium chloride, the ultimate production of the concentration of the Saginaw Valley brine. Samples of the chloride were obtained from Saginaw, Mount Pleasant, and St. Charles. These brines are known to contain considerable amounts of bromine, and they are worked for bromine at Midland and Mount Pleasant and were formerly worked at St. Charles. The results of the analyses of the more concentrated bitterns and the end product of their evaporation—viz, calcium chloride—must be given later, as the analyses have not yet been made.

The outlook for potash in the Michigan brines aside from those in the Saginaw Valley is rather dubious. The writer is hopeful that the more concentrated brines from Saginaw Valley, and especially the samples of calcium chloride (ordinarily known simply as chloride), will show appreciable amounts of potash, but whether these will be enough to be of commercial significance can not yet be stated.

*Composition of certain of the Ohio bitterns.*[a]

| Sample No. | Source. | Description of sample. | Constituents, in grams per liter. | | | | | | | | | Per cent of KCl in total solids. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K. | Na. | Ca. | Mg. | Cl. | $SO_4$. | Br. | Total. | Content of KCl. | |
| 112 | Union Salt Co., Cleveland. | Bittern from grainer, 5 days old. | 1.2 | 100.1 | 16.3 | 3.7 | 194.5 | 0.7 | ..... | 316.5 | 2.29 | 0.7 |
| 117 | Ohio Salt Co., Wadsworth. | Bittern accumulating 35 days. | .7 | 103.7 | 16.5 | 1.3 | 192.3 | 1.1 | ..... | 315.6 | 1.33 | .4 |
| 118 | .....do.......... | More concentrated bittern than No. 117; vacuum pan at boot. | 1.8 | 97.6 | 12.0 | 2.4 | 187.8 | 1.8 | ..... | 303.4 | 3.43 | 1.1 |
| [b]114 | Diamond Alkali Co., Fairport Harbor. | Natural bittern. | 3.9 | 43.4 | 48.6 | 11.2 | 188.4 | .2 | ..... | 295.7 | 7.43 | 2.5 |
| 122 | Pomeroy Salt Association, Pomeroy. | Bittern before passing to bromine plant. | 3.2 | 2.6 | 145.2 | 42.2 | 360.4 | 5.2 | 11.6 | 570.4 | 6.10 | 1.1 |

[a] These analyses constitute but a fractional part of those to be submitted in the final report.
[b] Samples of this natural bittern were also obtained near Akron and Barberton, Ohio.

*Composition of certain of the West Virginia bitterns.*[a]

| Sample No. | Source. | Description of sample. | Constituents, in grams per liter. | | | | | | | | | Per cent of KCl in total solids. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K. | Na. | Ca. | Mg. | Cl. | $SO_4$. | Br. | Total. | Content of KCl. | |
| 120 | Dixie Salt Co., Mason. | Bittern from grainer before passing to bromine plant. | .... | 3.3 | 135.8 | 48.4 | 366.2 | 4.8 | 11.0 | 569.5 | ...... | ........ |
| 129 | Liverpool Salt & Coal Co., Hartford. | Bittern before passing to bromine plant. | .... | .2 | 143.4 | 43.4 | 358.6 | 3.8 | 12.2 | 561.6 | ...... | ........ |

[a] These analyses constitute but a fractional part of those to be submitted in the final report.

The Ohio bitterns deserve more than passing notice. The samples of bitterns collected in Cleveland and at Wadsworth are from the Monroe formation of the Silurian system. They show appreciable but not workable quantities of potash salts. The bittern from Pomeroy, Meigs County, on Ohio River, also shows an appreciable amount of potassium chloride, a fact that can not be reconciled with the results shown in the analyses of West Virginia bitterns, which though from approximately the same levels if not the identical geologic horizons and showing almost the same amount of total solids, yet show no trace of potash salts. Further analyses may explain this discrepancy and, as a check, there will be given in a later publication the analyses of several samples of calcium chloride collected from the Ohio Valley near Pomeroy, Mason, and Hartford.

Only a single analysis of a natural brine or rather bittern is available at the present time, namely, that of sample 114, collected at the Diamond Alkali Co.'s plant at Fairport Harbor, northeast of Cleveland, on Lake Erie, from a well during the process of sinking. Samples of similar natural bitterns were procured near Akron and also at Barberton. The top of this bittern stratum varies from approximately 350 to more than 400 feet above the topmost salt bed from which artificial brines are pumped in northern Ohio. One record collected shows a difference of only 250 feet, but this seems very exceptional. It will be sufficient to state here that the bittern stratum is sharply defined and is of wide areal extent. The bittern is a "bugbear" to the salt industries of this part of the State, for if allowed to get into the brines from which salt is made it renders them bitter and as a consequence plays havoc with the resulting salt. As a container of potash salts, it may prove to be the richest known in the Eastern States.

On reducing the different constituents of this bittern from their ionic state to conventional combinations, the total solids would be divided as follows:

*Composition of natural bittern from Fairport Harbor, Ohio.*

| | Grams per liter. |
|---|---|
| Potassium chloride | 7.4 |
| Sodium chloride | 110.1 |
| Calcium chloride | 134.4 |
| Magnesium chloride | 43.2 |
| Calcium sulphate | .3 |
| Ferric chloride | .3 |
| | 295.7 |

In the fractional crystallization resulting from the evaporation of such a combination of salts (which can not be far from the truth) the sulphate of calcium (gypsum) and chloride of sodium (common salt) would first separate, leaving the chlorides of potassium, lime, and magnesium, together with small amounts of iron. The potassium chloride, after the removal of the other constituents, would constitute nearly 4 per cent of the mass. Whether the removal of the lime would be commercially practicable is a problem for the industrial chemist, but it seems that these Ohio bitterns deserve careful attention and experiment to ascertain the possibilities of the sodium-free residue as a fertilizer—if not in its present condition, possibly after some cheap chemical means has been devised of precipitating its lime and magnesia. A bittern of this composition seems to offer opportunities for research which should not be neglected.

# EXPLORATION OF SALINES IN SILVER PEAK MARSH, NEVADA.

By R. B. Dole.

## LOCATION AND EXTENT.

Silver Peak Marsh, comprising the lowest part of Clayton Valley, lies in Esmeralda County, Nev., about 20 miles west of Goldfield and 25 miles southwest of Tonopah, and is included in Tps. 1 and 2 S., Rs. 39, 40, and 41 E. It is about 10 miles long northeast and southwest and about 4 miles wide, its area being about 32 square miles. (See fig. 45.) It is most readily reached by means of the Silver Peak Railroad, which connects with the Tonopah & Goldfield Railroad at Blair Junction and runs south to Blair, a small mining town near the western edge of the marsh.

## TOPOGRAPHY.

The marsh is a salt playa entirely devoid of vegetation and covered for the most part with a white crust of sodium chloride. Tracts 3 or 4 acres in extent rising gently 1 to 3 feet above the general level appear as rough brown sun-baked patches without a covering of salt. The most noticeable topographic features are the Goat and Alcatraz "islands," two groups of steep limestone hills near the southwest end of the playa. The marsh, when viewed from a distance, seems not unlike a shallow icebound lake having two large high islands and many small low ones. The surface of this alkali flat is usually dry, though it is sometimes covered by a foot or more of water after excessively heavy rainfall. The ground-water plane is, however, always high, and holes a few feet deep anywhere on the flat enter mud, many parts of the marsh being too soft to bear the weight of a horse. The tailings from the cyanide mill of the Pittsburgh Silver Peak Mining Co. at Blair flow into the marsh 2 miles north of Silver Peak.

Clayton Valley, the lowest part of which is about 4,340 feet above sea level, is almost completely surrounded by high mountains, one spur of the Silver Peak Range ending abruptly at the west edge of the playa. Gently sloping washes, composed of small fragments of rock interspersed with stretches of shifting sand and bearing moderate growths of sagebrush and greasewood, extend from the bases of the hills to the playa and occupy the lower divides. The present drainage basin of the valley has an area of 570 square miles.

## WATER SUPPLY.

As the rainfall is less than 5 inches a year Clayton Valley is an arid region. No perennial stream exists, and the torrential discharges during the short wet season are quickly absorbed or evapo-

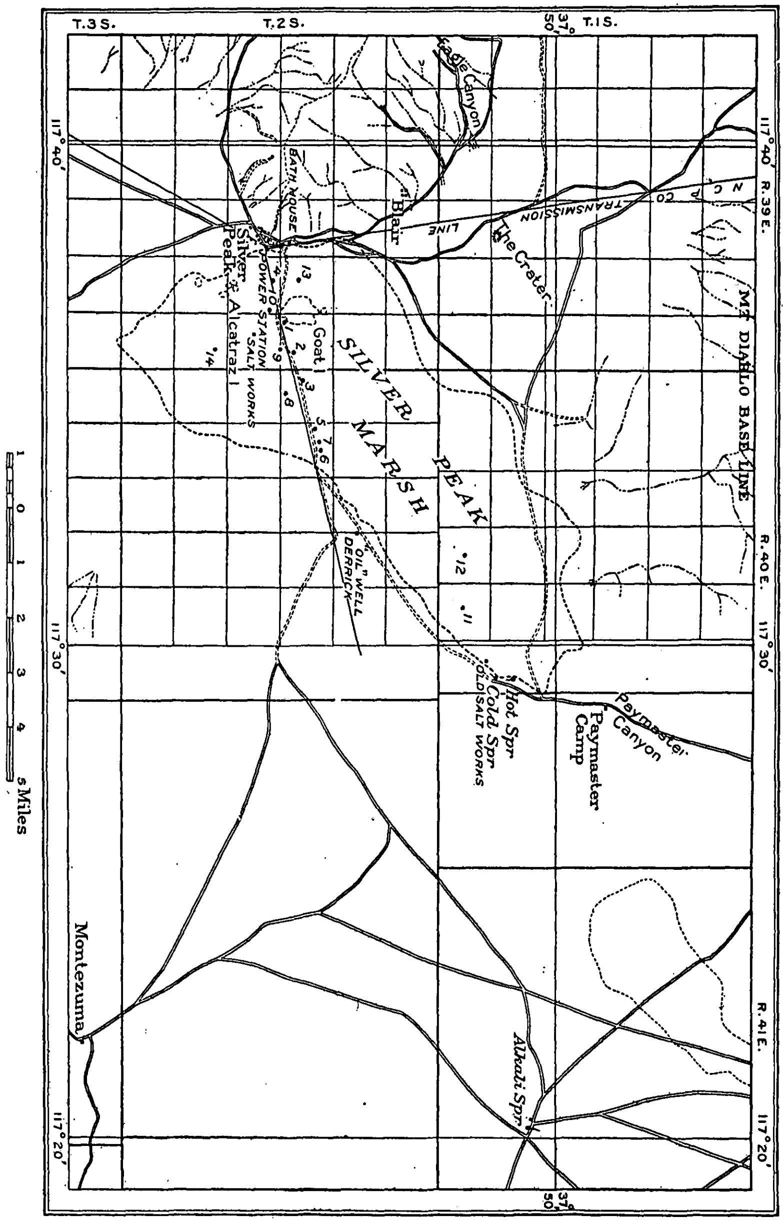



FIGURE 45.—Map of Silver Peak Marsh, Nevada, showing location of test borings.

rated. Enough water enters the rocks of the Silver Peak Range to furnish wells and springs at its base with a supply that is potable though hard and somewhat brackish. The largest spring, in the village of Silver Peak, discharges about 350,000 gallons a day, furnishing the supply for Blair and the near-by mines, to which the water is pumped through a 3-mile pipe line. There are a few shallow dug wells in Silver Peak and Blair and one in Paymaster Canyon, 3 miles from the northeast corner of the flat, but no other potable supplies have been found except in the high gulches of the mountains. Shallow excavations on the marsh yield concentrated brines. Hot and cold springs of weak brine at the edge of the marsh near Silver Peak are used for bathing, and similar springs were found at the northeast end of the marsh.

## SOURCE OF THE SALT DEPOSITS.

The geologic features of the district, including Clayton Valley, have been described by J. E. Spurr in his report on the ore deposits of the Silver Peak quadrangle, Nev.[1] The mountains are composed mostly of granitic rocks and lavas. Soft shales, sandstones, volcanic tuffs, and similar material, with interbedded layers of andesitic and rhyolitic lavas, are extensively distributed, and limestones are abundant. According to Spurr much of the material in the valley was laid down in an inclosed lake basin, within which the salt deposits have been formed chiefly by evaporation of more or less concentrated solutions. The character of the deposits makes this evident. Leachings, especially from the Tertiary stratified rocks, extensive areas of which lie in the basin, account for much of the saline residue.

It is possible that an area far greater than the present basin was formerly tributary to Silver Peak Marsh and helped to furnish the saline materials with which its clays and muds are impregnated. The lowest divide of the present watershed, 6 miles north of Blair, is at an elevation between 5,000 and 5,100 feet, or at least 650 feet above the present surface of the Silver Peak Marsh. This divide separates Clayton Valley from Big Smoky Valley, a long, large basin extending northward across Nye County. Another divide near Coaldale, however, at an elevation between 4,900 and 5,000 feet above sea level, is all that separates the drainage of Big Smoky Valley from the basin of Columbus Marsh, and it is therefore somewhat uncertain what influence this comparatively slight difference of 100 feet or less in the elevation of the divides has had on the discharge from Big Smoky Valley. Both divides may have been at the bottom of straits between divisions of a lake, if such a body of water ever filled these valleys above the level of these divides, but whether all or part or none of the discharge of Big Smoky Valley during the recession of such a lake would have come into Clayton Valley is problematic.

[1] Prof. Paper U. S. Geol. Survey No. 55, 1906.

Spurr suggests that the salt deposits of this and of other playas in the vicinity may have been made partly by concentration of weak brines from the hot springs around the marshes. The possibility, however, that these waters owe their content of salt to the marsh itself should not be overlooked. All the salt springs around Silver Peak Marsh emerge at the level of the salty surface and within or close to its edge. Seepages above that level are not salty but are rather hard carbonate waters, whereas all waters from any source within the playa are necessarily salty because of the ready solubility of the saline deposits. The composition of the waters from the marsh west of Goat "Island," where the ground flow is most abundant, is what might be given to limestone water by contact with salt, but the solutions farther out in the marsh are simply strong brines such as might be produced by leaching the salt muds with rainwater or by continued reaction of hard water with saline deposits. Therefore, it does not seem at all impossible that the brine springs may take their load of salt from the muds of the flat instead of adding salt to them.

## METHOD OF EXPLORATION.

The exploration on which this report is based was made principally by means of a Junior Empire drill, though a few shallow holes were bored with a 2½-inch auger attached to ½-inch piping. The Junior Empire drill consists essentially of a rotatable 2½-inch flush-joint casing in 4-foot lengths, bearing a toothed shoe. The borings were started with a 2½-inch auger so constructed that it retains and protects a sample during withdrawal from the hole; this tool was used till soft mud that slumped was encountered, when casing was inserted. Various drilling tools were operated by hand within the casing. Those most frequently used at Silver Peak were a ship auger and a drill bit, operated by means of ¾-inch steel rods in 4-foot lengths, and a flap-valve sand pump 3 feet long attached to a ½-inch rope. The ship auger was used in clay, mud, and similar materials that would stay on the auger during withdrawal; the sand pump was used for removing softer materials and for taking water samples. It was customary to bore below the casing 4 feet and then to rotate in a section of casing rather than to rotate and bore simultaneously. If it was impracticable to do that the casing was advanced by rotating and driving. The casing was revolved by a burro on an 8-foot sweep. It was necessary to drill through some strata of crystals and cemented hardpan. After a boring had been completed the casing was withdrawn without special difficulty. As the casing is watertight it was possible to obtain by means of the equipment uncontaminated samples of all materials encountered and also to ascertain whether strata contained water. Many alterations in the outfit and the manner of operating it were made to fit the conditions. The boring equipment with all necessary attachments weighs about 1,000 pounds and can readily be packed in the bottom of a two-horse wagon.

## LOGS OF BORINGS.

The following tables summarize the results of the exploration, locations being referred to the Mount Diablo meridian and base. Borings were made across the marsh eastward from Silver Peak. Two holes also were sunk at the northeastern end and one at the southern end of the playa. (See fig. 45.) The similarity of the materials encountered, as indicated by the records of these borings, rendered further exploration unnecessary.

*Summary of records of borings in Silver Peak Marsh, Nev.*

| Well No. | Location. | | | | Depth of boring. | Depths at which brine was encountered. | Total thickness of crystalline salt penetrated. |
|---|---|---|---|---|---|---|---|
| | Quarter. | Sec. | T. S. | R. E. | | | |
| | | | | | *Feet.* | *Feet.* | *Feet.* |
| 1 | SW. | 13 | 2 | 39 | 29.0 | 4, 27 | None. |
| 2 | SE. | 13 | 2 | 39 | 14.0 | 4 | None. |
| 3 | SW. | 18 | 2 | 40 | 55.0 | 4, 13.5, 22.5 | 2.25 |
| 4 | NW. | 23 | 2 | 39 | 11.5 | 3 | None. |
| 5 | NW. | 17 | 2 | 40 | 12.5 | 2 | None. |
| 6 | NE. | 17 | 2 | 40 | 52.0 | 21, 38 | 7.0 |
| 7 | NW. | 17 | 2 | 40 | 17.0 | 4 | None. |
| 8 | SW. | 18 | 2 | 40 | 13.0 | None. | None. |
| 9 | NE. | 24 | 2 | 39 | 13.0 | None. | None. |
| 10 | NE. | 23 | 2 | 39 | 8.0 | 3 | None. |
| 11 | NW. | 35 | 1 | 40 | 38.3 | 22.5, 31.5 | 13.2 |
| 12 | SW. | 34 | 1 | 40 | 36.0 | 8.5, 18, 22 | 15.7 |
| 13 | SW. | 14 | 2 | 39 | 41.0 | 4, 15.5 | None. |
| 14 | NE. | 25 | 2 | 39 | 40.0 | 8, 16 | None. |

*Record of boring No. 1.*

[Location, SW. ¼ sec. 13, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 7.0 | 7.0 |
| Same, containing more clay | 2.0 | 9.0 |
| Stiff blue clay containing small rock fragments | 18.0 | 27.0 |
| Fine gravel and sand | 1.5 | 28.5 |
| Rock fragments | .5 | 29.0 |

Ended in small rock fragments. Water encountered at 4 feet rose slowly to 2 feet. Water plentiful at 27 to 29 feet.

*Record of boring No. 2.*

[Location, SE. ¼ sec. 13, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 10.0 | 10.0 |
| Stiff blue clay | 4.0 | 14.0 |

Ended in blue clay. Water encountered at 4 feet rose slowly to 2.5 feet.

*Record of boring No. 3.*

[Location, SW. ¼ sec. 18, T. 2 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Damp sand containing salt | 2.0 | 2.0 |
| Brown mud containing small crystals of salt | 10.0 | 12.0 |
| Stiff blue clay containing small crystals of gypsum | 1.5 | 13.5 |
| Crystallized salt and brine | 2.0 | 15.5 |
| Black clay containing brine and crystals of salt | 6.5 | 22.0 |
| Crystallized salt and brine | .25 | 22.25 |
| Black clay containing brine and crystals of salt | 1.25 | 23.5 |
| Brown clay | 6.0 | 29.5 |
| Brown clay containing small crystals of salt | 9.5 | 39.0 |
| Drab clay and sand | 2.0 | 41.0 |
| Brown clay | 3.0 | 44.0 |
| Gray clay and sand containing small crystals of salt | 1.5 | 45.5 |
| Red clay containing sand and small crystals of salt | 9.5 | 55.0 |

Water encountered at 4 feet rose slowly to 2.3 feet. Plentiful supply of cold brine at 13.5, 22.5; none below 30 feet.

*Record of boring No. 4.*

[Location, NW. ¼ sec. 23, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 3.0 | 3.0 |
| Brown mud containing nodules of calcareous tufa | 4.0 | 7.0 |
| Greenish mud containing nodules of calcareous tufa | 3.0 | 10.0 |
| Calcareous tufa | .2 | 10.2 |
| Blue clay | 1.3 | 11.5 |

Water encountered at 3 feet rose slowly to 2.5 feet.

*Record of boring No. 5.*

[Location, NW. ¼ sec. 17, T. 2 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Damp brown sand containing small crystals of salt | 2.0 | 2.0 |
| Brown mud containing small crystals of salt | 6.0 | 8.0 |
| Blue clay | 4.5 | 12.5 |

Water encountered at 2 feet.

*Record of boring No. 6.*

[Location, NE. ¼ sec. 17, T. 2 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Crystallized salt and brown sand | 3.0 | 3.0 |
| Brown mud containing small crystals of salt | 16.5 | 19.5 |
| Blue clay | 1.0 | 20.5 |
| Black clay | .5 | 21.0 |
| Gray clay containing brine and crystals of gypsum | 2.5 | 23.5 |
| Crystallized salt and some gray clay | 2.5 | 26.0 |
| Crystallized salt and black clay | 4.0 | 30.0 |
| Black clay | 1.0 | 31.0 |
| Gray clay | 5.0 | 36.0 |
| Gray clay containing small crystals of gypsum | 2.0 | 38.0 |
| Gray sand and clay containing brine | 2.0 | 40.0 |
| Gray sandy clay | 7.0 | 47.0 |
| Crystals of salt (no water) | .5 | 47.5 |
| Gray sandy clay | 4.5 | 52.0 |

Brine encountered at 21 to 29 feet rose to surface. Brine at 38 to 40 feet.

*Record of boring No. 7.*

[Location, NW. ¼ sec. 17, T. 2 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown sand containing salt | 2.0 | 2.0 |
| Brown mud containing small crystals of salt | 8.0 | 10.0 |
| Blue clay | .1 | 10.1 |
| Brown clay | 6.9 | 17.0 |

Water encountered at 4 feet rose to 2.5 feet. Boring ended in brown clay on hardpan.

*Record of boring No. 8.*

[Location, SW. ¼ sec. 18, T. 2 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 12.5 | 12.5 |
| Blue clay containing small crystals of gypsum | .5 | 13.0 |

Boring ended in blue clay on hardpan. Dry hole.

*Record of boring No. 9.*

[Location, NE. ¼ sec. 24, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 12.5 | 12.5 |
| Blue clay containing small crystals of gypsum | .5 | 13.0 |

Boring ended in blue clay. Practically no water.

*Record of boring No. 10.*

[Location, NE. ¼ sec. 23, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt and nodules of calcareous tufa | 7.5 | 7.5 |
| Gray sandy clay | .5 | 8.0 |

Boring ended in gray sandy clay on hardpan (tufa?). Water at 3 feet.

*Record of boring No. 11.*

[Location, NW. ¼ sec. 35, T. 1 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 13.0 | 13.0 |
| Drab clay | 9.5 | 22.5 |
| Crystallized salt with brine and some clay | 7.5 | 30.0 |
| Drab clay containing small crystals of salt | 1.5 | 31.5 |
| Crystallized salt with brine and thin strata of black clay | 5.7 | 37.2 |
| Cemented hardpan | 1.1 | 38.3 |

Ended in cemented hardpan. Brine encountered at 22.5 to 30 feet rose to 6.5 feet. Brine at 31.5 to 37.2 feet rose to 8 feet.

*Record of boring No. 12.*

[Location, SW. ¼ sec. 34, T. 1 S., R. 40 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown mud containing small crystals of salt | 8.5 | 8.5 |
| Fine sand containing brine | .5 | 9.0 |
| Brown mud containing small crystals of salt | 2.0 | 11.0 |
| Drab and gray clay | 7.0 | 18.0 |
| Crystallized salt and brine | 2.5 | 20.5 |
| Drab clay containing salt | 1.5 | 22.0 |
| Crystallized salt and brine with thin strata of drab clay | 6.2 | 28.2 |
| Black clay containing crystals of salt | .8 | 29.0 |
| Crystallized salt and black clay | 7.0 | 36.0 |

Boring ended dry in black clay and salt on cemented hardpan. Water encountered at 8.5 to 10 feet rose to 1.8 feet. Water at 18 to 20.5 feet rose to 7.5 feet. Water at 22 to 35 feet rose to 8 feet.

*Record of boring No. 13.*

[Location, SW. ¼ sec. 14, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Damp sand | 1.0 | 1. |
| Hardpan containing nodules of calcareous tufa | .2 | 1. |
| Brown mud containing brine and nodules of calcareous tufa | 3.3 | 4. |
| Brown clay | 5.0 | 9. |
| White tufaceous material ranging in size from particles ½ inch in diameter to powder. | 4.5 | 14. |
| Same, looser and containing water | 25.5 | 39. |
| Small waterworn particles of calcareous tufa and water | 1.5 | 41. |

Water at 4 feet. Water at 15.5 to 41 feet rose to 1 foot and could not be lowered by pumping.

*Record of boring No. 14.*

[Location, NE. ¼ sec. 25, T. 2 S., R. 39 E.]

| | Thickness. | Depth. |
|---|---|---|
| | *Feet.* | *Feet.* |
| Brown sand and salt | 3.0 | 3.0 |
| Brown mud containing small crystals of salt | 6.0 | 9.0 |
| Gray clay | 7.0 | 16.0 |
| Loose, fine light-gray tufaceous material and water | 2.0 | 18.0 |
| Gray clay | 9.0 | 27.0 |
| Red clay | 13.0 | 40.0 |

Ended in red clay. Water at 8 to 12 feet rose to 4 feet. Water at 16 to 18 feet rose to 3 feet.

Brown mud 5 to 20 feet deep forms the upper layer of the marsh. (See fig. 46.) Because of the intense heat the surface of this mud is usually baked dry and hard enough to support the weight of teams. Small scattered tracts have become dry enough to be pulverulent for a depth of 1 to 2 feet, but over the greater part of the playa 4-foot holes are sufficiently deep to strike soft mud. As this layer is composed of very small particles and contains a large proportion of clay, the strong salt waters in it circulate very slowly. The mud contains a great quantity of salt, though the crystals are small. The brines obtained from it are very strong, and the surface is generally covered to a depth of one-eighth to one-quarter of an inch by a white crust of salt that has crystallized from solutions drawn to the surface by capillarity.

The upper mud along the west shore of the playa, particularly west of the "islands," contains nodules of calcareous tufa, which apparently have been formed by deposition of calcium carbonate from the hard waters percolating into the marsh from Mineral Ridge. The record of boring No. 13 shows that clay under the mud west of the "islands" is underlain by white tufaceous materials, but no salt occurs at a depth less than 41 feet except that in the abundant weak brines.

Well-defined beds of clay containing crystals of gypsum were penetrated east of Goat "Island" in borings Nos. 3 and 6, and these are underlain by beds of crystallized salt containing saturated brine. Very stiff black, blue, red, gray, and brown clays underlie the beds of salt or mixed salt and clay in boring No. 3 to a depth of 55 feet, but in boring No. 6 the clays are interrupted by a stratum of gypsum-bearing clay below the salt and a 6-inch stratum of salt at 47 feet below which clay was again encountered.

Except a shallow bed of light-gray calcareous material at 16 feet nothing but clay containing weak brine was struck to a depth of 40 feet in boring No. 14, at the south end of the playa. (See fig. 47.)

Borings Nos. 11 and 12 indicate that the beds of salt in the northeastern part of the marsh are denser than those farther south. The mud is underlain by clay and that in turn by crystallized salt so hard

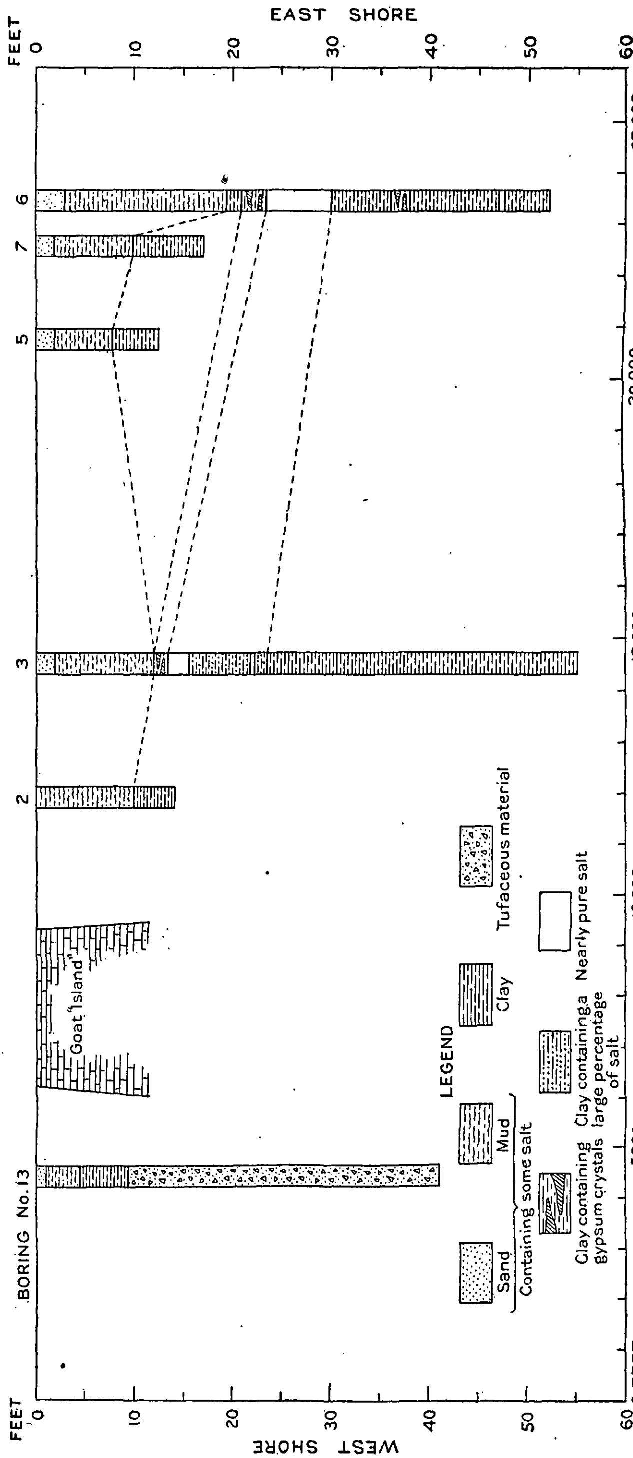



FIGURE 46.—Diagram showing beds penetrated by borings Nos. 2, 3, 5, 6, 7, and 13 in Silver Peak Marsh, Nevada.

that it has to be drilled. A much harder formation, probably calcareous tufa, was struck below the salt in both borings at a depth of about 36 feet.

The data afforded by the six deeper borings lead to the conclusion that the northeastern two-thirds of the playa is underlain at a depth of about 20 feet by beds 5 to 15 feet thick of crystallized salt mixed with more or less clay. It is doubtful if deposits of so great extent

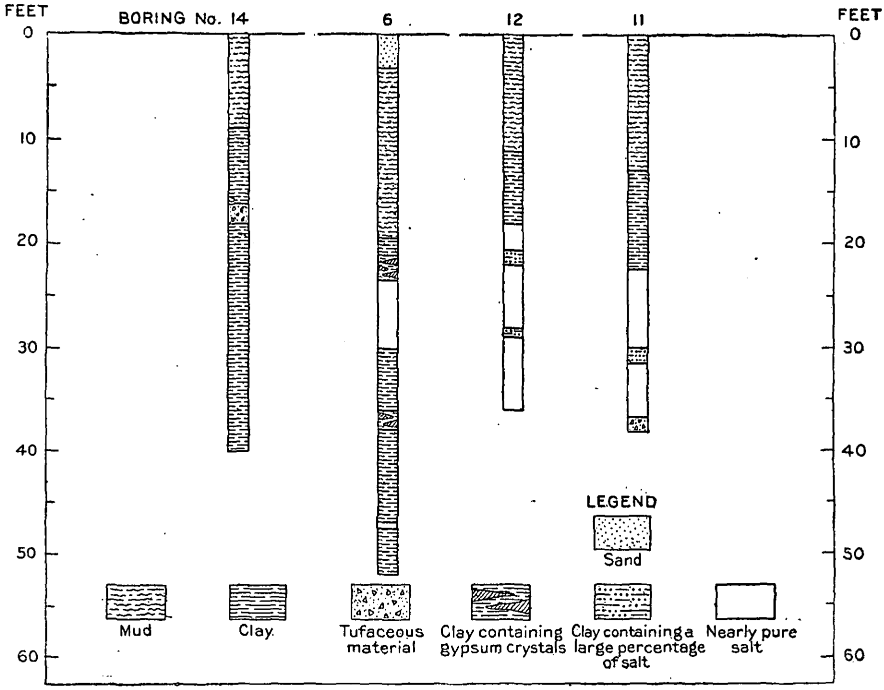



FIGURE 47.—Diagram showing beds penetrated by borings Nos. 6, 11, 12, and 14 in Silver Peak Marsh, Nevada.

occur west of Goat "Island" or south of Alcatraz "Island." Besides these beds practically all other strata to a depth of 50 feet contain appreciable proportions of salt that readily dissolves in water percolating through them.

## COMMERCIAL POSSIBILITIES.

Practically the entire surface of the playa, 32 square miles, is covered with salt that averages in depth about one-quarter of an inch. The upper muds, averaging probably 10 feet thick, contain not less than 2 per cent of salt. It is estimated that not less than 15 square miles of the northeastern part contains a 10-foot saline bed of which at least 60 per cent is salt. It is calculated from these moderate estimates that 15,000,000 tons of salt lies within 40 feet of the surface. The high rate of evaporation, which would permit solar concentration of brines, the absence of long-continued rainfall to interfere with operations, the nearness of a railroad, and more especially the high degree of purity of the product as indicated by analyses of the brines are extremely favorable features in considering the possibility of utilizing these deposits.

Salt is now being produced on a small scale by Frank Porter, of Silver Peak, whose works are situated in sec. 24, T. 2 S., R. 39 E. Brines from pits in the upper muds or from furrows filled with rain-water that has become saturated are concentrated and crystallized by solar evaporation in shallow vats dug in the playa, and the salt thus obtained is bagged for sale. Mr. Porter states that about 150 tons has been produced in three years.

## OCCURRENCE OF POTASH.

Potash was not found in sufficient quantity or concentration to be commercially valuable. Though all the clays, muds, and brines give indication of the presence of potash by the flame test, the percentage of that substance is low. Samples of all the brines were tested for potash by A. R. Merz at the Cooperative Laboratory, Mackay School of Mines, Reno, Nev.; the results of these examinations, shown in the following table, indicate the low content of potassium in the saline solutions. The figure for potassium has been expressed as the radicle (K), as the oxide ($K_2O$), and as the chloride (KCl), for convenience of reference. The saturated brines average a little more than 2.5 per cent in their content of potash ($K_2O$), a concentration much lower than that in the brines from Searles Lake, Cal. Whether more important deposits lie deeper than these explorations were carried is of course unknown.

*Total salts and potassium in brines from Silver Peak Marsh, Nev., June, 1912.*

[Examinations by A. R. Merz, Reno, Nev. Quantities in grams per 100 cubic centimeters unless otherwise designated.]

| Boring No. | Depth of sample. | Total solids at 105° C. | Potassium expressed as— | | | |
|---|---|---|---|---|---|---|
| | | | Potassium (K). | Potassium chloride (KCl). | Potassium oxide ($K_2O$). | Percentage of potassium oxide ($K_2O$) in saline residue. |
| | *Feet.* | | | | | |
| 3 | 15.5 | 33.28 | 0.91 | 1.74 | 1.10 | 3.30 |
| 6 | 21 | 33.13 | .77 | 1.47 | .93 | 2.80 |
| 6 | 40 | 33.75 | .75 | 1.43 | .90 | 2.67 |
| 11 | 27 | 32.25 | .74 | 1.41 | .89 | 2.76 |
| 11 | 35 | 32.05 | .55 | 1.05 | .66 | 2.07 |
| 12 | 10 | 26.56 | .61 | 1.16 | .74 | 2.78 |
| 12 | 20 | 32.90 | .59 | 1.12 | .71 | 2.15 |
| 12 | 27 | 32.97 | .64 | 1.22 | .77 | 2.34 |
| 13 | 16 | 4.15 | .12 | .23 | .14 | 3.36 |
| 13 | 31.5 | 4.61 | .13 | .21 | .16 | 3.43 |
| 13 | 40 | 3.38 | .11 | .21 | .13 | 3.80 |
| 14 | 11 | 26.82 | .66 | 1.26 | .80 | 3.00 |
| 14 | 17 | 26.21 | .66 | 1.26 | .79 | 3.01 |
| Average, exclusive of samples from boring No. 13 | | 30.99 | .69 | 1.31 | .83 | 2.69 |

## CHEMICAL COMPOSITION OF THE BRINES.

Samples of saline solutions from the borings in different parts of the marsh were tested for the purpose of ascertaining their relative purity as sources of salt. The waters of all the springs also were examined and the results of these tests are given in the following tables, the first showing partial analyses of the samples and the second complete analyses of composite samples. These analyses were made by Walton Van Winkle, assistant chemist.

*Partial analyses of brines, Silver Peak Marsh, Nev.*

[Milligrams per kilogram except where otherwise designated.]

| Source. | Depth. | Date, June, 1912. | Specific gravity at 20° C. | Total residue. | | Carbonate radicle ($CO_3$). | Bicarbonate radicle ($HCO_3$). | Sulphate radicle ($SO_4$). | Borate radicle ($B_4O_7$). |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Dried at at 180° C. | After ignition. | | | | |
| | *Feet.* | | | | | | | | |
| Boring No. 1 | 6 | 1 | 1.0281 | 39,330 | 38,620 | 0 | 532 | 570 | ........ |
| | 27 | 4 | 1.0406 | 57,600 | 56,240 | Trace. | 327 | 582 | ........ |
| Boring No. 3 | 15.5 | 4 | 1.2103 | 276,800 | 271,600 | 0 | 38 | 2,475 | 0 |
| Boring No. 6 | 21 | 7 | 1.2081 | 273,000 | 270,000 | 0 | 28 | 2,675 | 0 |
| | 40 | 10 | 1.2082 | 274,000 | 270,000 | 0 | 36 | 2,395 | 0 |
| Boring No. 11 | 27 | 13 | 1.2105 | 274,000 | 271,700 | 0 | 74 | 4,955 | 0 |
| | 35 | 14 | 1.2089 | 272,000 | 270,000 | 0 | 122 | 4,600 | 0 |
| Boring No. 12 | 10 | 15 | 1.1702 | 226,700 | 224,100 | 0 | 51 | 4,640 | ........ |
| | 20 | 17 | 1.2097 | 274,500 | 270,900 | 0 | 45 | 4,030 | ........ |
| | 27 | 17 | 1.2098 | 274,700 | 271,300 | 0 | 50 | 3,900 | ........ |
| Boring No. 13 | 16 | 20 | 1.0284 | 39,950 | 38,860 | 0 | 803 | 476 | ........ |
| | 31.5 | 21 | 1.0321 | 44,900 | 44,300 | 0 | 840 | 491 | ........ |
| | 40 | 22 | 1.0297 | 41,510 | 40,900 | 0 | 792 | 477 | ........ |
| Boring No. 14 | 11 | 24 | 1.1747 | 233,200 | 228,800 | 0 | 39 | 2,250 | ........ |
| | 17 | 24 | 1.1697 | 227,900 | 223,500 | 0 | 33 | 2,090 | ........ |
| Hot spring at bathhouse, Silver Peak | ........ | 8 | 1.0217 | 30,670 | 29,960 | 0 | 533 | ........ | Trace(?) |
| Cold spring at bathhouse, Silver Peak | ........ | 8 | 1.0226 | 31,980 | 31,530 | Trace. | 530 | ........ | Trace. |
| Cold spring at northeast end of marsh | ........ | 14 | 1.0124 | 16,830 | 16,620 | 0 | 274 | ........ | 0 |
| Hot spring at northeast end of marsh | ........ | 14 | 1.0177 | 24,430 | 24,180 | Trace. | 515 | ........ | ........ |
| Spring at pumping station, Silver Peak | ........ | 28 | .......... | 1,920 | 1,500 | 0 | 144 | ........ | ........ |
| 30-foot well at power house, Silver Peak | ........ | 28 | .......... | 1,520 | 1,220 | 0 | 132 | ........ | ........ |

*Analyses of water from Silver Peak Marsh, Nev.*

**Composition in milligrams per kilogram.**

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specific gravity at 20° C. | 1.2089 | 1.2019 | 1.0300 | 1.1722 | 1.0217 | 1.0226 | 1.0124 | 1.0177 | 1.0406 | 1.0281 | ........ | ........ |
| Silica ($SiO_2$) | 0 | 20 | 50 | 0 | 80 | 20 | 30 | 40 | 40 | 40 | ........ | ........ |
| Iron (Fe) | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. |
| Aluminum (Al) | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. |
| Calcium (Ca) | 1,800 | 940 | 790 | 2,800 | 580 | 420 | 130 | 220 | 470 | 490 | 170 | 150 |
| Magnesium (Mg) | 650 | 290 | 1,030 | 100 | 70 | 70 | 20 | 40 | 270 | 190 | 58 | 56 |
| Sodium (Na) | 97,180 | 95,190 | 13,620 | 77,480 | 9,650 | 10,110 | 5,770 | 8,370 | 19,210 | 13,030 | 352 | 195 |
| Potassium (K) | 7,290 | 5,890 | 1,290 | 6,590 | 930 | 930 | 500 | 800 | 2,060 | 1,180 | 21 | 15 |
| Carbonate radicle ($CO_3$) | 0 | 0 | Trace. | 0 | 0 | Trace. | 0 | Trace. | Trace. | 0 | 0 | 0 |
| Bicarbonate radicle ($HCO_3$) | 40 | 70 | 700 | 40 | 533 | 530 | 270 | 520 | 330 | 530 | 144 | 132 |
| Sulphate radicle ($SO_4$) | 2,360 | 4,420 | 540 | 2,210 | 410 | 480 | 580 | 690 | 610 | 610 | 95 | 160 |
| Chlorine (Cl) | 159,730 | 153,710 | 23,760 | 134,400 | 17,130 | 18,010 | 9,330 | 13,650 | 33,050 | 22,110 | [a] 858 | [b] 548 |
| Total residue dried at 180° C. | 278,760 | 264,030 | 42,820 | 233,440 | 30,670 | 31,980 | 16,830 | 24,430 | 57,600 | 39,330 | 1,868 | 1,379 |
| Total residue after ignition | 270,990 | 262,670 | 41,610 | 228,440 | 29,960 | 31,530 | 16,620 | 24,180 | 56,240 | 38,620 | 1,672 | 1,209 |
| Anhydrous residue [c] | 269,110 | 260,570 | 41,440 | 223,660 | 29,120 | 30,310 | 16,500 | 24,070 | 55,890 | 37,920 | 1,630 | 1,195 |

**Percentage composition of anhydrous residues.**[c]

| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 0.00 | 0.01 | 0.12 | 0.00 | 0.28 | 0.07 | 0.18 | 0.17 | 0.07 | 0.11 | ........ | ........ |
| Calcium (Ca) | .67 | .36 | 1.92 | 1.25 | 1.99 | 1.38 | .79 | .91 | .84 | 1.29 | 10.43 | 12.56 |
| Magnesium (Mg) | .24 | .11 | 2.49 | .04 | .24 | .23 | .12 | .17 | .48 | .50 | 3.55 | 4.70 |
| Sodium (Na) | 36.11 | 36.53 | 32.86 | 34.64 | 33.14 | 33.35 | 34.97 | 34.77 | 34.37 | 34.36 | 21.58 | 16.32 |
| Potassium (K) | 2.71 | 2.26 | 3.12 | 2.95 | 3.19 | 3.07 | 3.03 | 3.33 | 3.69 | 3.11 | 1.28 | 1.26 |
| Carbonate radicle ($CO_3$) | .01 | .01 | .83 | .01 | .90 | .86 | .81 | 1.05 | .29 | .69 | 4.35 | 5.44 |
| Sulphate radicle ($SO_4$) | .88 | 1.70 | 1.30 | .99 | 1.41 | 1.58 | 3.52 | 2.87 | 1.09 | 1.61 | 5.83 | 13.40 |
| Chlorine (Cl) | 59.35 | 58.99 | 57.33 | 60.09 | 58.82 | 59.43 | 56.55 | 56.70 | 59.14 | 58.30 | [a] 52.62 | [b] 45.87 |

[a] Nitrate radicle 5.6 milligrams per kilogram, or 0.33 per cent.
[b] Nitrate radicle 5.0 milligrams per kilogram, or 0.42 per cent.
[c] Computed on the assumption that iron, aluminum, borates, and other radicles constitute 0.03 per cent of the anhydrous residue.

1. Composite of samples from boring No. 3 at 15.5 feet and from No. 6 at 21 and 40 feet.
2. Composite of samples from boring No. 11 at 27 and 35 feet and from No. 12 at 10, 20, and 27 feet.
3. Composite of samples from boring No. 13 at 16, 31.5, and 40 feet.
4. Composite of samples from boring No. 14 at 11 and 17 feet.
5. Water from hot salt spring under bathhouse near Silver Peak, Nev., collected June 8, 1912.
6. Water from cold salt spring at bathhouse near Silver Peak, Nev., collected June 8, 1912.
7. Water from cold salt spring at northeast end of marsh, collected June 14, 1912.
8. Water from hot salt spring at northeast end of marsh, collected June 14, 1912.
9. Water from boring No. 1 at 6 feet, collected June 1, 1912.
10. Water from boring No. 1 at 27 feet, collected June 4, 1912.
11. Water from spring at pumping station, Silver Peak, Nev., collected June 28, 1912.
12. Water from 30-foot well of Nevada-California Power Co. at Silver Peak, Nev., collected June 29, 1912.

Borings Nos. 3, 6, 11, and 12 yield nearly saturated solutions that are remarkably uniform in composition and concentration, and it is therefore practically certain that an extensive deposit of salt lies in the playa. The brines from boring No. 14 are somewhat weaker than those from the main salt body farther north, a condition doubtless due to the presence of less salt and more water in the muds at the south end of the marsh. Boring No. 13 yields a solution still lower in salt but higher in magnesium. The salt springs at Silver Peak contain about 3 per cent of saline matter, or a little less than ocean water, whereas the springs at the northeast end of the playa, emerging at somewhat higher elevations above the marsh than those at the bathhouse, are only half as strongly mineralized. The spring at the pumping station and the well at the power house, both of which are fed from Mineral Ridge, yield fresher water. Therefore, though all the ground flow is undoubtedly increasing the soluble mineral content of the playa, the striking increase of salt in the waters with decrease of elevation makes it probable that nearly all the salt in the springs is dissolved from the muds of the marsh instead of being brought from the surrounding hills.

The table giving the percentage composition of the anhydrous residues shows that the brines from the main salt body are of great natural purity. Analyses Nos. 1, 2, and 4, of waters from borings Nos. 3, 6, 11, 12, and 14, indicate that these brines contain less than 2 per cent of sulphate and 0.02 per cent of carbonate. Only traces of borate were found. These brines on evaporation would yield a mass containing about 90 per cent of sodium chloride and the character of the other ingredients makes it certain that a much purer product could be obtained by one crystallization. The differences in the amounts and proportions of the alkaline earths are especially noteworthy, as they indicate progressive steps in the concentration and deposition of those substances.

The anhydrous residues of the brines represented by analyses Nos. 1, 2, and 4 average 2.64 per cent in content of potassium (K). The average potassium content of the same brines according to Merz is 2.23 per cent of the saline residue dried at 105° C. This apparent discrepancy in estimates is, however, caused mostly by difference in unit of expression, the actual determinations of the radicle being equivalent respectively to 0.79 and 0.69 gram of potassium (K) per 100 cubic centimeters of brine.

The water of the spring at the pumping station and that of the well at the power house are the only potable waters that were analyzed. Both are very hard and distinctly brackish but are used as sources of domestic supply without any apparent deleterious effect on health. The water of the power-house well is somewhat softer and notably lower in content of alkali and tastes better.

## SUMMARY.

Silver Peak Marsh is a salt playa containing a high grade of sodium chloride. No extensive deposits of potash-bearing salts were found. To a depth of 50 feet the formations are chiefly salt clays and muds with layers of crystallized salt covered irregularly by gypsum-bearing clays. It is estimated that 15,000,000 tons of salt lies within 40 feet of the surface of the playa.

# 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.

BREGER, C. L., The salt resources of the Idaho-Wyoming border, with notes on the geology: Bull. 430, 1910, pp. 555–569.

BUTLER, B. S., and GALE, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. 511, 1912, 64 pp.

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., Zuñi salt deposits, New Mexico: Bull. 260, 1905, pp. 565–566. 40c.

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.

KINDLE, E. M., Salt resources of the Watkins Glen district, New York: Bull. 260, 1905, pp. 567–572. 40c.

PACKARD, R. L., Natural sodium salts: Mineral Resources U. S. for 1893, 1894, pp. 728–738. 50c.

PHALEN, W. C., Salt and bromine: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 919–936.

——— 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 1911: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 889–917.

RICHARDSON, G. B., Salt, gypsum, and petroleum in trans-Pecos Texas: Bull. 260, 1905, pp. 573–585. 40c.

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: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 857–866.

# SULPHUR AND PYRITE.

## A SULPHUR DEPOSIT IN THE SAN RAFAEL CANYON, UTAH.

By FRANK L. HESS.

The sulphur deposit described in this paper lies in southeastern Utah, in the canyon of San Rafael River, 18 or 20 miles west of the town of Greenriver. It was examined by the writer during a reconnaissance in July, 1911. The deposit is on the south side of the river, about 5 miles from the mouth of the canyon, and is in limestone débris through which rise a number of springs carrying large volumes of hydrogen sulphide gas from which the sulphur has probably been formed.

San Rafael River flows southeastward across the northern part of the San Rafael Swell and has cut a deep canyon with nearly perpendicular walls a thousand feet or more high which are in places impressively beautiful. Broad and narrow bands of red, white, and buff alternate in the sedimentary rocks of the walls, and with the bright blue of the sky and the green of the cottonwoods and brush on the floor of the canyon produce very striking color effects. The river rises a considerable distance west of the Swell and apparently follows the rule laid down by Dutton [1] for the high plateau region—that "the principal drainage channels are older than the displacements."

The San Rafael Swell is an oval elevation, the long axis of which runs somewhat east of north and is about 40 miles long; its breadth is from 10 to 20 miles. From the body of the Swell the rocks down to the lowest Triassic [2] have been removed. The canyon is cut still lower and gives excellent exposures of rocks which may be of upper Carboniferous age.

At the point where the sulphur deposit under consideration occurs the canyon widens until the floor is probably a quarter of a mile across. As the spot is approached in coming up the canyon the existence of the springs is indicated a mile or more away by the odor of hydrogen sulphide, possibly more because the spring water has mingled with that of the river than because the gas has been carried

[1] Dutton, C. E., Report on the geology of the high plateaus of Utah: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880, p. 163.

[2] Idem, pp. 19-20.

so far by the breeze. At the springs the river flows near the south side of the canyon. In the middle of the valley half an acre of bright green cane and rushes grow in the wet soil around one of the springs, and on the south side of the river is a smaller patch covered with cane. Up the river 100 yards the cane climbs 40 or 50 feet up on the bank, showing that seepages must occur, for in most places only a scanty, drought-resisting vegetation can exist on the slopes.

In the patch of cane on the south side of the river bottom is a spring occupying an area of about 15 by 20 feet, the water of which is of a clear light greenish-blue color. It is in constant ebullition from gas rising at more than a hundred points. The odor of hydrogen sulphide is strong, and the water, which is cool, tastes noticeably of the gas. It is not known whether carbon dioxide also is emitted.

The stream issuing from the spring is about 20 inches wide and 4 inches deep and flows with a velocity of about 1 foot per second, so that the discharge is probably a little more than half a cubic foot per second. The temperature is probably not above 60° F.

Up the river for a distance of 250 yards are other springs, perhaps a dozen in all, several of which would each fill a 2-inch pipe. All seem to be equally charged with hydrogen sulphide except the farthest, which apparently carries less of the gas but much iron oxide. The water of this spring, however, tastes strongly of hydrogen sulphide. It is about 25 feet above the river, but all the others are nearer the river's level. A dead spring 20 or 25 feet above the river and about 75 yards from the uppermost spring now flowing has built a terrace of travertine 20 feet high, which contains many impressions of cane leaves and stems. The large accumulation of travertine suggests that the spring may at one time have been hot, but the vegetable impressions show that the spring could not have been near the boiling point at the time they were made.

All the springs, except those in the flat, issue from impure limestone débris which apparently covers a thin-bedded stratum of limestone. Above the springs, particularly about the middle of the strip, the ground is impregnated with sulphur, much of which is in small crystals, but a large part of it, so far as is visible to the unaided eye, is amorphous and of a pale dirty yellow color. Where the sulphur occurs the limestone is partly altered to gypsum.

The deposit evidently belongs to the common type formed from the oxidation of hydrogen sulphide. Here the gas has diffused from the springs through the débris. The deposition of sulphur from the gas is supposed to take place according to the equation $2H_2S + O_2 = 2H_2O + 2S$. Further oxidation takes place, changing part of the sulphur to sulphuric acid, which attacks the limestone and converts it to gypsum.

No selenium and no arsenic could be detected in the specimen collected.

If, as is supposed, the deposits are formed through the oxidation of hydrogen sulphide rising from the springs, they must be shallow and comparatively small. So far as could be seen in the hasty visit made, the strip bearing sulphur is only about 100 or 150 feet wide by 750 feet long. A little prospecting has been done by digging shallow trenches, but not enough to show much of the extent of the deposits. There is no doubt that sulphur can be extracted, but with fuel scarce locally, an 18 or 20 mile haul to the railroad, and a restricted market it is not likely that the deposits can at present be worked at much profit.

Sulphur deposits not accompanied by springs are reported to occur near San Rafael River 5 to 8 miles above the ones described. Others, 15 miles north of the upper deposits, are said to occur with cool springs on Cedar Mountain on a wash tributary to Price River. They are reached from Woodside.

The origin of the hydrogen sulphide in the water is unknown. The presence of the sulphur deposits at several places in the northern part of the Swell suggests the possibility that the Swell is underlain by a laccolith (a mushroom-shaped intrusion of igneous rock) the exhalations of which may furnish the gas directly. A laccolith is also suggested by the indications that the springs may have been formerly hot—by the shape of the San Rafael Swell and by proximity to the Henry Mountains, a known laccolithic mass 25 miles to the south. However, it is possible that the gas is derived from the sedimentary beds. Hydrogen sulphide is common in artesian water derived from sedimentary beds containing organic matter. The organic matter reacts upon sulphides to form $H_2S$.

# SULPHUR DEPOSITS OF SUNLIGHT BASIN, WYOMING.

By D. F. Hewett.

## INTRODUCTION.

The following description of the sulphur deposits of Sunlight Basin, Wyo., is based on an examination made during the summer of 1911. The presence of sulphur was noted by Arnold Hague,[1] of the United States Geological Survey, who studied and mapped the areal geology of the Crandall quadrangle, in which the deposits are situated. Recent exploitation of the deposits has appeared to justify more detailed examination. During the course of this examination the officers and employees of the Sulphur Mining & Milling Co. of Cody, Wyo., extended hospitality in this region of difficult access and placed claim maps at the disposal of the writer. Mr. Russell Kimball, of Cody, gave much assistance in the form of notes necessary for the construction of the accompanying map.

## LOCATION AND EXTENT.

The location of these sulphur deposits as well as those near Cody[2] and Thermopolis,[3] Wyo., is shown on figure 48. The deposits here described are situated in the upper portion of Sunlight Basin, Park County, Wyo., about 32 miles in a direct line northwest of Cody and 14 miles east of the east boundary of the Yellowstone National Park. The district is accessible by a fair wagon road from Cody, by which the distance is 52 miles. A weekly stage service is operated between Cody and Painter, which is 12 miles east of the sulphur deposits. Transportation into or away from the basin is greatly hindered by a steep hill between Dead Indian Creek and Pat O'Hara Creek, over which the ascent amounts to approximately 2,000 feet in less than 2 miles. Though it is possible to construct a road with a lower gradient, the present road is the only means of access.

The sulphur deposits occur in seven isolated groups, six of which lie in a belt about 3½ miles long, which crosses the valley of Sunlight

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

[2] Woodruff, E. G., Sulphur deposits at Cody, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908, p. 454.

[3] Woodruff, E. G., Sulphur deposits near Thermopolis, Wyo.: Bull. U. S. Geol. Survey No. 380, 1909, p. 378.

Creek. The other deposit is situated on Little Sunlight Creek, about 4 miles northeast. Prospecting has been limited to digging numerous shallow trenches and pits, none of which has penetrated more than 12 feet below the surface.

## SURFACE FEATURES.

The accompanying topographic sketch map (Pl. VII) shows the character of the region in which the sulphur deposits are found. This map has been constructed by determining by planetable methods the location and altitude of numerous prominent features and may be

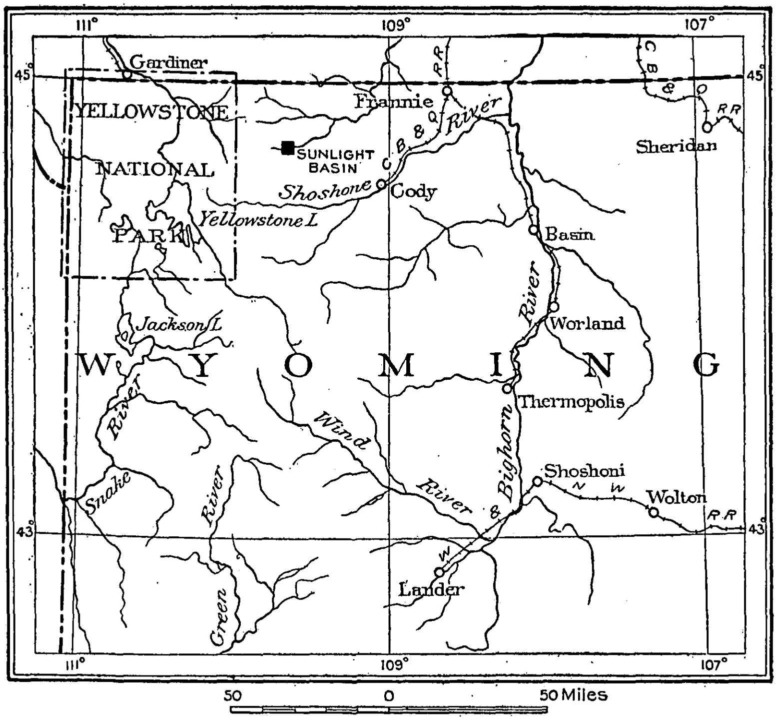



FIGURE 48.—Index map showing location of Sunlight Basin, Wyo.

considered relatively accurate for the central portion of the region adjoining the sulphur deposits. For the area beyond the limits of the higher surrounding ridges it has general value only, but is more reliable than the corresponding portion of the Crandall topographic sheet,[1] upon which the rugged ridges are shown with broadly sinuous contours.

Viewed from prominent ridges in the eastern portion of the valley, the basin is seen to be broad and flat, surrounded by steep ridges whose southern slopes are smooth but whose northern slopes are exceedingly rugged. The upper end of the valley, in the vicinity of the sulphur

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

deposits, is narrow, but here, as below, Sunlight Creek meanders in the flat valley bottom. In the neighborhood of the sulphur deposits the slopes of the ridges are generally smooth below 8,500 feet, but, except for the meadows in the high glacial cirques, there are few smooth slopes above 9,500 feet. To the west, on the sky line, are the sharp, snow-covered peaks of the main divide of the Absaroka Mountains.

Sunlight Basin appears to owe its origin to the damming of a deep glacial valley by a terminal moraine, which is a prominent feature a mile below Painter post office and behind which an accumulation of glacial gravel and lake sediment has formed the present valley floor.

Timber line ranges in altitude from 9,000 to 9,500 feet, though there are a few groves in sheltered areas as high as 10,000 feet. The heaviest timber grows below 9,000 feet on north and east slopes and valley bottoms, but the south and west slopes are relatively sparsely covered.

## GEOLOGY.

### GENERAL FEATURES.

The geologic features of this region have been described by Hague, who also noted the presence of the sulphur. As the attention of the present writer was directed particularly toward the nature and extent of the sulphur deposits, only a small portion of his time was devoted to the study of the general geology of the region. So far as this was studied, however, the observations made confirmed those of Hague. The areal geology shown on the accompanying map is based on the observations of the writer.

With the exception of two small bodies of Paleozoic limestones in the eastern half of the area represented by the map, the outcropping rocks belong to the Tertiary early basic series of lavas and breccias described in Hague's report. Though the Threeforks (Devonian) limestone is probably present in the area of limestones shown on the map, the exposures did not permit its separation from the overlying Madison (Mississippian) limestone. Observations in the region east of the area mapped showed that the limestones are gently folded along axes extending northwest and southeast. On Plate I the beds are shown dipping at low angles to the southwest.

The Tertiary lavas and breccias lie upon a surface of the limestones which possesses features of relief much resembling those of the present surface. From this it seems highly probable that limestone underlies all of the area represented by the map, though it is not possible to estimate accurately the depth below the present surface at which limestone would be met at any particular place. Attention is called to this fact, because the examination of the sulphur deposits near Cody and Thermopolis appeared to indicate a relation between the presence of limestone where solfataric springs found an outlet and the deposition of sulphur. This relation, however, was noticed in superficial deposits and could hardly exist where the limestones are buried.

## THE LAVAS.

Examination of the exposures on several of the ridges north of Sunlight Creek up to an altitude of 9,200 feet and south of it to 10,000 feet showed that the lavas could be divided into two groups, the upper being of distinctly more basic composition than the lower. The line of division is well defined on the south side of the creek, but not on the north.

The lower group, extending from the lowest exposures on Sunlight Creek to an altitude of about 8,500 feet, is composed of a number of interbedded lava flows and breccias of basic andesite. In hand specimens the lavas vary greatly in color as well as in texture, from greenish-gray rocks showing prominent phenocrysts of plagioclase and a few of augite in a finely crystalline groundmass to brownish-red and dark-purple rocks with only minute plagioclase crystals in a fine groundmass. No biotitic types were found, though hornblende was noticed here and there.

The more or less horizontal zones of breccia are extremely irregular. The zones are composed of fragments of basic andesite suspended in lavas of similar rock types so as to constitute about half of the mass. The fragments are angular to subangular and range in diameter from 2 to 6 inches, but there are localities in which the fragments are as much as 3 feet in diameter.

When examined in thin section under the microscope, the various types of lavas are found to show fewer differences than is suggested by the hand specimens. The feldspar is wholly basic labradorite, which with small amounts of augite forms about one-fourth of the rock. The texture is porphyritic and in the fine groundmass flow structure is generally pronounced. The lower group is therefore composed of similar types of augite andesite lava flows and associated flow breccias.

The basal member of the lower group where exposed along Little Sunlight Creek in the vicinity of the single isolated sulphur deposit is composed of basic andesitic tuffs in which vertical jointing is well developed.

The upper group of the Tertiary lavas under consideration is composed of basalt flows interbedded with flow breccias. The basalts are dark green, are generally vesicular, and commonly show augite and olivine as phenocrysts. The breccia fragments, in contrast to those of the lower group, are well rounded and range in maximum diameter from 4 to 20 inches. They resemble the rock types of the lower group, are gray to light red in color, and show plagioclase and augite, which is generally in greater amount than in the rocks of the lower group. The vesicular character and the structure prove the lavas of the upper group to be surface flows also.

The lavas are cut by numerous dikes, some of which are shown on Plate VII. These vary in width from 2 to 20 feet and several were traced for about 3,000 feet. They dip at angles varying between 45° and the vertical and, as is shown in a few places on the high ridges, cut the flows in a most intricate manner. Dikes of several rock types were found—pale green and gray andesites, dark-green olivine basalt, and gray orthoclase porphyry. In the group of five parallel dikes shown on Plate VII, cutting the ridges north of Sunlight Creek, there are two types of augite andesite porphyry and one of olivine basalt. The area probably contains more dikes than are shown on Plate VII, but they are either wholly covered with surface débris or poorly exposed. The order of intrusion of the dikes could not be determined, nor could any direct connection be established between the dikes and the sulphur deposits.

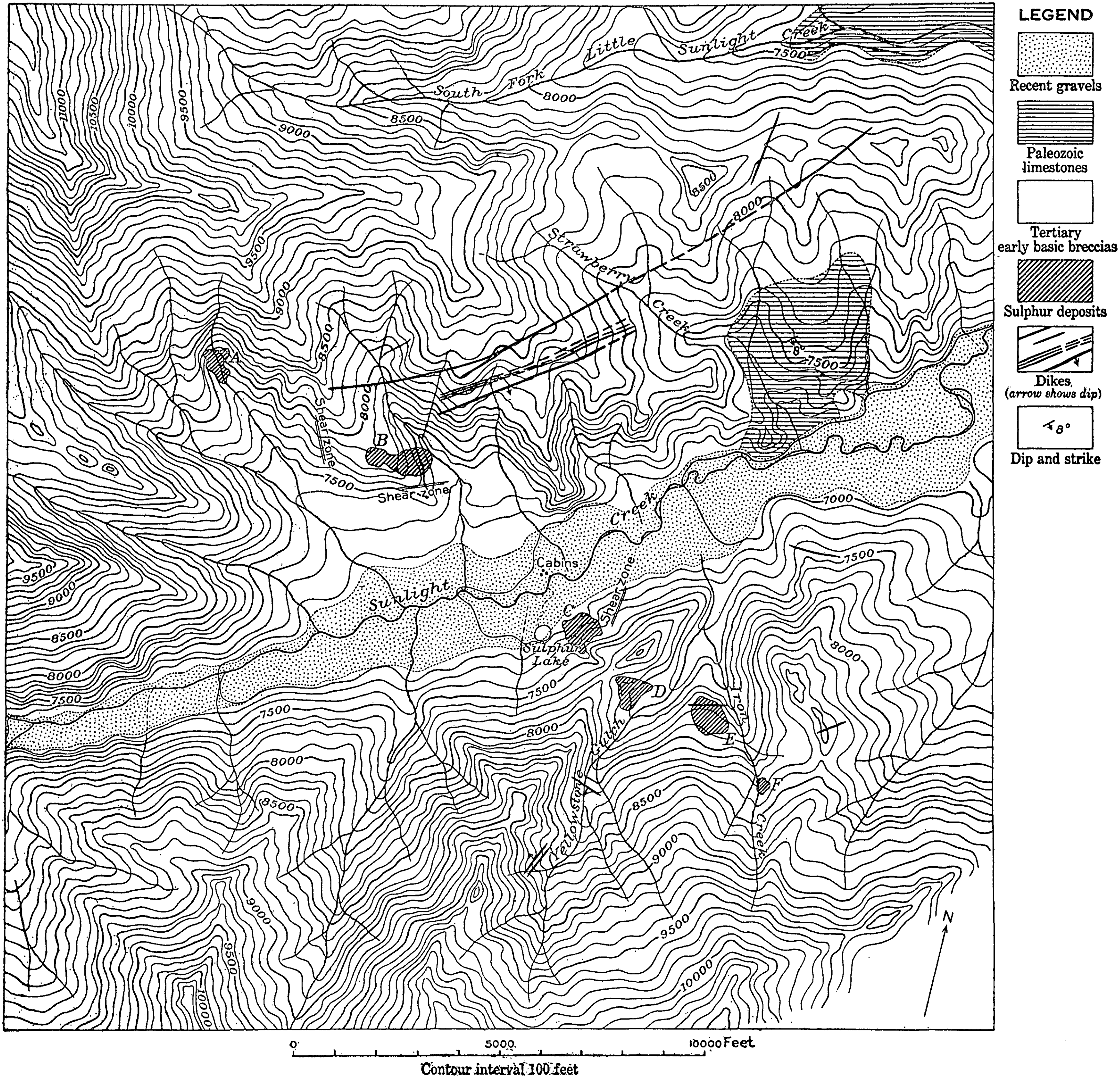
A feature of general geologic interest is the occurrence of zeolites in a large area south of Sunlight Creek, best shown in the upper basic group of lavas. The vesicles of the basalt flows, which range in diameter from a small fraction of an inch to 5 inches, contain thompsonite, heulandite, and analcite. Analcite was also found as an alteration product of the feldspars in rocks of the lower group of andesitic flows. Stilbite was found incrusting small fissures which cut both the lower and upper flows.

Hague does not mention the presence of zeolites in any of the lavas in the Crandall quadrangle, and it can not be stated whether or not they are restricted to this occurrence. From the fact that the portion of the area represented by Plate VII in which zeolites occur is not coincident with the zone of sulphur deposits, it is thought that the two are not directly related.

## THE SULPHUR DEPOSITS.

### LOCATION AND MODES OF OCCURRENCE.

There are six groups of sulphur deposits in the area represented by Plate VII. A smaller deposit situated on the north fork of Little Sunlight Creek is not shown on this map. The six groups lie in an approximately straight line, and each is situated on the slope of a ridge, practically adjacent to a ravine. The sulphur deposits are irregularly distributed in areas of the bleached igneous rocks. The groups of deposits, when seen from the high surrounding ridges, appear as large bleached areas from 5 to 20 acres in extent, devoid of vegetation and standing in striking contrast to the well-wooded slopes surrounding them.




TOPOGRAPHIC SKETCH MAP SHOWING SULPHUR DEPOSITS IN SUNLIGHT BASIN, PARK COUNTY, WYO.

Where vegetation does not conceal bedrock outside of the thoroughly bleached portions, the rocks are intricately fractured and show a tendency toward spheroidal weathering. This fracturing is locally controlled by two systems of joints, but generally it is extremely irregular. Four minor shear zones were found and are shown on Plate VII, but it appears that the positions of the groups of sulphur deposits are determined by a broad zone of intricate fracturing on a small scale, rather than by an extensive shear zone, such as might be produced by faulting.

A series of rock specimens was taken near one of the deposits with the view of determining the character of rock alteration which accompanied the bleaching referred to above. Examination of thin sections of these rocks under the microscope showed that the fresh rock is composed of crystals of basic labradorite feldspar and augite in a glassy ferruginous groundmass. The intermediate specimens showed successive stages of alteration to the most altered specimen, taken nearest the vents, which was found to be practically wholly opaline silica. A few kernels of undecomposed augite remain, but the feldspar is completely decomposed and there remains only finely granular amorphous silica. There is neither evidence of metasomatic replacement of the feldspars nor of alunitization, such as often accompanies solfataric spring action. The original texture of the rock is practically obliterated.

Sulphur occurs in two forms—cementing surface débris and incrusting irregular open fractures in the lava. The first mode of occurrence is more widespread, superficially, than the second, but at numerous localities exploration has shown that the sulphur-bearing débris is merely a mantle covering smaller areas in which sulphur is found in the second form. The sulphur occurs as a clear lemon-yellow incrustation, the surface of which is covered with numerous minute crystals. Here and there it is greenish yellow, owing probably to the presence of mechanically included impurities, but none was found having reddish or brownish tints. Both alkali alums and ferrous sulphate were detected in the sulphur-bearing débris at numerous openings. Iron sulphide, probably marcasite, occurs as a thin incrustation on spheroidally weathering nodules of the lavas in the vicinity of two of the sulphur-incrusted fractures.

The débris of the first mode of occurrence is composed of angular fragments ranging from an eighth of an inch to 2 inches in diameter. It is roughly stratified throughout and, though generally less than 5 feet thick, it has not been penetrated at some localities by trenches and pits 9 feet deep. The thickness of the débris appears to depend on the slope of the surface and the situation with reference to gulch lines, as it is thin or wholly absent on steep slopes and 8 to 10 feet thick over areas adjoining the stream channels. This débris is of local origin, being washed to lower slopes as it is set free by weathering. It is almost certainly not more than 15 feet thick at any place. Sulphur fills the interstitial spaces of the débris in varying degree. It is not found over the entire surface exposures of débris, but appears to impregnate the mantle of this material irregularly, so that there are one or more small areas of sulphur-bearing débris within the larger areas of débris free from sulphur. The largest area over which sulphur is found in this condition is slightly in excess of 2 acres, but most of the deposits are less than half an acre in extrent.

Though no analyses have been made, inspection indicates that those portions of the débris nearest the present surface are richest in sulphur, their maximum content being about 60 per cent. The débris lying upon bedrock generally contains much less, the amount varying with the thickness of the entire cover of débris but as a rule not exceeding 10 per cent. The débris also contains twigs and trunks of small trees and other vegetable matter, such as seeds. The smaller pieces of wood are impregnated with sulphur, but there does not appear to be any evidence of replacement of the wood fiber by sulphur.

The odor of hydrogen sulphide was detected in the neighborhood of every deposit and was especially strong in the deeper pits. A heavy noncombustible gas, apparently carbon dioxide, has accumulated in the bottoms of most of the pits and trenches in the sulphur-bearing débris.

The second mode of occurrence of sulphur is seen both at the present surface where the bedrock is not covered with débris and where explorations have exposed bedrock under the débris mantle. It was observed in most of the groups of deposits and probably would be shown by thorough exploration to be present in all. The sulphur occurs as a clear-yellow incrustation upon the walls of open fractures in the lava and as an impregnation in the partly or wholly decomposed rock near these fractures. The incrustation varies from a small fraction of an inch to 3 inches in thickness and is practically pure sulphur, but the impregnated rock does not generally contain more than 10 per cent of sulphur and would probably average much less when considered in large masses.

In only one deposit has a series of sulphur-incrusted fractures been developed sufficiently to permit observations bearing on the extent of this mode of occurrence. A trench on the hill south of Sulphur Lake has explored a well-defined zone of fractures about 4 feet wide, having a strike of due north and a dip of 70° W. Sulphur incrusts the walls of all open spaces and completely envelops small fragments of rock which have fallen from the walls. The entire mass of material between the walls would probably yield 10 per cent of sulphur, but the wall rock contains little more than a trace. At several places there are roughly conical mounds, the largest being about 20 feet in diameter and 5 feet high, which are composed of angular fragments of decomposed andesite heavily incrusted with sulphur. The fractured and more or less altered bedrock surface surrounding these mounds contains only a trace of sulphur. At the center of each, where the accumulation of sulphur is greatest, there is an open vent from which gases containing hydrogen sulphide and carbon dioxide are issuing freely, and there can be no doubt that sulphur is being deposited at present. It is probable that these mounds stand in relief owing to the greater susceptibility of the fractured bedrock to weathering processes, as well as to the growth which would accompany deposition of sulphur. The size of these mounds indicates the small areal extent of this second mode of occurrence of sulphur when compared to the overlying mantle of sulphur-bearing débris.

Gypsum occurs locally as a thin crystalline incrustation on small fractures but is not found in large masses such as are formed where sulphur is deposited in limestone. Alkali alum and ferrous sulphate were found in most of the pits and trenches in bedrock.

## GASES.

Gases are issuing from all the open fractures which were found. The rate of flow varies greatly among the vents and in several is sufficient to be clearly detectable several feet away from the opening. Gas also bubbles freely from the beds of several of the streams which adjoin the sulphur deposits. Chemical tests on the ground indicated that these gases contain hydrogen sulphide with a great excess of carbon dioxide, but sulphur dioxide was not noticed. The temperature of the gases, which was estimated at three places, was approximately that of the atmosphere, about 85° F., though in one place it was probably 10° higher.

A sample of gas was collected from the bed of Iron Creek where it adjoins group F and was forwarded to the laboratory of the Bureau of Mines in Pittsburgh, where it was analyzed by G. A. Burrell with the following results:

*Composition of gas from bed of Iron Creek.*

| | |
|---|---|
| Carbon dioxide | 14.28 |
| Oxygen | 18.28 |
| Carbon monoxide | .00 |
| Methane | 1.62 |
| Nitrogen | 65.27 |
| Hydrogen sulphide | .00 |

The report accompanying this analysis states:

This sample had a very pungent odor and rather sweet taste. No hydrogen sulphide was present, but, it is believed, some sulphur dioxide. Not enough of the sample was available for a satisfactory quantitative determination of the sulphur dioxide. The carbon dioxide is high but as presented in the analysis includes the sulphur dioxide, or that constituent which gives the gas the pungent odor and sweet taste. Please do not accept the carbon dioxide as stated as official, but mail to the bureau at least a liter more of this gas, if you can obtain it, for a more searching examination. The oxygen content is high, but is puzzling because of the apparent indication of free oxygen in the sample. The bureau simply submits this report as preliminary, because not nearly enough sample was present for a precise examination of this unusual gas.

The absence of hydrogen sulphide from the sample may be explained by the fact that the sample was collected over running water, which may have extracted it. The odor of hydrogen sulphide is always stronger in the vicinity of the higher vents than near those which issue from or near the stream beds.

If the nitrogen present is considered as admixed air, the amount shown, 65.27 per cent, would require 17.28 per cent of oxygen, indicating an excess of 1 per cent of free oxygen in the gas. Though the sample was taken by water displacement, it is not certain that air may not have previously been mixed with the other gases. The presence of an appreciable amount of methane is interesting but not unusual in such gases.[1]

The presence of a large percentage of carbon dioxide, which was also indicated by numerous tests with burning matches in the fractures and pits, is not uncommon.

## GENESIS.

Any statement concerning the genesis of these deposits must take several salient features into consideration.

The rocks containing the deposits are surface lava flows and associated breccias, and there is nothing to suggest the presence of a volcanic crater. No definite connection between dikes and sulphur deposits can be recognized.

The igneous rocks show no evidence of replacement by sulphur or sulphates such as alunite, but a tendency toward complete silicification.

Relatively dry gases, composed principally of carbon dioxide and hydrogen sulphide, are issuing from all the deposits. Sulphur is apparently being deposited from these gases at present.

Travertine and siliceous sinter are not present on the surface and there is no evidence of hot-spring action at any stage of the formation of the deposits.

The thin mantle of surface débris contains a greater amount of sulphur than the decomposed and fractured bedrock.

From these features it is thought that the sulphur deposits have been formed through the decomposition of hydrogen sulphide rising

[1] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 491, 1911, pp. 251, 255. A number of analyses of similar gases from Sicilian springs are here given.

through irregular fractures in the lava flows. This decomposition has probably taken place according to the well-known reaction $2H_2S + O_2 = 2H_2O + 2S$.

The amount of sulphur deposited in the bedrock lava is small, owing apparently to the inability of relatively dry gases to replace or dissolve siliceous rocks. Whether deposition of sulphur in the lavas below the drainage lines may be a factor is uncertain, but very improbable. Though the gases issuing from the vents are relatively dry, it is not impossible that any moisture which they may contain below the surface is condensed and joins the ground-water circulation. As every deposit is cut or bordered by a stream channel, any added water may be escaping under the stream gravel. There is no evidence that the limestone substratum has been dissolved nor that it has had any effect upon the gases. The presence of relatively high grade sulphur-incrusted débris on the surface is apparently due to the exceptional conditions favoring the relatively complete aeration and oxidation of the gases. It is thought that each deposit of this character covers one or more vents from which the sulphurous gases are escaping.

The alums and gypsum associated with the sulphur have been formed by the combination of sulphuric acid produced by the complete oxidation of hydrogen sulphide, with the bases of the igneous rock. The attack of the silicate minerals by sulphuric acid appears to have produced silicic acid, which by the loss of water has deposited the opaline silica that now constitutes the greater portion of the altered igneous rock.

The sulphur deposits are thought to be of relatively recent origin, probably being wholly postglacial. In one of the mounds from which gases are issuing freely at present the dead root of a cedar tree, similar to those growing near by, penetrates the fractured sulphur-bearing rock in such a manner as to make it certain that the tree once grew there. It is difficult to imagine the growth of a tree at the same time that the deposition of sulphur was taking place, so that it is thought that the sulphur at this locality at least is of extremely recent origin. This view is also favored by the discovery of twigs and other organic remains distributed through the débris.

The small lake adjoining group C is about 250 feet in diameter and it could not be determined whether its level is perceptibly higher than the water in the surrounding marshes and stream channels, or that there was a current issuing from it. No gas issues from the surface, though the water is noticeably warmer than that in the near-by marshes. The water is distinctly greenish blue, suggesting the presence of finely divided sulphur. It is possible that the lake owes its origin to a solfataric vent which has killed the vegetation in the vicinity.

## DETAILS OF THE DEPOSITS.

The deposits of group A are located at the head of a narrow gulch at the northwest end of the belt. The area of bleached and decomposed lava is approximately 7 acres, within which there are four deposits, the largest covering about one-third of an acre. The sulphur is found incrusting the coarse bowlders in the gulch bottom and the surface débris of the surrounding slopes. There are but a few shallow trenches, and the maximum thickness of the mantle of débris has not been proved.

At group B the lavas and breccias are bleached over an area of 20 acres. There are three sulphur deposits, two about an acre in extent and the third much smaller. Most of the pits have passed through the cover of sulphur-bearing débris at a depth of 4 feet, and the decomposed bedrock underlying this material contains only traces of sulphur. Gas issues vigorously from the bed of the stream which adjoins the group on the east.

At group C the superficial extent of bleached débris and rock is approximately 10 acres, in which there are two separate deposits of sulphur-bearing débris, one 1 acre and the other half an acre in extent. Numerous pits and trenches have been dug, most of which have gone through the cover of débris. The thickness of this cover is variable, in most of the pits being from 5 to 10 feet. Its content of sulphur is also variable, ranging from a mere trace to about 60 per cent. Several open vents from which gases are issuing occur on the eastern border of the area, and others have been found under the cover of débris.

At group D the total area over which the lavas and débris are bleached is about 11 acres. Within this area is located the largest deposit of sulphur-bearing débris in the region, its size being due to its occurrence at the junction of two ravines. It has an area of about 2 acres, and as several pits 8 feet deep, where the surface is flat, have not gone through it, the maximum thickness probably exceeds 10 feet. Other pits on the steeper slopes near by prove this portion of the débris to be about 3 feet thick. The only other deposits in this group are two mounds of sulphur-bearing material surrounding open vents, within an area of fractured and decomposed andesite about half an acre in extent.

At group E the superficial extent of bleached rock and débris is about 15 acres, within which there are two deposits of sulphur, one about 1 acre and the other one-quarter of an acre in extent. Only the larger deposit has been prospected. The mantle of sulphur-bearing débris probably does not exceed 5 feet in thickness. Where explored by two pits 10 feet deep the underlying decomposed bedrock contains but a trace of sulphur.

Group F contains only one deposit of sulphur, within a bleached area of débris of about 3 acres. In the few pits which have been dug sulphur has been found only as an incrustation of the surface débris, the total area being about half an acre. The deposit adjoins Iron Creek, from the bed of which gas bubbles freely.

## PRODUCTION.

No sulphur has been produced from these deposits, and it is extremely improbable that they will be sources of production until the transportation facilities of the region are greatly improved.

The amount of sulphur existing in the surface débris is capable of easy demonstration but is not thought to be great compared with that in workable deposits of sulphur in general. The maximum content of sulphur in material of this class can not exceed 50 per cent in large amounts of material, as it is governed by the pore space of loosely packed slide rock, which seldom exceeds 40 per cent. The amount of sulphur existing below this superficial cover is undoubtedly very much less, owing both to the relatively poorer chance for oxidation of the sulphurous gases and to the small amount of open space available for the deposition of sulphur. The occurrence of sulphur is distinctly superficial and it is not thought that the deposits will become important.

## COMPARISON WITH OTHER DISTRICTS.

Sulphur deposits similar to those here described are found at Sulphur Bank, Lake County, Cal.;[1] on Cove Creek, Utah;[2] on an island in the Aleutian Peninsula;[3] and in northern Japan.[4] Of these the Cove Creek and Japanese deposits are being exploited at present. The deposits in Sunlight Basin bear a striking resemblance to the one at Sulphur Bank, which has been exploited for quicksilver. In both places the deposits occur in basic igneous rocks—basalt at Sulphur Bank, augite andesite in Sunlight Basin—and the character of alteration of the inclosing rock and the analyses of gases issuing from the deposit are strikingly similar. The deposits at Sulphur Bank were also noticed to contain marcasite, which, though not seen in most of the deposits in Sunlight Basin, was found in one of the few pits which penetrated to the level of ground water. The two groups of deposits differ, however, in that cinnabar, quartz, and pyrite are present at Sulphur Bank, but not in Sunlight Basin. It is stated that although sulphur is present at the surface at Sulphur Bank, it is confined to the

---

[1] Becker, G. F., Quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, p. 251.

[2] Lee, W. T., The Cove Creek sulphur beds, Utah: Bull. U. S. Geol. Survey, No. 315, 1906, p. 485.

[3] Lawton, N. O., Makushim sulphur deposits, Unalaska: Min. and Sci. Press, vol. 98, 1909, p. 259.

[4] Mining in Japan: Geol. Survey Japan, 1909, p. 114.

zone of oxidation, which extends to a depth of about 20 feet. Cinnabar, however, is absent near the surface and increases in amount toward the bottom of the zone of oxidation. In view of these facts it would be advisable to direct prospecting in Sunlight Basin toward the demonstration of the possible presence of cinnabar at a zone lower than that yet explored. In the Alaskan deposits sulphur is being deposited by sublimation and by the decomposition of hydrogen sulphide that issues freely from crevices around the crater of a volcano whose activity is waning.

# TWO SULPHUR DEPOSITS IN MINERAL COUNTY, COLORADO.

By Esper S. Larsen and J. Fred. Hunter.

## INTRODUCTION.

The two sulphur deposits here described are located in Mineral County, Colo., about 25 to 30 miles southwest of Creede. They were examined during the summer of 1911 in the course of the geologic mapping of the San Cristobal quadrangle under the direction of Whitman Cross.

## GENERAL GEOLOGY.

Both deposits are in volcanic rocks of Miocene age belonging to the Potosi volcanic series. These volcanic rocks extend for many miles to the north and east, but are now preserved for only a few miles to the southwest. The prevolcanic rocks to the southwest comprise pre-Cambrian granites, quartzites, and schists, and a great variety of sediments ranging from the Cambrian to the Cretaceous.

The Potosi volcanic series may be divided broadly into four parts. The lowest of these is made up chiefly of andesitic agglomerate, but contains massive rock and angular breccia near the base and the top. Its present thickness varies greatly but in a large area exceeds 1,500 feet. Overlying a rather irregular surface of this material are thick flows of pink quartz latite with associated tuffs and thinner flows. The thickness of these latites is usually a thousand feet or more. Another series of andesitic breccias with associated flows and intrusives follows. This breccia is generally very chaotic and is made up of rocks which contain prominent tabular crystals of feldspar and some augite and hypersthene in a groundmass that is usually rather rich in orthoclase. A little quartz is present in some of the rocks and olivine in others. The thickness of the breccia may vary from 1,000 feet to the vanishing point within a distance of 1 mile. This variation in thickness is due to the irregular erosion which preceded the extrusion of the overlying flows of rhyolite and latite, constituting the fourth division of the volcanic series.

In general, the volcanic rocks are nearly flat, but only a short distance to the south of the sulphur deposits complex block faulting has given rise to local dips of 30° or more. To the east, west, and north of the deposits are other great faults. This main faulting took place later than the rhyolite flows and probably later than the deposition of the sulphur ore.

Both of the sulphur deposits are in the andesitic division which overlies the quartz latite and they are in all respects very similar.

## TROUT CREEK DEPOSIT.

The Trout Creek deposit is about 25 miles southwest of Creede, and is reached from that town by a wagon road that is good over most of the distance.

The deposit lies entirely in the second basic division of the Potosi volcanic rocks, about 700 feet below the base of the overlying rhyolite. The underlying quartz latite is not exposed in the east fork of Trout Creek, but only a little over a mile to the northwest, just beyond the forks of the creek, the latite is faulted up. Farther down the creek, opposite the mouth of Copper Creek, 1,500 feet of this quartz latite lies between the two andesitic divisions.

The division near the sulphur deposit is an angular breccia of dark-colored andesites. Most of the rocks have phenocrysts of labradorite, augite, and hypersthene, and the groundmass is glassy to rather coarsely crystalline. It usually contains abundant orthoclase and in places also quartz. Much of it which lacks the fluidal and other textures of lavas may be called latite porphyry. Many of the beds are made up almost entirely of one kind of rock. The rock is always bleached and much altered for a distance of 20 feet or more from the sulphur deposit. The less-altered rock is bleached white and the dark minerals are completely removed, being represented by cavities partly filled with pyrite. The plagioclase phenocrysts and the othoclase of the groundmass are still fresh. On more intense alteration the plagioclase is partly or entirely replaced by opal and in extreme decomposition the rock becomes an aggregate of opal, chalcedony, pyrite, and locally barite, with only a suggestion of the original texture. Another type of alteration consists in the replacement of the pyroxene by a brown pleochroic serpentine-like mineral, and the introduction of much pyrite. In such places the feldspars may still be fresh. A more intense alteration of the same type gives a rock which shows only remnants of the original feldspars and consists of quartz, chalcedony, and a sericite whose lowest index of refraction is nearly equal to that of Canada balsam.

Abundant pyrite and a considerable amount of apatite are also present. The sericite is scattered throughout the mass, but also occurs in veinlets together with the apatite. In addition to occurring in the veinlets, grains of secondary apatite are collected in bunches scattered through the rock. Pyrite is present here and there between rock fragements of nearly fresh breccia. Gypsum was seen in fractures associated with partly oxidized pyrite, but sulphates are rather unusual and were found in only a few places. The sulphur rock exposed in the tunnels is reported to be in contact with "black clay with angular and rounded bowlders and pebbles of various eruptive rocks."

The sulphur rock is remarkably well banded and except for the presence of sulphur the specimens resemble well-bedded tuff. The bands are less than half an inch wide and are either drab or yellowish gray. Narrow bands or lenses of yellow sulphur and of gray chalcedony are present. Yellow sulphur also lines fractures in the ore. The drab bands have a conchoidal fracture and a vitreous luster and burn readily. The yellowish-gray bands have a dull luster and resemble siliceous sinter. Some of the ore consists of brecciated fragments of the banded ore cemented by similar material. Thin sections of the ore show that the drab bands are nearly pure sulphur in very minute crystals and the yellowish-gray bands are opal in which are embedded numerous minute crystals of sulphur. The yellow sulphur is more coarsely crystalline and is probably secondary. In addition to sulphur, opal, and chalcedony, which are the only minerals observed by the writers, gypsum and iron sulphide are reported as occurring sparsely in some parts of the deposit. A determination of sulphur on an average sample of the material taken from the ore bins was made by R. C. Wells and showed 63.4 per cent of sulphur and no selenium. The remaining 36.6 per cent is almost pure silica, as it showed a residue of less than 1 per cent on ignition after treatment with hydrofluoric and sulphuric acids.

The underground workings are east of the east fork of Trout Creek, a few hundred feet above the creek bed, and just above an alluvial flat along the creek. As they were not accessible at the time of the writers' visit, the available information regarding the form of the deposit and its relations to the country rock is limited to that obtained from a hurried observation of the surface workings and the statements of reliable persons who examined the property several years ago.

The deposit is on a northwesterly fissure which appears to be the extension of a fault clearly exposed only 2 miles northwest of the main deposit, where the top of the quartz latite is thrown down about 500 feet on the northeast side of the fault. On the line of this fault there is an altered zone which passes through the sulphur deposit and continues to a point half a mile beyond, where it appears to go under the rhyolite flow that overlies the andesitic breccia. It is reported to reappear from under the rhyolite in a gulch about a mile to the southeast, but to go under the rhyolite again within a quarter of a mile; that is to say, the line of alteration continues to the southeast beyond the limit of visible faulting. Other areas and zones of alteration are common farther down Trout Creek.

Some of the bodies of sulphur rock exposed in the surface pits appear to have filled irregular, nearly vertical underground openings, but this could not be definitely determined. Much of the material is fractured and recemented. The banding is irregular, but it was thought on the whole to be nearly vertical. The available data on the deposits as exposed in the tunnels, however, indicate that it is a surface deposit about the opening of a series of hot springs arranged along the northwesterly fault. The sulphur rock exposed in the tunnels appears to be irregular in thickness and somewhat discontinuous. The greatest observed thickness was about 16 feet.

The principal underground workings are an upper and a lower tunnel, with some drifts and shafts. For the reduction of the sulphur rock, it was loaded on steel cars which were run into a cylindrical retort and treated with steam under pressure. The sulphur was drawn from the bottom of the retort. The mill was operated for only a very short time, and it is believed that little or no sulphur was placed on the market.

## MIDDLE FORK DEPOSIT.

The Middle Fork deposit is located about 5 miles south of the workings on Trout Creek, on the south side of the Continental Divide, at an elevation of about 11,000 feet, in the flat basin at the head of the west branch of the Middle Fork of Piedra River. It is exposed in the bed of the stream in the eastern part of the basin, just southwest of the peak whose elevation is marked as 12,080 feet on the topographic map of the San Cristobal quadrangle. The deposit is just north of a northwesterly fault which throws up the quartz latite to the southwest. Exposures are poor, but so far as could be seen the deposit is entirely in the second andesitic breccia and is associated with a zone of intense but irregular alteration which runs about N. 20° W.

Sulphur was found in two places, only a few hundred yards apart. The upper exposure has been uncovered for about 10 feet just south of the creek by a surface prospect. Its contacts are not exposed, and but little could be learned of its relations. The sulphur-bearing mass is in all respects similar to that of the deposits in Trout Creek and needs no special description.

Lower down, on the south side of the creek, there are a few short tunnels, now caved in. They are located in a white altered rock which carries in places a few scattered grains of yellow sulphur. The altered rock retains evidence of the original porphyritic texture of the andesite, but it is now a mass of opal, chalcedony, and kaolinite. A little pyrite is present in all the rock, but is much more abundant in the type which contains the sulphur and there exceeds the sulphur in amount; the opal and chalcedony are also more abundant in this phase of the rock.

About a mile to the northwest of these exposures is a large area of more or less decomposed breccia, which is probably closely related in origin to the sulphur deposit, although no evidence of sulphur was found. The final stage in the alteration of this andesitic breccia has given rise to quartz-alunite rocks and less often to quartz-gypsum rocks; pyrite is everywhere present and kaolinite is locally abundant. In this area of altered rock are veins of finely granular quartz and some hard, dense chert which resembles some of the brecciated sulphur ore in the manner of banding and brecciation.

## GENESIS OF THE ORE.

The typical banded ore is made up almost entirely of sulphur and opaline or chalcedonic silica and is characteristically free from sulphates, sulphides, or carbonates. A complete analysis was not made, but a partial analysis shows a remarkable resemblance to a hot-spring deposit from Lamar River, in the Yellowstone National Park.[1] This analysis, together with the approximate partial analysis of ore from Trout Creek, follows:

*Analyses of sulphur ore from Trout Creek, Colo., and hot-spring deposit from Lamar River, Yellowstone National Park.*

| | Trout Creek. | Lamar River. |
|---|---|---|
| $SiO_2$ | 35.5 | 29.23 |
| $H_2O$ | | 3.03 |
| C, organic | | 1.04 |
| S | 63.4 | 64.29 |
| $Al_2O_3$ | 1 | ........ |
| $Fe_2O_3$ | | 1.91 |
| MgO | | .07 |
| CaO | | .50 |
| | | 100.07 |

Dr. Hague kindly examined some of the specimens of the Trout Creek ore and said that they might easily have come from the Yellowstone National Park. Hot sulphur springs are still abundant in this part of Colorado, there being large springs at Pagosa Springs, others some miles farther up the Piedra, and another group at Wagon Wheel Gap, several miles below Creede, on the Rio Grande. These facts lead to the conclusion that the banded sulphur ore was deposited by

[1] Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 197, analysis F. For further information regarding this deposit the writers are indebted to Mr. Arnold Hague.

ancient hot springs or geysers connected with the igneous activity of the period, partly in the vents of the springs and partly on the surface about them. The sulphur deposits are thought to be younger than the second andesitic breccia but older than the overlying rhyolite. The volcanic rocks are known to be Miocene in age.

An understanding of the solutions and conditions of deposition at the Lamar River locality would do much to aid in interpreting the deposits of Colorado, but data other than the analysis of the deposit are not available.

The composition of the Colorado deposits and the alteration of the country rock accompanying them indicate the action of a solution very rich in sulphur and silica but undersaturated in respect to all other oxides. The pyrite of the altered rock is hardly sufficient to account for the iron of the original rock, and in the typical altered rock the $Al_2O_3$, $Na_2O$, $K_2O$, CaO, and MgO have been almost completely removed. Sulphates and carbonates were not observed in the ore and are very uncommon in the altered rock. It is believed that if sulphates had been abundant in the solution alunite would be found in the altered country rock, as it is a common mineral elsewhere in the altered rocks of this region. Alunite is abundant at a locality less than a mile from the Middle Fork deposit, where it is believed to have been formed at about the same time as the sulphur deposits but under somewhat different conditions.

The conditions which give rise to the deposition of sulphur from hot springs have been discussed by Chase Palmer,[1] who has suggested the following possibilities: (1) The oxidation of $H_2S$; (2) the action of certain bacteria; (3) the action between $CaCO_3$ and $H_2S$; (4) the decomposition of polysulphides or thiosulphates. In addition the competency of solutions to carry colloidal sulphur has recently been shown by Raffo and Marncini,[2] who found that a solution of the composition S (colloidal) 2.79–2.60 per cent, $H_2SO_4$ 6.43–7.00 per cent, and $Na_2SO_4$ 3.75–3.92 per cent is stable and that a change in the concentration of the salt causes precipitation of sulphur.

If the oxidation of $H_2S$ with the formation of S and $H_2SO_4$ were the dominant factor in forming the Trout Creek deposit there should be more sulphates, such as gypsum and alunite, associated with the ore.

The action of bacteria may account for some sulphur and likewise some silica, but the banding of the deposit and the absence of gypsum, which should be a result of this action, indicate some other origin for most of this sulphur. The complete absence of carbonates eliminates the action of $H_2S$ on $CaCO_3$, but a modified form of this reaction in which silicates take the place of carbonates may have been

[1] Woodruff, E. G., Sulphur deposits at Cody, Wyo.: Bull. U. S. Geol. Survey No. 340, 1908, p. 455.
[2] Zeitschr. Chemie Ind. Kolloide, vol. 9, 1911, p. 58.

important. The decomposition of the readily changeable polysulphides and of thiosulphates might also have been a factor. However, it is believed by the writers that most of the sulphur was deposited from a colloidal solution, as was also the silica, and that both were probably brought up from below in that form. The evidence in favor of this view lies in the cryptocrystalline character of the sulphur and the opaline character of the silica, the intimate association of the two, the banding of the ore, and the poverty of the ore and the altered country rock in all other minerals, especially sulphates and carbonates. The fact that the solutions precipitated the iron of the wall rock as pyrite and the association of pyrite and sulphur in the altered wall rock may be explained as due to the action of S and $H_2S$ on the $FeSiO_3$ of the iron-bearing silicates,[1] after the equation $FeSiO_3 + H_2S + S = FeS_2 + H_2O + SiO_2$. Ferric silicate would first be reduced to ferrous silicate thus: $Fe_2 (SiO_3)_3 + H_2S = 2FeSiO_3 + H_2O + SiO_2 + S$.

## PROBABLE EXTENT OF THE DEPOSITS.

The surface deposits of hot springs have not, as a rule, great persistency but are commonly formed as a number of separate lenslike deposits, more or less closely related. The size of such individual deposits may vary greatly and their form would in general be lenticular but in detail very irregular. The deposits within the vents of such springs would be irregular in form and the sulphur would probably not continue to a great depth.

[1] Allen, E. T., Crenshaw, J. L., and Johnston, John, The mineral sulphides of iron: Am. Jour. Sci., 4th ser., vol. 33, 1912, p. 173.

## 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. 40c.

Lee, W. T., The Cove Creek sulphur beds, Utah: Bull. 315, 1907, pp. 485–489.

Phalen, W. C., Sulphur pyrite and sulphuric acid: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 937–964.

Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: Prof. Paper 66, 1909, 258 pp. [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. 40c.

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.

——— Sulphur deposits near Thermopolis, Wyo.: Bull 380, 1909, pp. 373–380.

# MISCELLANEOUS NONMETALLIC PRODUCTS.

## GRAPHITE NEAR RATON, NEW MEXICO.

By W. T. Lee.

A large body of amorphous graphite occurs in the canyon of Canadian River, about 7 miles southwest of Raton, in Colfax County, N. Mex. The bed lies practically horizontal and has been prospected for a distance of several miles along the outcrop in the Canadian and its tributary canyons and traced laterally into the principal coal bed of the Raton field, which contains bituminous coking coal. Igneous material was forced into the coal-bearing sedimentary rocks in many places in this field and usually formed coke where it came into contact with the coal, but in the Canadian Canyon the intrusive mass took the form of many sills above, below, and in the coal bed and apparently heated the sedimentary rocks through a considerable thickness. The coal has been most completely graphitized where the bed was fractured and diabase forced into it. The graphite occurs in "pockets" or irregular masses in the diabase and is more or less columnar, the columns usually standing normal to the faces of the igneous rock. The columnar parts are relatively pure, but the noncolumnar parts seem to have resulted from what was originally bony coal or carbonaceous shale.

Analyses of this graphite were made by Andrew S. McCreath, of Harrisburg, Pa., who reported that it contains no sulphur or other material detrimental to its use in the manufacture of paint. To test the effect that weather might have on the paint, the graphite was subjected to caustic alkali and to strong acids, including aqua regia, but these produced so little effect that the graphite was pronounced satisfactory as a base for paint.

Two analyses of graphitic coal from this region were published years ago,[1] as follows:

*Analyses of graphitic anthracite from the Raton coal field, New Mexico.*

| | Soft. | Hard. |
|---|---|---|
| Moisture | 1.19 | 1.22 |
| Volatile matter | 4.37 | 5.45 |
| Fixed carbon | 76.07 | 71.79 |
| Ash | 18.37 | 21.54 |
| Sulphur | .19 | .17 |
| Iron | .......... | .63 |
| Sulphur required for $FeS_2$ | .......... | .72 |
| Sulphur± | .......... | .55 |

The writer collected a sample of the graphite for analysis 160 feet from the mouth of an old opening, at a point where the bed was about 3 feet thick. In order to obtain a representative sample, the weathered material was cleared from the exposed face of the bed. The sample represents the entire thickness of the graphite at this point, and therefore the analysis shows a greater percentage of impurity than would be found in pieces selected from the best material. The sample was analyzed as coal in the laboratory of the United States Geological Survey at Pittsburgh. The analysis is given in the table that follows as No. 6521.

The unmetamorphosed coal of the bed containing the graphite is mined at Van Houten, a mining camp located 4 miles southwest of the graphite opening. For purposes of comparison with the graphite two analyses of this coal are given. The bed in the mine is 10 to 15 feet thick. In some places it carries very little impurity, but in others small amounts of shale and bony coal are encountered. The following section of the coal bed was measured in the mine where the samples were taken for analysis:

*Section of coal bed in the Willow mine, Van Houten, N. Mex.*

| | Ft. | in. |
|---|---|---|
| Sandstone. | | |
| Coal[2] | 1 | 3 |
| Bony coal | | ½ |
| Coal[2] | | 6 |
| Bony coal | | 4 |
| Coal[2] | 3 | 4 |
| Bony coal | | 10 |
| Coal | | 1½ |
| Shale | | 3 |
| Coal[3] | 4 | 5 |
| Shale. | | |
| | 11 | 1 |

[1] Potter, W. B., The character and composition of the lignite coals of Colorado: Trans. Am. Inst. Min. Eng., vol. 5, 1877, pp. 365–375.
[2] Represented by analysis No. 6417 of the following table.
[3] Represented by analysis No. 6418 of the following table.

*Analyses of graphite and coal samples from the Raton coal field, New Mexico.*

[F. M. Stanton, chemist in charge.]

| Laboratory No. | Air-drying loss. | Condition of sample. | Proximate. | | | | Ultimate. | | | | | Heat value. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Moisture. | Volatile matter. | Fixed carbon. | Ash. | Sulphur. | Hydrogen. | Carbon. | Nitrogen. | Oxygen. | Calories. | British thermal units. |
| 6521 | 0.40 | Graphite, as received | 1.31 | 6.07 | 76.11 | 16.51 | 0.17 | .... | ...... | .... | ...... | ...... | ...... |
| | | Graphite, air-dried | .91 | 6.09 | 76.42 | 16.58 | .17 | .... | ...... | .... | ...... | ...... | ...... |
| | | Graphite, moisture-free | .... | 6.15 | 77.12 | 16.73 | .17 | .... | ...... | .... | ...... | ...... | ...... |
| | | Graphite, moisture and ash free. | .... | 7.39 | 92.61 | ...... | .20 | .... | ...... | .... | ...... | ...... | ...... |
| 6417 | 1.40 | Coal, as received | 2.42 | 33.69 | 54.42 | 9.47 | .66 | 5.21 | 72.84 | 1.10 | 10.72 | 7,303 | 13,145 |
| | | Coal, air-dried | 1.03 | 34.17 | 55.20 | 9.60 | .67 | 5.12 | 73.87 | 1.12 | 9.62 | 7,407 | 13,333 |
| | | Coal, moisture-free | .... | 34.53 | 55.77 | 9.70 | .68 | 5.06 | 74.65 | 1.13 | 8.78 | 7,484 | 13,471 |
| | | Coal, moisture and ash free | .... | 38.24 | 61.76 | ...... | .75 | 5.60 | 82.67 | 1.25 | 9.73 | 8,288 | 14,918 |
| 6418 | 1.50 | Coal, as received | 2.51 | 34.64 | 54.03 | 8.82 | .76 | 5.50 | 73.65 | 1.20 | 10.07 | 7,404 | 13,327 |
| | | Coal, air-dried | 1.03 | 35.17 | 54.85 | 8.95 | .77 | 5.41 | 74.77 | 1.22 | 8.88 | 7,517 | 13,531 |
| | | Coal, moisture-free | .... | 35.53 | 55.42 | 9.05 | .78 | 5.35 | 75.54 | 1.23 | 8.05 | 7,594 | 13,669 |
| | | Coal, moisture and ash free | .... | 39.07 | 60.93 | ...... | .86 | 5.88 | 83.06 | 1.35 | 8.85 | 8,350 | 15,030 |

Although the graphite was originally coal, as is clearly indicated by its position, its chemical character gives little indication of its origin, and it was somewhat surprising to find 6.07 per cent of "volatile matter" in it, a percentage considerably higher than that carried by some other graphites of similar origin. At the writer's request Dr. H. C. Porter made a chemical examination of this volatile matter, with the following results:

*Analysis of volatile matter contained in the graphite of Raton coal field, New Mexico.*

Twenty grams, as received, crushed to rice size, heated 20 minutes in atmosphere of nitrogen at 930°–950° C.

| | | 1 | 2 |
|---|---|---|---|
| Total loss (includes moisture 1.31 per cent) | per cent | 5.6 | 6.0 |
| Water (includes moisture 1.31 per cent) | do | 4.22 | 4.23 |
| Tar | | Trace. | Trace. |
| Gas | liters per kilo | 16.2 | 15.0 |
| | cubic feet per ton | 520 | 480 |
| Composition of gas: | | | |
| $CO_2$ | per cent | 9.1 | ......... |
| Illuminants | do | 3.1 | ......... |
| CO | do | 9.3 | ......... |
| $CH_4$ | do | 19.5 | ......... |
| $H_2$ | do | 52.7 | ......... |
| $N_2$ | do | 6.3 | ......... |

This material seems to retain its graphitic streak after heating at a high temperature, which would seem to indicate that it is a true graphite, as does also the fact that it is extremely difficult to burn. The volatile matter * * * is very largely water, which I should say is in the form of combined water or water of crystallization. This is indicated also by the decrepitation on heating.

The prospect from which this sample was taken was opened in 1889 by the Standard Graphite Co., of New York, and 250 tons of graphite was shipped from it to Moosic, Pa., where the ore was tested as to its availability in the manufacture of paint. One of the objects of the company was to ascertain whether the graphite could be handled profitably, and careful accounts were kept. According to the statement of one member of the company it was ascertained that the graphite could be placed in the bins at Moosic for $17.50 a ton, the greater part of the cost being shipping charges. At Moosic, at an additional cost of 90 cents a ton, it was ground and separated from some of its impurities by means of air blasts. The refined product contained 80 per cent of carbon, the 20 per cent impurity being mostly silica, which was not regarded as objectionable in the manufacture of paint. The tests were satisfactory to the company, and the mill was being taken apart for shipment to Raton when it was destroyed by fire. Nothing has since been done toward developing the graphite.

# MICA IN IDAHO, NEW MEXICO, AND COLORADO.

By Douglas B. Sterrett.

## INTRODUCTION.

The mica deposits described in this paper were briefly examined during the course of other work. The deposits in Idaho were visited in June, 1910; those in New Mexico in June, 1911; and the one in Colorado in July, 1911.

The mines examined in Idaho and New Mexico include some of the best mica deposits known in those States and some that are no more than prospects. An examination of the deposit of mica in Colorado was made in consequence of numerous requests for information regarding its possible value. Idaho and New Mexico have been large contributors to the production of sheet mica in the past. During the last few years, however, these States have produced little or no mica. Colorado has been more important as a producer of scrap mica.

Muscovite or white mica is the only variety mined in the United States, with the exception of a small quantity of biotite and lepidolite, the latter of which is used in the manufacture of lithia salts. In 1910 the production amounted to 2,476,190 pounds of sheet mica, valued at $283,832, and 4,065 tons of scrap mica, valued at $53,265. This output came chiefly from North Carolina, South Dakota, and New Hampshire. That there is a market for a far larger output of sheet mica is shown by the fact that 1,961,523 pounds, valued at $724,525, was imported and entered for consumption during the same year. The value of the imports of mica has for many years, with the exception of the year 1908, greatly exceeded that of the domestic production. The imports consist chiefly of large sheet mica and the softer phlogopite or "amber" mica, which is not found in deposits of commercial value in the United States.

In the mining of mica there is always a considerable yield of scrap, and the most desirable type of mine is that in which the output of good sheet mica is large. To work at a profit a deposit yielding scrap mica only it is essential that the mica be mined cheaply, for there is a limited market for scrap mica and a large part of the present production of about 4,000 tons a year is supplied by waste from mining and trimming sheet mica. If such a deposit can not be made to pay a sufficient profit with a production of a few hundred tons of scrap mica annually, and a guaranteed market is not secured for a larger output, it will be an investment of doubtful value.

The principal use for mica at the present day is in the manufacture of electric apparatus. In the early days of the industry in this country the chief demand for mica was for use in glazing, principally in stoves. This is now one of the less important uses. The value of good sheet mica that is suitable for glazing is greater than that of the material suitable for electric purposes. The demand for glazing mica is insufficient to use all the sheet mica produced, so only the best quality and larger sheets are used for this purpose. "Micanite," or built-up mica board, for the manufacture of which much smaller sheets can be used, is an amply good substitute for large sheet mica in much electric work. Waste and scrap mica when ground have a wide application in the manufacture of wall paper, lubricants, and electric insulating material.

## OCCURRENCE OF MICA.

Mica deposits of commercial value in the United States are confined to pegmatites. In these rocks mica occurs as an accessory mineral of more or less prominence, the essential constituents of pegmatite being feldspar and quartz. The feldspars are commonly orthoclase or microcline, though plagioclase, in the form of albite or oligoclase, is present in some pegmatites, and locally plagioclase is the predominant feldspar. Pegmatite is therefore allied to granite in composition but is distinguished from it by having a coarser texture. Pegmatite also presents greater variations in texture and composition than granite. The texture ranges from the coarsely granular to that in which the individual minerals occur in crystals or masses several feet across. These masses may be very irregular in shape or arranged in sheets, in places parallel with the walls. The proportions of the constituent minerals are rather variable. In some pegmatites the quantity of feldspar present is several times greater than that of the quartz and other minerals; in others quartz is the principal constituent and may compose more than four-fifths of the mass. Here and there over half of the pegmatite is composed of mica.

Pegmatite bodies are of various shapes. Some are rather persistent in length and form dikelike or veinlike sheets that can be traced for several hundred yards. Others are lenticular and occur either in long, slender bodies or in short, thick masses, some of which are nearly round. Some pegmatite bodies lie conformable with the schistosity of the inclosing gneiss or schist either through part or the whole of their extent; others cut across the bedding of the rock formations. Pegmatites range in thickness from less than an inch to many yards.

Mica-bearing pegmatites in the United States have been found in areas of metamorphic crystalline rocks of pre-Cambrian age. Some of these rocks are gneisses and schists in which the predominating constituent is muscovite or biotite mica, garnet, cyanite, staurolite, or hornblende. These rocks have been much folded, faulted, mashed, and recrystallized in most areas where they are exposed and some have been intruded by later granite and other igneous rocks. The pegmatites owe their origin to the intrusion of masses of granite into the gneisses and schists and in some places probably to the metamorphic processes that produced those rocks. They are common associates of granite masses and cut other rocks surrounding the granite. They represent the later phases of activity of the granite magmas and were probably given off as magmas, solutions, and emanations and introduced into the surrounding rocks as dikes and veins. It is not generally possible to state whether a pegmatite body is a dike or a vein, as the characters of these forms, like their modes of origin, grade into each other.

## MICA IN LATAH COUNTY, IDAHO.

Deposits of mica have been found in several counties in Idaho, and some of them have been developed on a large scale. The deposits described below are in Latah County and lie in a north-south belt about 2 miles wide and several miles long. The mines and prospects examined are in T. 41 N., R. 2 W., from 3 to 6 miles north of Avon. They lie at elevations of 3,400 to 4,700 feet above sea level, along the top and to the west of a high mountain ridge extending south from the Thatuna Hills. The principal properties are the Muscovite claim of Alexander Munro, about 5 miles north of Avon, in sec. 22; the Levi Anderson mine, about 4 miles north of Avon, in secs. 22 and 27; the Maybe mine of Alexander Munro, about 1 mile southwest of the Muscovite claim, in sec. 22; and the Luella mine of the Western Mica Co., about 1½ miles southwest of the Muscovite, in sec. 21. Other claims are owned by Alexander Munro and David Peterson, in sec. 15. In order from south to north along the ridge the mines are the Levi Anderson claim, the Muscovite, Atlas, Violet, and Morning Star claims of Alexander Munro, and the Sunshine claim of David Peterson. The Maybe and Luella mines are in the valley to the west of this ridge. The location of the different deposits is given in figure 49. At the time of the writer's visit the Muscovite was the only mine in operation; it had been idle a few years and was being cleaned out preparatory to mining. The elevations given were determined by barometric measurement.

The mica deposits occur in an area of highly schistose metamorphic rocks of pre-Cambrian age. Muscovite and biotite schists and gneiss, in which quartz is generally a prominent constituent, are the principal rock types of the region. Locally certain bands of the gneiss

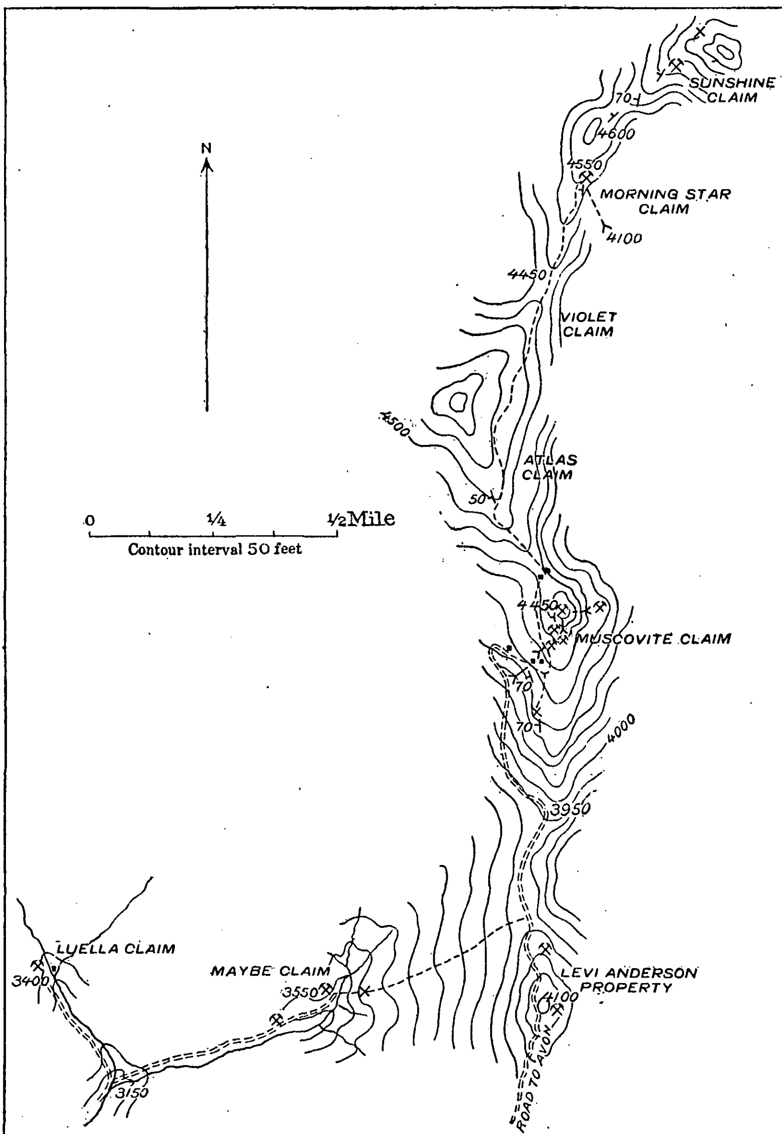



FIGURE 49.—Map showing mica deposits in Latah County, Idaho.

have an abundant development of black tourmaline crystals, especially near large pegmatite bodies. The gneisses and schists of this region strike roughly north and south, and the dips range from 50° W. to vertical. Masses of pegmatite cut the gneiss and schist and are in many places entirely conformable with the schistosity and in others only in part or not at all. Some of the pegmatite bodies outcrop continuously for distances of several hundred yards, with few variations in thickness or direction. Others have smaller outcrops. A bulging or swelling of the pegmatite bodies into chimney-like deposits also occurs and in some places is associated with rich deposits of mica. The gneisses and schists apparently contain more pegmatite in the valley to the west of the high mountain ridge than in the ridge itself. It is asserted by the miners that the deposits along the top of the mountain are on the same ledge of pegmatite. This may be true, but it has not been proved. There may be separate sheets of pegmatite that do not connect, though nearly in line or overlapping one another. Even if a single pegmatite body should prove so persistent as to extend over several claims, the mica content is variable and in places the rock contains none.

The rocks have been deformed, but the larger folds are not easily distinguished in the small area under consideration. Small folds whose dimensions can be measured in feet and with schistosity turned across the bedding were observed in a few places. In general the strike and dip are rather regular for a region of tilted metamorphic rocks.

The Levi Anderson mine is in a low, rounded knob on the ridge, at an elevation of nearly 4,100 feet. The main opening is on the east side near the top, and a second opening has been made about 200 yards to the north at a lower level. The main working consists of an open cut about 20 feet wide, 30 feet long, and 15 feet deep, with short tunnels to the north and to the south and an incline from the bottom. The workings have fallen in badly. As exposed in the open cut the pegmatite is about 20 feet wide and approximately conformable with the inclosing rock. The country rock is mica schist and gneiss, with a strike of N. 10° W. and a dip of 60° W. The pegmatite carries a large amount of quartz with some black tourmaline and beryl crystals. Only small-sized crystals and sheets of mica were observed around the mine; mica in sheets of valuable size was seen in the possession of Mr. Anderson at Spokane. At the other working a shaft was sunk on a pegmatite ledge. Only small mica was left around this opening also. Part of the muscovite had biotite associated and intergrown with it.

The Muscovite mine was first worked in 1888 by Woody & Lamb. After that it was operated intermittently, the last work being done by the Muscovite Mica Co., of Spokane. The mine then passed into the hands of Alexander Munro, of Moscow, Idaho. The "vein" in the Muscovite mine cuts through the apex of a sharp knob whose elevation is 4,450 feet. The position of the different workings is shown in figure 50. An open cut with a shaft has been made on the outcrop at the apex and other open cuts with drifts and a 60-foot shaft to the south on the hillside. The principal work was done from two crosscut tunnels with drifts and stopes at the ends. One

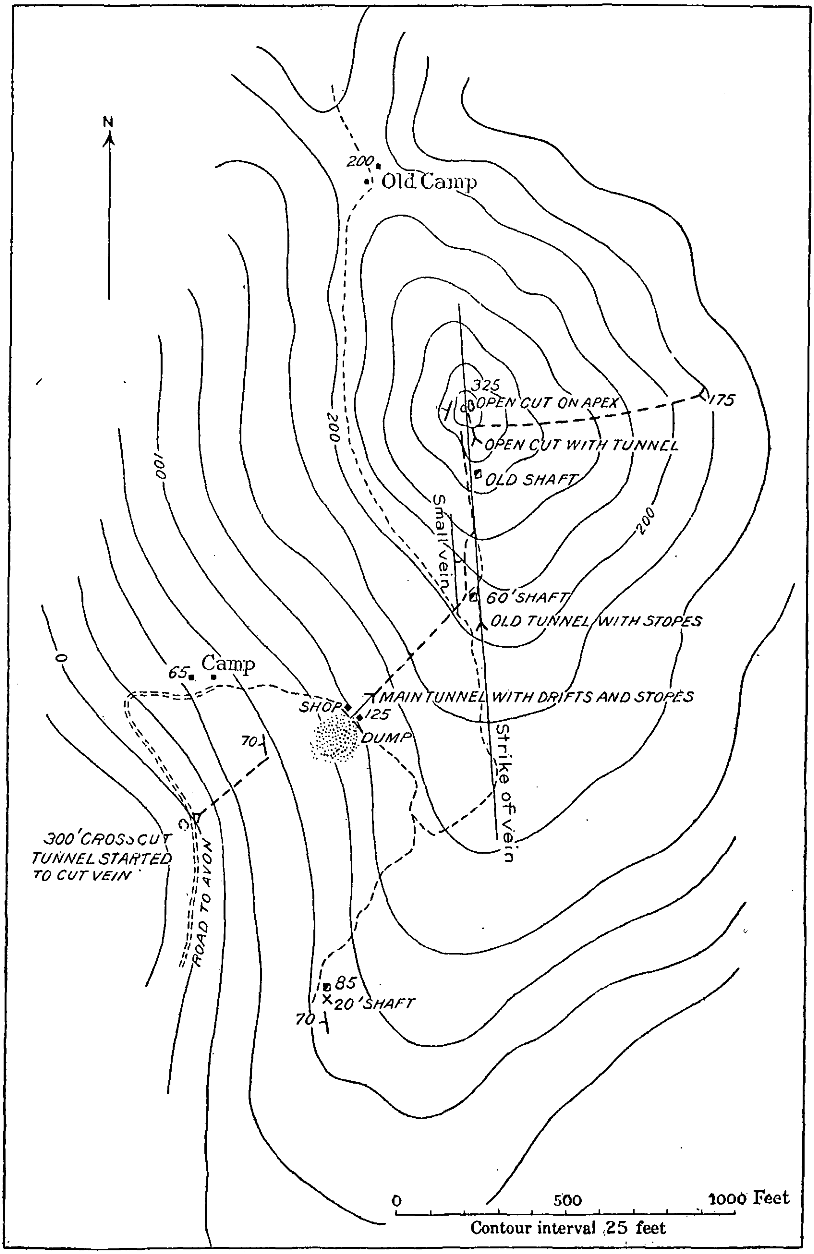



FIGURE 50.—Map showing position of workings on Muscovite mica claim of Alexander Munro, Latah County, Idaho.

of these tunnels was 150 feet lower than the apex and on the east side of the hill; the other was on the southwest side of the knob and 200 feet lower than the apex, and in June, 1910, this was the only part of the mine open for examination. Another crosscut tunnel was started still farther down, about 325 feet below the apex; this has been driven about half of the 600 feet necessary to reach the "vein." Other test pits have been made nearly a quarter of a mile south of the apex, on a pegmatite outcrop, which may or may not be the same "vein." The tunnel open for examination had been driven some 200 feet to the "vein." Over 300 feet of drifts, with a large amount of stoping above them, were then carried to the north. At the junction of the tunnel and the drift at this level a room for a turntable had been made during previous operations. The timbers of the roof over this turntable and of the stopes in places farther along had given way, so that in order to reach the better part of the mine it was necessary to drive a new tunnel alongside of the main original drift. The 60-foot shaft formerly connected with the drift at the end of the crosscut tunnel. A short crosscut tunnel to the west of the new drift cut a pegmatite "vein," from 12 to 18 inches thick, in which small blocks of good mica and some beryl crystals were found.

The main pegmatite "vein" ranges in thickness from 4 to 6 feet in the main original drift and the stopes above and widens out to 12 feet thick at the end of the drift, where the vein includes a horse of gneiss several feet across. There was a large showing of mica "books," some of good size, in the end of the tunnel and at two places seen in the stopes above. It is said that the best mica in sight was removed when mining was stopped, though even then the "vein" contained sufficient mica to be termed rich. In the open cut at the apex the pegmatite mass encountered appears to be nearly 40 feet thick. The pegmatite at this point and to the side of the open cut carries considerable quartz. A portion that had not been mined still contains numerous blocks of fair-sized mica on the outcrop.

The country rock is strongly foliated muscovite-biotite gneiss. It has a strike of N. 10° W. to N. 10° E. and dips about 70° W. The pegmatite is conformable, or nearly so, with the gneiss. The course of the pegmatite is fairly regular, but a few minor deformations were encountered in the workings. Evidently the outcrop at the apex represents a large bulge or swelling of the pegmatite. The increasing thickness of the pegmatite in the end of the drift 200 feet lower than the apex indicates a continued thickness with depth. This drift probably does not lack more than 60 or 70 feet of being under the apex. This chimney or shoot of pegmatite outcropping at the apex is considered to be the richest part of the "vein." In the tunnel on the east, 150 feet lower than the apex, a large vein very rich in mica is reported to have been encountered. A peculiar feature of the "vein" is the small amount of quartz and feldspar it contains at a distance from the apex chimney. In the chimney the quartz and feldspar are plentiful and the pegmatite is more nearly normal in composition. The production of mica from this mine has been large. No records have been kept, but Mr. Munro estimates that during two periods of operation in the past at least $40,000 worth of mica was taken out each time. The quality of the sheet mica from the Muscovite is very good, the color being light "rum" and the sheets clear. It is probable that the proportion of good sheet mica obtained from an average lot of books would not equal that of some of the better mines in other parts of the country, though there are probably few mines that will yield so abundantly from an equal amount of vein matter as the Muscovite mine.

The two claims taken up by Alexander Munro extending to the north from the Muscovite are intended to cover the outcrop, if any exists, of the pegmatite between the Muscovite and the Morning Star. On the latter claim the pegmatite outcrops strongly for some distance along the east side of the ridge. The hill slope below is steep, almost cliff-like in places. The pegmatite is about 20 feet thick and incloses a horse of gneiss, or there are two ledges of pegmatite separated by a sheet of gneiss. The ledge is conformable with the mica schist country rock and strikes east of north with a dip of about 60° W. Both the schist and the pegmatite contain black tourmaline. The amount of mica exposed in the outcrop of this ledge is small. About 450 feet lower a crosscut tunnel was started on the east side of the ridge and driven 660 feet under the outcrop. The dip of the pegmatite carries it still farther west and the tunnel will probably have to be carried about 90 feet farther. The rocks through which the tunnel cuts are muscovite and biotite schist and gneiss, with a slight banding in places across the foliation. The schistosity strikes east of north and dips 50°–70° W.

The Sunshine claim adjoins the Morning Star on the north. The pegmatite ledge outcrops strongly on the hillside and is probably the same ledge as that opened on the Morning Star. An open cut 20 feet long and 10 feet deep has been made in the hillside on a pegmatite body striking east of north with a dip of 50° W. It is conformable with the inclosing gneiss. Very little mica was found in this cut. The pegmatite carries tourmaline and also garnets larger than walnuts. It is said that a better showing for mica was found in a prospect opened about 200 yards to the north over the hill.

The Maybe mine, sometimes called the Silver White mine, is in a steep hillside in the bend of a stream. Several tunnels have been run into the hill and a few pits and other openings made, but these have caved in so badly that little could be seen. Either there are two or more ledges of pegmatite, or a single ledge is folded and lies somewhat like a blanket on the hillside. In one of the openings the mica schist country rock has a strike of N. 55° W., about parallel with the contour of the hill at that point. The pegmatite carries considerable tourmaline and some garnets up to walnut size. The mica is clear and of a very light color, inclining to "rum." Judged by the waste mica left around the mine the sheets are of good quality and split well.

On the hillside, across the small stream to the east of the Maybe mine, several prospects for mica have been operated. This work is old, though the indications for mica are good. A few hundred yards southwest of the Maybe mine, near the corner of the claim, another pegmatite body was prospected for mica. A very good deposit of mica was found in the open cut, but a tunnel started 15 feet lower down very quickly lost the main "vein" and followed a stringer for nearly 300 feet.

The Luella mine was opened by a crosscut tunnel, run in a southwest direction, and an open cut on the outcrop above it. Evidently a large pegmatite deposit was found and much of it stoped out. Only small mica, though of good quality, was left around the mine. The pegmatite blocks on the dump contain black tourmaline and pink garnets, some of which are embedded in mica crystals. The country rocks are muscovite and biotite schist and gneiss. Blocks of fine-banded tourmaline-quartz rock, associated with the schists, were left on the dump.

A prospect was opened for mica on the roadside, at an elevation of 3,800 feet above sea level, on the spur of the mountain ridge, about half a mile south of the Levi Anderson claim. Little could be seen of the formation encountered or mica found.

The operation of mines in this region is facilitated by an abundant supply of good timber. Part of this timber is included in the claims and part is either on State land or in the Cœur d'Alene National Forest. On the mountains the important trees are tamarack or larch and red fir; in the valleys there are good stands of white pine, red pine, tamarack, red fir, and cedar. The rocks are not hard to drill, and Mr. Munro states that in some of the mines tunnels can be driven at the rate of 3 feet a day without power drills. The shipping point for the mines is Avon, on the Washington, Idaho & Montana Railway.

## MICA IN RIO ARRIBA COUNTY, N. MEX.

The mica deposits described below are but a few of a large number that have been located in Rio Arriba County, N. Mex. Many of the deposits of this region were mentioned in a report by Holmes,[1] who gave brief descriptions of some of them. Notes for the accompanying descriptions were obtained during a very brief visit at a time when none of the deposits were in operation. Through the kindness of Mr. Moritz Leichtle, of Petaca, N. Mex., the few examinations made were possible.

[1] Holmes, J. A., Mica deposits in the United States: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1899, pp. 706-707.

Deposits of mica have been found in other parts of New Mexico. One of these, in the Glorieta Mountains, was worked during 1909 by the Anderson Mica Co., of Topeka, Kans. The shipping point for this mine was Ribera, about 10 miles to the south, on the main line of the Santa Fe Railway. Other mica deposits are reported in Taos County.

Rio Arriba County lies west of the central part of northern New Mexico. The eastern part of the county, in which the mica region is situated, is composed of broken mountain country merging into partly dissected table-land. The mountains are a continuation of the San Juan Mountains of Colorado. The mica deposits lie at elevations ranging from 6,500 feet to over 8,000 feet, chiefly in the mountain country. The region is drained by the tributaries of Caliente River, some of which are dry during part of the year. The region is a semidesert at the lower elevations but better watered and forested with pine in the higher parts. The mica deposits outcrop in two or more groups in a roughly north-south direction and are from 8 to 15 miles west of the Denver & Rio Grande narrow-gage tracks between Santa Fe, N. Mex., and Alamosa, Colo. Railroad stations that would serve as shipping points for the different mica deposits are Servilleta and Barranca. Petaca, a small settlement, chiefly of Mexicans, near the larger group of deposits, is about 9 miles by road southwest of Servilleta.

The mica mines examined were the Cribben or Cribbenville mine, about 2 miles southwest of Petaca; the American, about three-fourths of a mile S. 75° W. of Petaca; the Globe, about 5 miles south-southwest of Petaca and 12 miles north of west of Barranca; and the Antonio Joseph, 2 miles north of Ojo Caliente and 14 miles southwest of Barranca. All the mines but that near Ojo Caliente are within the area of the Jemez National Forest. The elevations at several points in the mica region, determined by barometer, are: Petaca, 7,500 feet above sea level; camp at Cribbenville mine, 7,800 feet, highest working, 8,000 feet; American mine, 7,750 feet; Globe mine, 7,650 feet; Joseph mine, 6,900 feet; Ojo Caliente, 6,500 feet.

The mica deposits of New Mexico yield some sheet mica of fairly good quality and merchantable size. As usual with mica mines, a large proportion of the output is scrap mica, suitable only for punching into disks or cutting into small sheets and grinding. At some of the mines the principal value lies in this scrap mica. With several of the better mines in active operation, New Mexico would occupy a prominent place among the mica-producing States. By establishing cutting or trimming plants and grinding mills, either in the mica region or at a convenient point on the railroad, the mining industry would be stimulated by a more convenient market and advantage could be taken of the low-priced labor offered in that section. Mr. Leichtle states that miners get from $1.25 to $1.50 a day of eight hours and blacksmiths

$2. It is probable that much of the trimming and splitting of mica could be done by girls and women, and most of such labor would be supplied by Mexicans.

The description of the Cribbenville mine by Holmes gives a good idea of the extent of the work when the mine was in operation. It is here quoted:

At the Cribben mine, the best known of them all, a considerable amount of work was done between 1884 and 1889, and on a smaller scale since that time. Openings were made on the property at several different locations—(1) the I Excell tunnel, 300 feet long; (2) San Carlos tunnel, 40 feet long, where there are also stopes and drifts under the crest of the hill; (3) an open cut of 100 feet long and a tunnel 40 feet long, near the San Carlos; (4) El Capitan tunnel, shaft, and open cut, some 1,000 or 1,200 feet northwest of Nos. 2 and 3; (5) Columbia tunnel, 40 feet long, with an open cut of 40 feet, in a dike 50 feet thick, located some 200 or 300 yards east of the San Carlos; (6) the Rafugea tunnel, 20 feet long, and open cut, 30 feet long, located some 200 feet east of the last. The larger part of the work at the Cribben mine was done and most of the mica was obtained from the San Carlos and El Capitan openings, and it is in these also that there is the greatest promise of successful future operations. The mica from these openings is all of fairly good quality, generally free from specks, though in places badly ruled.

The several workings described by Holmes are not now readily recognized, as many of them have fallen in badly. The I Excell tunnel is blocked by a cave-in. The San Carlos workings are still open, in part at least, and mica can be obtained by continuing the stopes. The El Capitan workings are nearly all closed. Mr. Leichtle states that the rich deposit of mica encountered in these workings was mined out. A quantity of mica that would yield scrap and small sheet remained around the workings.

The principal work during the last few years has been concentrated on a deposit in a hill about 100 yards southwest of the camp and about 100 feet higher. A tunnel has been started in the hillside toward the "vein" and a shaft 25 feet deep and 12 feet across sunk near the summit of the hill. Massive coarse pegmatite, with feldspar crystals 2 to 3 feet across, was encountered. The principal yield of mica appears to come from a mica-bearing streak about 8 feet across, with a north-south strike and west dip, included in the main mass of the pegmatite. The mica is more plentiful along the sides of this streak, especially in shoots with a pitch to the south. Rough crystals of mica 12 inches across were seen in the shoots and larger ones are reported to have been found. The quality of the mica is fair, and good sheets can be cut from many of the crystals. The thick sheets have a greenish color.

The mine is now owned by the New Mexico Mutual Mining Co., with an office in Milwaukee, Wis. Mr. Leichtle, who owns an interest in the mine, is in charge. But little more than assessment work has been done for several years, and only small shipments of sheet mica have been made during this time. Two or three hundred tons of scrap mica have accumulated on the dumps and in the storehouses. Small sheet mica could be cut from some of the scrap.

Holmes mentions the following other mines:

> Several other claims have been prospected recently near the Cribben, notably that of the Old Judge claim, probably one-half mile to the north.
>
> The Buckshot and Mica Producer claims, some 3 miles south of the Cribben, and the Petaca, Coyote, The Gulch, Bachelder No. 1, Bachelder No. 2, Summit, Keystone, Mica King, Fleming, Bobtail, and Young America, extending north of the Cribben for some 4 or 5 miles, have been opened up for mica to a small but varying extent and some of them are promising prospects. All yield mica of good quality, except that in many places it is badly ruled. The Old Black Horse (Sandoval or Kentucky) mine, some 3 or 4 miles northwest of the Cribben and on the slope of the canyon, is, next to the Cribben, the best-known and most extensively worked mine in the district, and it may be expected to yield in the future considerable quantities of good mica. The Highland mine, on top of a hill above the Sandoval, and the California, a short distance to the east of the Highland, have both yielded considerable quantities of mica of good quality and can be counted on for further developments in this direction.

Whether the names given include any of the deposits described below was not ascertained. It is possible that the names of some of the claims were changed when the claims changed hands.

The American Mica mine, formerly owned by the American Mica Mining Co., is now reported to have become the property of Moritz Leichtle. The mine is on the brow of a hill facing east. It was first opened by irregular stoping from the surface to a depth of 25 feet and for some 40 feet along the vein. Later a tunnel about 200 feet long and 40 feet lower than the outcrop was run into the hillside to the south of the workings and an air shaft raised to the stopes.

The country rock at the mine is fine-grained gneiss, apparently coarser grained near the pegmatite. The pegmatite as exposed in the workings has a north-south strike and a dip of 20° W. The tunnel cuts through more than 30 feet of pegmatite, which, allowance being made for dip, would give a thickness of over 10 feet. In texture the pegmatite varies from moderately coarse rock to some that is very coarse, with feldspar crystals up to 2 feet thick. In the tunnel the mica was found to be more plentiful near the footwall of the pegmatite, but some occurs in the interior of the mass. The crystals of mica range from those of small size up to one measuring 15 inches in diameter. They are irregularly distributed in the vein zone but are fairly numerous. Some mica crystals occur in pockets or bunches and others in streaks in the pegmatite. The greater part of the mica from the upper workings is suitable for grinding only. It is nearly all small and occurs in mashed lenticular pieces up to 2 or 3 inches across. This mica has been partly hydrated and has a soapy feel. It occurs in a vein 3 to 6 feet thick, with a few irregularities, in the pegmatite. It can be obtained easily in large quantities and has been shipped to Denver for grinding.

The Globe Mica mine has been opened by three shafts—35, 30, and 25 feet deep—with drifts from them on the vein. The 30-foot shaft is about 200 feet S. 75° E. of the 35-foot shaft, and the 25-foot shaft is about 50 feet farther away in the same direction. The 35-foot shaft has been equipped with a hoist, an air drill, and two 25-horsepower gasoline engines. From the bottom of the shaft a drift was run 12 feet to the east and another 30 feet to the west. At the end of the west drift a crosscut tunnel has been carried 16 feet to the south. The drifts are 6 to 8 feet wide and about 15 feet high, so that they might be called small stopes.

The country rock is quartz-muscovite schist with a variable northwest strike and a prevailing dip of about 25° SW. The schist has minor folds and crumplings that are visible in the mine workings, as well as larger similar regional structures. The pegmatite cuts the schist with a strike of N. 75° W. and a vertical or high north dip. The thickness of the pegmatite is not exposed but is at least 30 feet near the main workings. From the 35-foot shaft an irregular mica streak from 3 to 8 feet thick was followed in the drifts. This streak lies near the north wall of the pegmatite and has an irregular dip of 85° N. The quartz-muscovite schist wall rock is exposed in places in the drifts. The crosscut tunnel from the end of the west drift follows a branch streak of mica. In parts of the main mica streak the mica crystals are plentiful and form nearly solid masses 2 or 3 feet across. Blocks of mica nearly 2 feet in diameter were seen in the vein, but most of the mica is badly ruled and broken, so that only a small proportion of it would be serviceable for cutting into sheets. The feldspar occurs in large masses and crystals and consists of both pink microcline and white albite. Some of the feldspar masses measure 10 feet across. The pink microcline occurs in the largest crystals. The mica streak is separated from the north wall of the pegmatite by an irregular sheet of massive feldspar. Irregular masses and sheets of quartz occur on the south side of the mica streak in massive feldspar.

In the 30-foot and 25-foot shafts relations similar to those in the main workings were found. A mica streak 2 to 4 feet thick, with a high north dip, occurs in massive feldspar. Quartz segregations, some of them 3 or 4 feet thick, lie along the south side of the mica streak. The mica encountered is of about the same quality as that of the main workings.

A 20-foot shaft has been sunk on a mica vein one-fourth mile north of the Globe, on the Peacock claim. The name chosen for this claim is an allusion to the iridescent tarnish on seams of limonite found in the workings. A mica streak 1½ to 3 feet thick was exposed in the shaft. Nearly all the mica is small, and some of the crystals are bunched together in nearly solid masses.

Two prospects for mica, opened by Antonio Joseph, are in the foothills of the mountains west of Caliente River. One of them is in the walls of a gulch about 1½ miles north of Ojo Caliente and half a mile west of the river. It has been opened by prospects on each side of the gulch. The other prospect, which is the more promising, is about half a mile northwest of this one, in the east end of a ridge between two draws tributary to the same gulch. Here several openings have been made in the hillside on the spur of the ridge and on the south side. The larger opening is a cut 15 feet long, with an 18-foot tunnel from it and a 12-foot shaft at the end of the tunnel.

The country rock of the region is complex and consists of mica, cyanite, quartz, garnet, and hornblende schist and gneiss, with granite, pegmatite, and basalt. The schist and gneiss have been much folded and have received smaller flexures crossing the axes of larger folds. The general strike near the mica deposits is N. 45°–60° E., with a vertical to west dip, but large variations from this attitude occur. Pegmatite is common in the gneiss and schist of this region.

At the best prospect a mass of pegmatite at least 100 feet wide outcrops across the end of the ridge, with a probable northeast strike. This pegmatite has the usual variations of composition and texture, part containing feldspar and quartz, with or without mica, in granular mixtures and part containing segregations of these minerals. The feldspar is of gray and pink to red colors and is chiefly the potassium variety. The mica occurs in pockets and streaks up to 20 feet thick in the pegmatite. The streaks have an approximate northeast strike and are richer in mica in some parts than in others. A large quantity of mica is exposed in the main working. Most of it is in small crystals, but some crystals 12 to 18 inches across and 4 to 12 inches thick were seen. Nearly all were so badly crushed and cut by "ruling" and irregular fractures that only small perfect sheets, not over 2 to 3 inches across, could be obtained from them. The principal values in mica from this deposit would be in material for grinding and small sheets. The mica has a greenish color in sheets one-sixteenth of an inch or more thick and some of it contains magnetite specks. From 50 to 100 tons of scrap and small sheet mica have accumulated on the dumps.

At the other locality a pegmatite mass 8 to 15 feet thick outcrops on each side of the gulch, with a strike of N. 40° E. and a nearly vertical dip. This pegmatite contains streaks of mica gneiss from 1 inch to 2 feet thick. The mica crystals are more plentiful near these inclusions. Only small mica crystals, 1 to 4 inches across, were seen and many of these were crushed and "ruled" into small pieces.

## MICA IN MESA COUNTY, COLO.

A deposit of mica was located some 15 to 18 years ago in Ladder Canyon, Mesa County, 8 miles south of Grand Junction, Colo. The discovery is said to have been made by Benton Cannon, but the prospect is now held by S. A. Grady, of Grand Junction. The locality is at present reached by trail only, though a road was once made up the canyon within half a mile of it. The trail leaves the Grand Junction road and enters the canyon about a mile north of the prospect. This part of Ladder Canyon is from 200 to 300 feet deep.

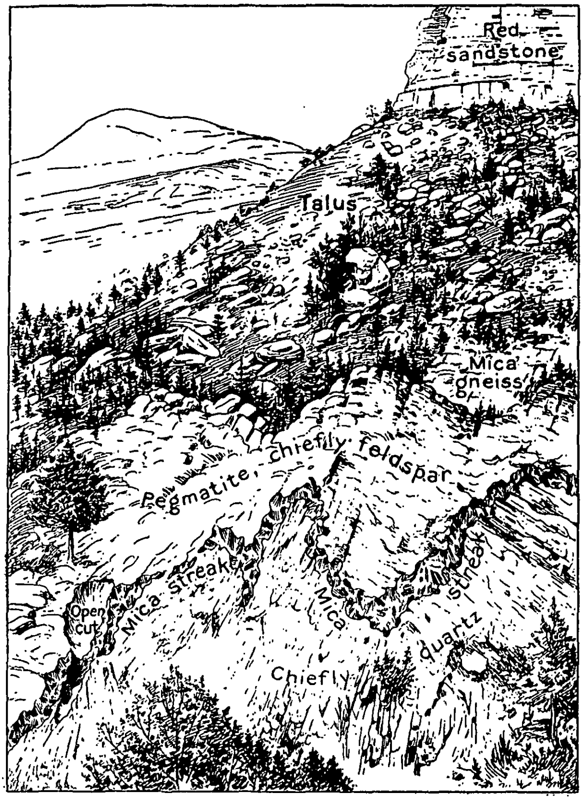



FIGURE 51.—Outcrop of irregular streak of mica between quartz and feldspar, S. A. Grady claim, Mesa County, Colo.

The development consists of a short tunnel about 10 feet long and an open cut about 25 feet long in the side of the canyon. The deposit occurs in a dome of pre-Cambrian rocks exposed in the bottom and lower walls of the canyon. Red sandstone, probably of Carboniferous age, overlies the dome and forms the country rock of the region, even outcropping in the bottom of the canyon one-third of a mile farther north. Near the mica prospect the older rocks outcrop to a height of 100 feet in the canyon walls. They consist of biotite and muscovite schist and gneiss cut by pegmatite. The pegmatite is over 200 feet wide in the bottom of the canyon and is thinner at the top of the exposure. Apparently it is at the top of an anticline whose axis strikes nearly east and west. The main anticline has smaller folds upon it and the pegmatite exhibits these irregularities. The minerals of the pegmatite are segregated in large masses. The feldspar is chiefly the potassium variety and has a pinkish or flesh color. It occurs in an irregular mass or streak over 10 feet thick in the interior of the pegmatite and grades into material containing considerable quartz or with the composition of ordinary pegmatite. A large segregation of massive quartz, the thickness of which is not exposed, lies below the feldspar mass, and more massive quartz overlies it. A few blocks of translucent rose-colored quartz were observed in the bottom of the canyon, but the quartz is too pale for use as gem material. The upper part of the pegmatite outcrop is concealed by talus from the overlying red sandstone.

The mica occurs principally along the contact between the feldspar and quartz masses, where it forms an almost continuous streak across the face of the pegmatite outcrop. (See fig. 51.) The mica streak ranges from 1 to 3 feet in thickness and is composed of nearly solid masses of mica crystals. These range from less than 1 inch to over 1 foot in length and are more commonly arranged in tufts and radiating groups. In places quartz, feldspar, and black tourmaline are associated with the mica. Rosettes of radiated mica crystals cover the south wall of the open cut for a space 12 feet long by 8 feet high. The exposure here gives an impression of a very thick mica streak, but an examination shows that the cut has opened the "vein" along its wall. The full thickness of the streak of mica is not exposed but is probably 3 feet or more. The mica crystals are much "ruled" and broken and nearly all have either the "A," "wedge," or "herring-bone" structure. It is probable that the entire yield of mica from this deposit will be suitable for grinding only, and that little if any mica valuable for cutting into sheets will be obtained. The quantity of scrap mica for grinding that can be mined near the surface is considerable.

# SURVEY PUBLICATIONS ON MISCELLANEOUS NON-METALLIC PRODUCTS—ASBESTOS, BARITE, FELDSPAR, FLUORSPAR, GRAPHITE, MICA, QUARTZ, ETC.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various nonmetallic mineral products. The Government publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BAIN, H. F., Fluorspar deposits of southern Illinois: Bull. 225, 1904, pp. 505–511. 35c.

BALL, S. H., Mica in the Hartville uplift, Wyoming: Bull. 315, 1907, pp. 423–425.

——— Graphite in the Haystack Hills, Laramie County, Wyo.: Bull. 315, 1907, pp. 426–428.

BASTIN, E. S., Feldspar and quartz deposits of southeastern New York: Bull. 315, 1907, pp. 394–399.

——— Economic geology of the feldspar deposits of the United States: Bull. 420, 1910, 85 pp.

——— Geology of the pegmatites and associated rocks of Maine, including feldspar, quartz, mica, and gem deposits: Bull. 445, 1911, 152 pp.

——— Graphite: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1079–1112.

BREWER, W. M., Occurrences of graphite in the South: Seventeenth Ann. Rept., pt. 3, 1896, pp. 1008–1010. $1.

BURCHARD, E. F., Fluorspar and cryolite: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 867–875.

BUTTS, CHARLES, Dolomite for flux in the vicinity of Montevallo, Shelby County, Ala.: Bull. 470, 1911, pp. 525–527.

DARTON, N. H., and BURCHARD, E. F., Fluorspar near Deming, N. Mex.: Bull. 470, 1911, pp. 533–545.

DILLER, J. S., The types, modes of occurrence, and important deposits of asbestos in the United States: Bull. 470, 1911, pp. 505–524.

——— Asbestos: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 995–1001.

——— Talc and soapstone: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1197–1203.

EMMONS, S. F., Fluorspar deposits of southern Illinois: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 31–53.

FULLER, M. L., The occurrence and uses of mica: Stone, vol. 19, 1899, pp. 530–532.

GALE, H. S., Supposed deposits of graphite near Brigham, Utah: Bull. 430, 1910, pp. 639–640.

HAYES, C. W., and PHALEN, W. C., A commercial occurrence of barite near Cartersville, Ga.: Bull. 340, 1908, pp. 458–462.

——— Graphite deposits near Cartersville, Ga.: Bull. 340, 1908, pp. 463–465.

HOLMES, J. A., Mica deposits in the United States: Twentieth Ann. Rept., pt. 6, 1899, pp. 691–707. $1.

KEITH, ARTHUR, Talc deposits of North Carolina: Bull. 213, 1903, pp. 433–438. 25c.

KEMP, J. F., Notes on the occurrence of asbestos in Lamoille and Orleans counties, Vt.: Mineral Resources U. S. for 1900, 1901, pp. 862–866. 70c.

——— Graphite in the eastern Adirondacks: Bull. 225, 1904, pp. 512–514. 35c.

MIDDLETON, JEFFERSON, Feldspar and quartz: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1023–1030.

PHALEN, W. C., Barytes: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 965–970.

SMITH, G. O., Graphite in Maine: Bull. 285, 1906, pp. 480–483. Exhausted. May be seen at many public libraries.

STERRETT, D. B., Mica deposits of western North Carolina: Bull. 315, 1907, pp. 400–422.

——— Meerschaum in New Mexico: Bull. 340, 1908, pp. 466–473.

——— Mica deposits of South Dakota: Bull. 380, 1909, pp. 382–397.

——— Mica: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1129–1135.

——— Mica deposits of North Carolina: Bull. 430, 1910, pp. 593–638.

——— Gems and precious stones: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1037–1078.

STOSE, G. W., Barite in southern Pennsylvania: Bull. 225, 1904, pp. 515–517. 35c.

ULRICH, E. O., and SMITH, W. S. T., Lead, zinc, and fluorspar deposits of western Kentucky: Bull. 213, 1903, pp. 205–213. 25c.

WINCHELL, A. N., Graphite near Dillon, Mont.: Bull. 470, 1911, pp. 528–532.

# INDEX.

O