As the subtitle indicates, most of the papers in these volumes are of three classes—(1) short papers describing as thoroughly as conditions will permit areas or deposits on which no other report is likely to be prepared; (2) brief notes on mining districts or economic deposits whose examination has been merely incidental to other work; and (3) preliminary reports on economic investigations the results of which are to be published later in more detailed form.

Although these papers set forth mainly the practical results of economic investigations they include brief theoretical discussions and summary statements of conclusions if these appear to require prompt publication.

THE CANDELARIA SILVER DISTRICT, NEVADA.

By Adolph Knopf.

OUTLINE OF REPORT.

Candelaria, an old silver-mining camp in western Nevada, has produced $20,000,000, mainly during the seventies and eighties of the last century. The ore worked in those early days averaged $40, $50, or more a ton, but the bonanza ore has long been exhausted, and the attempt now being made to revive the camp is based on the belief that there is left a considerable amount of ore of moderate grade—ore carrying 10 to 15 ounces of silver to the ton—from which a profit may be won by applying modern methods of mining and metallurgy.

The rocks of the district consist of a steeply dipping series of cherts, argillites, and felsites, all very probably of Ordovician age. These rocks have been intruded by peridotite or allied rock (now completely altered to serpentine) and quartz monzonite porphyry at Candelaria itself, and large intrusions of granite appear a few miles from the camp. Resting unconformably on this group of older rocks and showing by its complete lack of any alteration that it is later than the mineralization is a series of Tertiary volcanic rocks, mainly rhyolite lavas and tuffs. Later than both these groups are the series of horizontal basalt flows that form the prominent cappings of the district. These flows were subsequently dislocated by normal faulting, and by this faulting the present relief of the district was determined.

The silver ores are highly oxidized, forming a friable aggregate deeply stained by oxides of manganese and iron. No silver minerals are visible, and the value of the ore can be determined only by assays.

The unoxidized vein filling consists chiefly of a manganiferous ferrodolomite containing pyrite, zinc blende, and jamesonite. On oxidation the jamesonite has yielded bindheimite (the so-called hydrous antimonate of lead); the zinc blende has yielded calamine and possibly other compounds, such as smithsonite; the pyrite has altered to limonite; and the manganiferous ferrodolomite has yielded black oxide of manganese and abundant limonite.

The veins are fairly persistent and dip at high angles. The greatest depth attained on them is 1,365 feet below the outcrop, and at this depth water level has not been reached. The original unoxidized vein filling appears to have been of too low a grade to be workable. The ore was the result of the enrichment of this low-grade material during oxidation.

The veins were formed by the filling and replacement of fissured and shattered zones, and the solutions that deposited the primary vein filling were able to effect notable alterations of the rocks through which they flowed, causing replacement by tourmaline, sericite, and dolomite. The primary or hypogene vein filling was deposited as one of the final consequences of the great intrusions of granite at approximately the end of Jurassic time.

The future prosperity of Candelaria is not to be sought by exploring in depth but must be won from the territory lying above the deepest levels already worked. Modern progress in metallurgy has solved the problem of economically reducing the rebellious silver ore of Candelaria; but the efficient mining of the ore—the discovery and extraction of the ore at a lower cost than was possible in bonanza days—is a matter in which the passage of time has not so unreservedly favored the present generation. To achieve success in reviving Candelaria will especially require engineering and administrative skill of the first order.

GEOGRAPHY.

The Candelaria district is in western central Nevada, not far east of the California-Nevada State line. (See fig. 1.) It lies in an

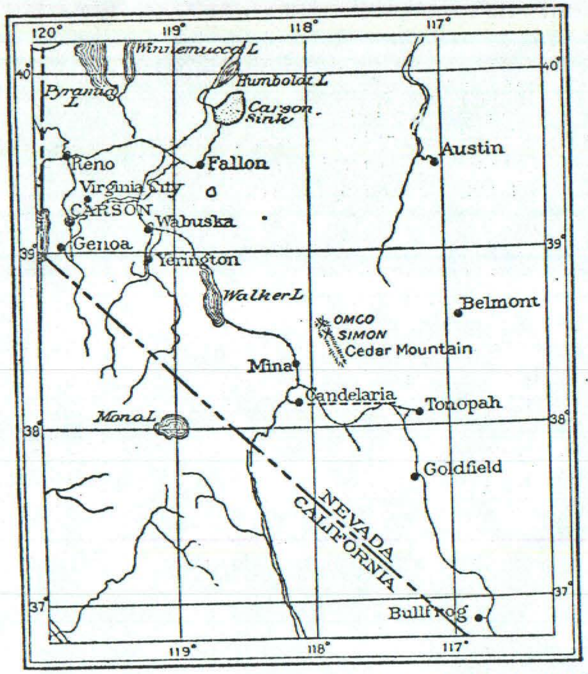

FIGURE 1.—Index map showing the location of the Candelaria district, Nev.

irregular group of mountains to which Spurr[1] gave the name Candelaria Mountains—a particularly dry and barren group extending eastward from the lofty Inyo Range (or White Mountains, as the northern portion of the range is known), to Columbus Marsh. In older reports the district is commonly referred to as Columbus, from the name under which the area was organized as a mining district in 1863, but it is now more generally known as the Candelaria district. It is situated in the southern part of Mineral County, a county that was created from the northern portion of Esmeralda County in 1911.

[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 113, 1903.

The topography of the region in which Candelaria lies is shown on the United States Geological Survey's topographic map of the Hawthorne quadrangle on the scale of 1 to 250,000 (or roughly 4 miles to the inch), but the mineralized portion of the Candelaria district itself is all represented within an area of half a square inch on that map. The altitude at the town of Candelaria is 5,665 feet.

A branch 6 miles long from the Nevada & California Railroad of the Southern Pacific system gives the camp the occasional freight service needed at present, about once a week. Redlich, the nearest station on the main line of the Tonopah & Goldfield Railroad, is only 7 miles distant. The nearest supply point is Mina, 25 miles distant, hardly more than an hour's run by automobile.

HISTORY.[2]

The silver veins in the Candelaria Mountains were dicovered by a company of Spaniards in 1863, and a mining district was organized in the same year. The veins themselves crop out in a particularly barren and inhospitable part of Nevada, and the town that grew up, called Columbus, was situated where water was obtainable, 5 miles southeast of the principal mines, on the western edge of a great alkali flat, the Columbus salt marsh. In 1867 the town had 200 inhabitants, many of whom were doubtless dependent on the salt industry, for in those days the metallurgic plants of Nevada consumed a large quantity of salt; but the work that had been done to prove the silver veins of the district was small. Ross Browne, writing at that time, says that crushings of small lots of ore yielded from $50 to $200 a ton, "a good result considering the quantity of ore of this class that can easily be obtained; so that the prospect is not unfavorable." The remoteness of the district, the complex metallurgic treatment required by the ores, and the fact that the veins were held in numerous small holdings all combined to retard the growth of the new camp. Not until the middle of the seventies did the district come into its own, but then, owing to the successful development of the Northern Belle mine, it became the most productive silver camp in Esmeralda County and one of the foremost in Nevada.

Two 20-stamp mills, erected 8 miles west of the mines at Belleville, where water is available, were put in operation, one in 1873 and a second in 1876. Roasting furnaces were also installed, for the ore was refractory and required preparatory roasting. In April, 1875, the Northern Belle began paying monthly dividends, and for

[2] Based largely on the biennial reports of the State mineralogist of Nevada, published during the decade 1870–1880, and on the annual reports of the Director of the Mint upon the production of precious metals in the United States, 1880 to 1884.

a period of ten years it produced annually a million dollars in bullion.

The success of the Northern Belle mine led inevitably to the growth of a town near the mine, the present Candelaria, which was started in 1876. Prosperity was everywhere apparent at this time. The town grew large enough to support a newspaper, and on June 5, 1880, the Candelaria True Fissure appeared for the first time. In naming his paper thus the editor was regarded as having made a peculiarly happy stroke. The name was intended to convey the thought that the Northern Belle and the other mines of Candelaria were on a true fissure vein, "which was the hope of every camp in Nevada which aspired to rival the Comstock lode."[3]

A water system was completed in 1882, which brings water from the White Mountains through a pipe line 27 miles long. The camp still benefits from this system. In March of the same year the Carson & Colorado Railroad, a narrow-gage line projected in 1880, reached Candelaria by a branch from the main line near Belleville and gave the camp much needed transportation facilities, connecting it with the transcontinental line of the Central Pacific by way of Mound House, near Reno. In later years, after the discovery of Tonopah in 1900, the narrow-gage line was taken over by the Southern Pacific system, changed to a broad-gage line as far as Mina, 25 miles from Candelaria, and renamed the Nevada & California Railroad.

Litigation broke out in 1883. The Holmes Mining Co., whose property adjoined that of the Northern Belle Co., sued that company for trespass and asked for $1,500,000 damages in compensation for ore taken from its ground. The jury gave their verdict in favor of the Holmes Co. and awarded it $360,000 damages. Thereupon the Northern Belle Mining Co. ceased operations and wound up its affairs. The mine at Candelaria and the reduction mills at Belleville were sold by the United States marshal on March 20, 1884, and were purchased by the Holmes Mining Co. The Northern Belle, after having yielded $10,000,000 in bullion and $2,122,500 in dividends, thus went out of existence. The Holmes and the Northern Belle were consolidated as one mine, which has since the consolidation been known as the Argentum.

About this time the Mount Diablo mine became a heavy producer, and in 1883 it began paying its first dividends. The richness of the ores then available is perhaps shown most impressively by the fact that the total cost per ton of ore treated in 1883, including charges for mining, milling, transportation, overhead, taxes, and other expenses, was $44; nevertheless the mine was able to pay dividends

[3] Drury, Wells, Journalism, in History of Nevada, edited by Sam P. Davis, vol. 1, p. 484, 1913.

The ore milled in 1883 yielded $56 a ton in bullion; as mined it must have carried at least $65, or roughly 60 ounces of silver to the ton. In the Callison stope there was a body of ore from 100 to 140 feet long; it was worked for 110 feet on the dip, and in the widest place it contained 12 feet of $200 ore.[4]

The Argentum and Mount Diablo mines were the mainstays of the camp; together they are credited with having produced $19,000,000. As the bonanza ores of the early days became exhausted in the late eighties and early nineties the camp declined and fell into decay. To-day there are hardly a dozen buildings in the town, even though some revival has taken place as a result of new activity.

In 1918 the Candelaria Mines Co. was incorporated. It owns or controls under lease and bond the Argentum, Mount Diablo, Lucky Hill, and other properties, including the water system from the White Mountains. It has carefully sampled the old workings, nearly 10,000 samples having been cut and assayed. Active development has been concentrated on the Lucky Hill mine, and new ore bodies have been found. An extraction plant of 150 tons daily capacity is projected, which, it is estimated, can earn a profit of $216,000 a year, or $4 on each ton treated. It is planned to extend an electric power line from Mina into the district early in 1922.

PRODUCTION.

The district has produced about $20,000,000, chiefly in silver, amounting roughly to 20,000,000 ounces. Estimates ranging as high as $55,000,000 are current, but like those for other old camps they rest upon tradition and err greatly upon the generous side.

The United States Geological Survey has collected detailed statistics since 1903, and for the following summary of production from 1903 to 1920, inclusive, I am indebted to Mr. Victor C. Heikes, of the Survey: Ore, largely tailings re-treated, 148,340 tons; gold, 6,475.13 ounces; silver, 1,021,867 ounces; copper, 50,129 pounds; lead, 653,982 pounds; total value, $977,868.

Since 1913 about 125,000 tons of old tailing at Belleville has been treated by cyanidation. In 1918 the 130-ton tailing mill ceased operations.[5]

ACKNOWLEDGMENTS.

To Mr. E. E. Carpenter, of the Candelaria Mines Co., I am indebted for many courtesies during my examination of the district. In the field work on which this report is based I was assisted by my wife, Eleanora Bliss Knopf, of the United States Geological Survey.

There are no previous accounts of the geology of the Candelaria district and its silver deposits. Within the compass of the small

[4] Director Mint Rept. for 1883, pp. 510-511, 1884.
[5] Heikes, V. C., U. S. Geol. Survey Mineral Resources, 1918, pt. 1, p. 248, 1921.

area of this district is crowded an unusual variety of formations and geologic phenomena of much interest, complex in character but fortunately well exposed. With sufficient time and adequate maps the details could doubtless be deciphered and would prove of direct economic value in the search for more ore in the old mines.

AREAL GEOLOGY.

ORDOVICIAN (?) ROCKS.

GENERAL CHARACTER.

The oldest rocks at Candelaria, which are those that inclose the silver-bearing lodes, show in a rough way a threefold succession. The lowermost rocks are predominantly thin-bedded cherts with interstratified dolomite, the middle portion consists largely of argillite and felsite, and the upper portion of felsite. To distinguish between these exceedingly fine grained rocks—cherts, argillites, and felsites—which commonly resemble one another to the point of absolute identity of appearance, is as a rule extremely difficult.

The lowermost rocks are well exposed on the ridge south of the Lucky Hill mine. They consist of thinly stratified cherts in beds which average 1 inch in thickness but which pinch and swell. Black chert predominates, but brown and light-colored varieties also occur. At the top of the section that consists dominantly of cherts is a 25-foot bed of graywacke which is made up of small angular and subangular fragments of chert and perfectly rounded grains of quartz. It strikes east and dips 60° N., and as it conforms in strike and dip to the underlying cherts and the overlying argillites, it does not appear to mark an erosion interval. The cherts aggregate at least several hundred feet in thickness, but the base on which they rest was not found, so that the full thickness is unknown.

The argillites in the middle portion of the section are thin-bedded nonfissile indurated rocks of argillaceous composition. Cherts and fine-grained banded calcareous sandstones are associated with them. They are all difficult rocks to distinguish with the unaided eye.

The felsites are nonporphyritic aphanitic rocks resembling cherts, from which they differ, however, in forming thicker, more massive bodies. Some felsite on the ridge east of the Diablo mine resembling a white chert shows, when carefully examined, a faint flow banding and a few exceedingly inconspicuous phenocrysts of feldspar. This felsite is one of the few that give some megascopic evidence of their igneous origin. Some of the intercalated masses of felsite are of notable thickness—for example, that at the Lucky Hill mine is 50 feet thick. Most of the felsites appear to represent ancient flows of highly glassy lava, long since devitrified. Doubtless some sills and dikes that were injected contemporaneously with the eruption of the lavas occur in the district, but most of the recognized dikes appear to have been injected during the period of plutonic igneous activity that affected the region near or soon after the end of Jurassic time.

AGE.

No fossils were found other than a few obscure radiolaria seen in the chert under the microscope, so that the age of the chief rocks at Candelaria is not directly determinable. However, the same intimate association of chert and felsite occurs at Silver Peak, 35 miles in an air line southeast of Candelaria, where Turner[6] found dark cherts interbedded with "very numerous streaks of light-colored felsite rocks," which the microscope showed to be altered rhyolitic or dacitic tuffs and lavas. In the slate layers associated with dark thin-bedded cherts graptolites were found, which proved that the rocks are of lower Ordovician (Normanskill) age. This peculiar association of thin-bedded chert and felsite is unknown elsewhere in Nevada in rocks of any other age, and it therefore suggests strongly that the series at Candelaria is Ordovician.

According to Spurr,[7] "on the road between Columbus and Candelaria there occur dark-gray, nearly black quartzites and stretched conglomerates, with some coarse sandstones and nearly white fine-grained chert." Fossils collected by H. W. Turner at a locality 3 miles northwest of Columbus on the trail to Candelaria, at an elevation of 4,900 feet, show that these rocks are of Carboniferous age. What relation the probably Ordovician rocks at Candelaria sustain to these Carboniferous rocks remains unknown.

JURASSIC (?) ROCKS.

Igneous rocks cut the cherts, argillites, and felsites. Their general relations suggest that they were intruded at or near the end of Jurassic time.

SERPENTINE.

Serpentine is the prevaling rock in Pickhandle Gulch, and it has been cut underground in numerous places in the Argentum mine. It is generally a dark olive-green fine-grained rock mottled with yellowish patches of waxy luster, but, as is common in most masses of serpentine, many other facies occur. Dikes of serpentine cut the argillites, so that the intrusive origin of the parent igneous rock is firmly established. The variety of peridotite or pyroxenite repre-

[6] Turner, H. W., A sketch of the historical geology of Esmeralda County, Nev.: Am. Geologist, vol. 29, p. 266, 1902.

[7] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 113, 1903.

sented by the parent rock could not be determined, however, as the alteration to serpentine has been so thorough as to obliterate all clues.

QUARTZ MONZONITE PORPHYRY.

Quartz monzonite porphyry is abundant as dikes throughout the district, and a considerable body of this rock, the largest in the district, occurs near the shaft house of the Mount Diablo mine. Generally the porphyry is highly sericitized or sericitized and tourmalinized, and in such thoroughly altered rocks the phenocrysts of quartz are the only constituents that have remained intact. The least-altered porphyry occurs on the ridge east of the Mount Diablo mine. It contains numerous porphyritic crystals of feldspar and biotite and a few of quartz. Under the microscope the feldspars are seen to comprise both orthoclase and plagioclase, which are set in a microgranular groundmass, and the rock is therefore a quartz monzonite porphyry.

TERTIARY ROCKS.

THE TWO GROUPS.

The Tertiary rocks are almost all volcanic. They are mainly rhyolites and aggregate 750 feet in thickness. They fall naturally into two groups—an older group consisting chiefly of rhyolite overlain by hypersthene basalt, which is tilted and faulted, and a younger group consisting of the olivine basalt that forms the prominent black cappings of the district, which lies horizontal but is displaced by faults. The faults that have dislocated the older group no longer have topographic expression, whereas those cutting the olivine basalt determine the relief of the district. A columnar section of the Tertiary rocks is shown in figure 2.

The Tertiary rocks are fresh and unmineralized and are clearly younger than the silver veins of the district.

OLDER GROUP.

GENERAL FEATURES.

The older group of the Tertiary rocks consists chiefly of light-colored siliceous tuffs and lava—rhyolite and the closely allied species dacite. They make up a conformable sequence, 645 feet thick, dipping 20° NW. Noteworthy is the occurrence of a coarse conglomerate, probably of fluvial origin, 200 feet above the base of the series. The topmost member of the series is a hypersthene basalt.

These rocks rest with conspicuous unconformity on the cherts and other older rocks, but more generally, as exposed at the surface, they have been brought into contact with the older rocks by faults of large displacement. As to their age not much more can be said than

that they are Tertiary. However, a considerable interval of time separates them from the youngest eruptions in the district, the olivine basalt flows, which are supposedly of late Pliocene age.

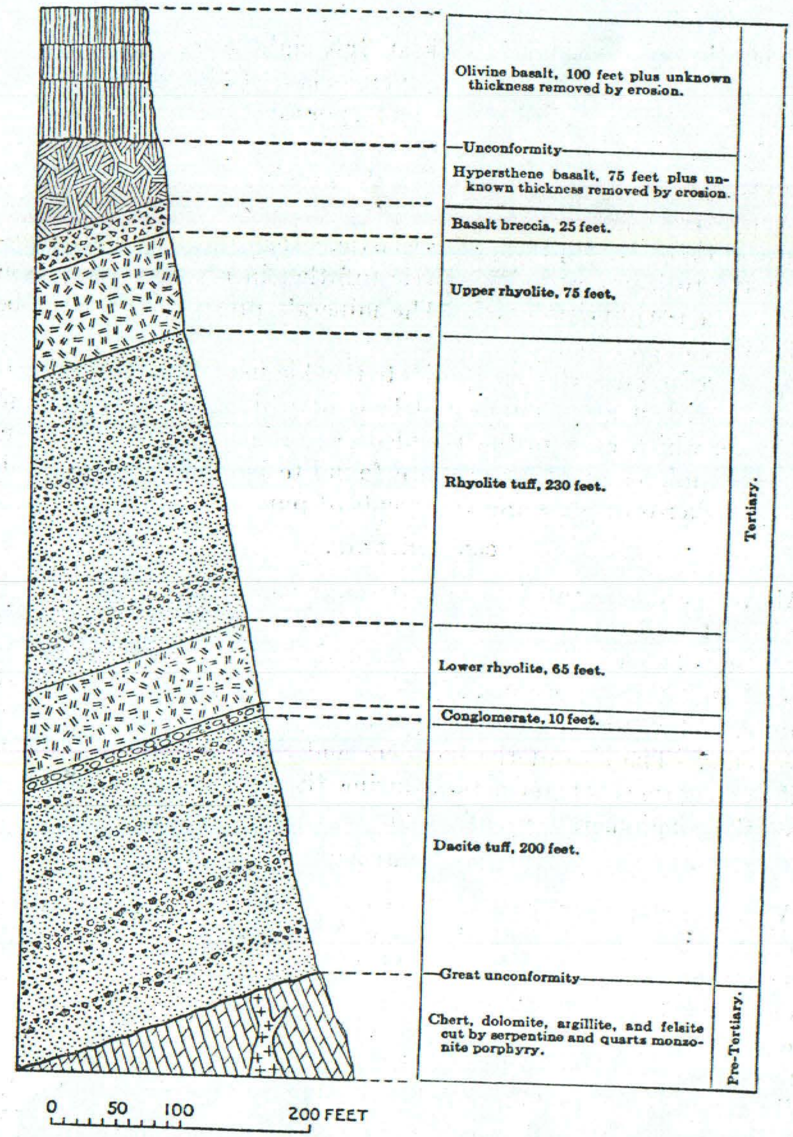

FIGURE 2.—Columnar section of the Tertiary rocks of the Candelaria district, Nev.

DACITE TUFF.

The base of the local Tertiary section consists of dacite tuff, occurring in the ridges south and southwest of the Lucky Hill mine.

It rests upon the upturned edges of the cherts, dips 20°, and is 200 feet thick. It is a light-colored fresh rock, which in the field would be called a biotite vitrophyre, as it carries innumerable hexagonal plates of biotite embedded in a glassy matrix. Angular inclusions of chert or felsite are fairly common in it.

Under the microscope the rock at first sight seems to be a porphyry carrying phenocrysts of plagioclase ($Ab_{55}An_{45}$), quartz, biotite, deep-brown hornblende, and sporadic augite in a glassy groundmass. The feldspar phenocrysts are generally broken and angular. But on closer examination the seeming groundmass, which is ideally fresh, proves to be composed of sherds of glass, and the texture is therefore typically vitroclastic. Instead of being a vitrophyre, the rock proves to be a vitric tuff that in remarkable fashion simulates a porphyritic glass. The minerals present show it to be of dacitic composition.

The preceding description applies to the dominant member. Interstratified with it are a number of beds of white tuff nearly devoid of biotite, which even to the unaided eye are of pyroclastic origin. Under the microscope they also are found to be composed predominantly of sherds of glass and fragments of pumice.

CONGLOMERATE.

Above the dacite tuff is a bed of conglomerate 10 feet thick. It consists of well-rounded cobbles and boulders as much as 4 feet in diameter. The rock is poorly cemented, having hardly advanced beyond the stage of gravel. The material in it consists of chert, granite, and a dark highly porphyritic rhyolite crowded with chert fragments. The size of the boulders and their thorough rounding indicate vigorous stream action during that part of Tertiary time when the conglomerate was formed.

LOWER RHYOLITE.

A pale cream-colored rhyolite 65 feet thick overlies the conglomerate. It is particularly well exemplified northeast of the Diablo mine, where it caps the ridge. The base of the rhyolite flow has been frozen to a dark glass about 20 feet thick. The normal rhyolite above the glassy lower portion of the flow carries numerous small phenocrysts of quartz and sanidine, but dark minerals are practically absent, sporadic biotite flakes being found only with difficulty. The pale cream-colored groundmass of the rhyolite has a lithoidal appearance, which is due to partial devitrification and the prevalence of spherulitic growths.

RHYOLITE TUFF.

Above the pale cream-colored rhyolite are white and gray rhyolite tuffs, aggregating 230 feet in thickness. They are especially characterized by the large number of quartz crystals they contain and by the white pumice fragments scattered through them, some as much as 2 inches in diameter.

UPPER RHYOLITE.

A flow of rhyolite, whose basal portion has been chilled to a dark porphyritic glass 5 feet thick, overlies the rhyolite tuffs. The aggregate thickness of the flow is 40 feet. The rock has a distinctive hackly fracture and on freshly broken surfaces is of pale rose-gray color. Phenocrysts of sanidine and quartz are common, but those of biotite are sporadic. The microscope shows in addition that the numerous small gas cavities in the rhyolite are lined or partly filled with tridymite. In general this flow of rhyolite lava resembles closely the rhyolite lava that lies immediately below the rhyolite tuffs.

HYPERSTHENE BASALT.

A flow of hypersthene basalt underlain by a bed of basaltic tuff 25 feet thick rests conformably on the upper rhyolite and forms the topmost member of the older group of the Tertiary rocks. The tuff incloses angular fragments of basalt as much as 2 inches in diameter and blocks of rhyolite pumice as much as 2 feet in diameter. The basalt flow is now 75 feet thick, but an unknown amount has been removed by erosion. The basalt is a compact aphanitic black rock with inconspicuous phenocrysts of pyroxene and plagioclase. Under the microscope the pyroxene proves to consist of both hypersthene and augite and the plagioclase phenocrysts are found to be bytownite ($Ab_{22}An_{78}$). The groundmass is hyalopilitic, consisting of microlites of plagioclase, minute prisms of pyroxene (probably hypersthene), and magnetite embedded in glass. A little secondary calcite occurs throughout the rock.

YOUNGER GROUP.

OLIVINE BASALT.

General features.—Olivine basalt is the youngest rock of the district and caps many of the summits in the vicinity of Candelaria. It forms a series of thin horizontal flows whose aggregate thickness nowhere exceeds 100 feet. In many places the basalt is extremely and coarsely vesicular.

It is a dark rock, nearly black. Olivine in small grains is the only constituent recognizable by the unaided eye. Under the microscope the basalt is seen to be holocrystalline, and in addition to the olivine already mentioned there appear labradorite ($Ab_{40}An_{60}$), augite, and magnetite. The augite is in grains, which together with the magnetite are crowded into the angular interspaces between the feldspar prisms, giving rise to the fabric termed intergranular. In mineral composition and in texture this basalt differs widely from the older basalt.

Faulting.—The basalt has been displaced by normal faults, but it still retains a horizontal attitude. The effect of the faulting is thus to produce a steplike topography in which the tread of each step is capped by basalt. The largest displacement is that which has produced the escarpment of the north flank of Candelaria Mountain. The basalt capping of this mountain has been faulted down through a vertical distance of 400 feet. Some of the workings of the Argentum mine penetrate the country rock below the dropped block and reveal the actual fault surface on which the movement took place. The fault thus exposed is found to strike N. 70° W. and dip 50° N. Resting on the fault surface is 18 to 24 inches of brecciated basalt, above which is the normal fresh, highly vesicular basalt. The older rock below the fault surface has assumed a roughly schistose structure, parallel to the fault surface, over a width of 1½ feet. The mine workings amply confirm the physiographic evidence of faulting and in addition show how steep the fault scarp must originally have been—about 50°.

Age.—The olivine basalt is much younger than the hypersthene basalt, as is proved by the fact that an unconformity marking a considerable erosion interval separates the two rocks. At some time after the eruption of the hypersthene basalt the older group of the Tertiary was greatly faulted and moderately tilted, so that the general dip of the beds is now 20°. The older rocks were then eroded sufficiently so that in places the olivine basalt rests in horizontal sheets directly on the lower rhyolites. Since then the olivine basalt has been vigorously faulted, though without disturbance of its horizontal attitude. The present relief of the Candelaria Mountains is due to this faulting, and the canyons, such as Pickhandle Canyon, have been eroded since it occurred. On the assumption that this faulting, which initiated the present cycle of erosion, marks the beginning of Quaternary time, the olivine basalt flows are regarded as of late Pliocene age.

SILVER VEINS.

GENERAL FEATURES.

The ore deposits are highly oxidized manganiferous silver veins. The principal veins are inclosed in felsite and argillite and lie between well-defined walls. They generally conform to the strike of the rocks but may cut across them on the dip, as they stand less steeply than the inclosing rocks. That the felsite is a somewhat more favorable rock for ore than the argillite is suggested in places. Most of the productive territory in the Argentum vein system, for example, is in felsite, and at many places the vein can be seen to pinch out or fray out into small stringers, where it passes from felsite into argillite; though opposing this evidence is the fact that the wide glory hole on the vein, on the summit of Candelaria Mountain, is in argillite, where, however, the vein strikes at right angles to the strata.

The veins are several hundred feet in length and are relatively narrow, averaging not more than a few feet in width. The Potosi vein, which was stoped continuously for 600 feet or more, averages about 2 feet in width. The shoot of ore recently developed in the Baldwin vein of the Lucky Hill mine, however, is in places as much as 20 feet thick. In some of the vein systems, such as those of the Argentum and Mount Diablo mines, the fissuring was complex and gave rise to a zone, in places as much as 100 feet wide, within which ore shoots were distributed en échelon. As many as three shoots may thus occur lying parallel to one another and partly overlapping. They are separated by firm, solid rock, which would not invite exploration by those unacquainted with this peculiarity of the district. The former operators had grasped the principle of successful exploration for these ore bodies, and those who have become most familiar with the old workings have perforce become most appreciative of the skill of the "old timers."

CHARACTER AND COMPOSITION OF THE ORES.

The ores are thoroughly oxidized. They consist of easily pulverulent material, which is colored black where manganese oxide predominates, yellowish red where limonite predominates, and brownish where these compounds are more evenly distributed. Recognizable minerals are rare. The manganese occurs as the soft earthy black dioxide, the mineral wad; the iron occurs as limonite; and a content of zinc is made apparent in places by the occurrence of calamine, the hydrous silicate of zinc, in glassy crystals. The silver is present in an unrecognizable form, and the only way in which the value of the ore can be determined is by assay. The silver is often said to be present as the chloride, but the fact that the rich ore of early days required chloridizing roasting proves that much of the silver was not in the form of chloride. Tests on ore now being developed in the Lucky Hill mine failed to show any silver chloride.

Ore from Potosi Mountain, which is more quartzose than that typical of the Argentum, Mount Diablo, and Lucky Hill mines, carries considerable bindheimite, the so-called hydrous antimonate of lead, which is of a deep brownish-yellow color and pitchy luster. An assay of some of this bindheimite-bearing ore shows that it carries 21 per cent of lead and 25 ounces of silver to the ton, proving that the bindheimite is notably argentiferous. That the typical manganiferous silver ore of the district carries bindheimite is highly probable, for the unoxidized ore carries jamesonite, and this mineral on oxidation generally yields bindheimite. This bindheimite, however, is masked by the prevalence of the deeply colored oxides of iron and manganese.

The chemical composition of the ores is well shown by the following analyses:

Chemical composition of the ores of the Candelaria district, Nev.

[J. A. Carpenter, analyst.]

	1	2	3
Fe_2O_3	13.1	12.9	12.1
CaO	9.6	10.8	4.0
MgO	2.6	4.8	0.7
Zn	4.6	8.3	2.3
Mn	1.7	3.5	2.0
H_2O	1.0	....	1.0
S	Trace.	....	0.2
Insoluble (mostly SiO_2)	48.4	4.8	70.4

1. Representative of the milling ore of Argentum mine.
2. Control samples of 12 carloads of Lucky Hill ore shipped to Western Ore Purchasing Co.
3. Average milling ore of Mount Diablo mine.

The thoroughly oxidized ores do not extend quite down to the greatest depth attained in the old workings, 1,353 feet vertically below the outcrop. Water level has not been reached at that considerable depth; evidently oxidation has not been able to keep pace with the rate at which the water level sank during the progressive increase in aridity of the region in late Quaternary time.

Sulphides are uncommon. Jamesonite and pyrite occur in the Baldwin vein, though in hardly more than traces. The jamesonite forms small lead-gray aggregates of minute closely felted fibers, and the pyrite occurs as small cubes. Pyrite, resinous zinc blende, and microscopic needles of sulphide, probably jamesonite, occur in vein material from the seventeenth level of the Argentum mine. A narrow vein in serpentine in Pickhandle Gulch contains zinc blende, pyrite, chalcopyrite, galena, and arsenopyrite. The gangue in which these sulphides were inclosed is a white carbonate showing characteristically curved cleavage surfaces. On chemical examination it proves to contain calcium, magnesium, iron, and manganese and is therefore a manganiferous ferrodolomite. On oxidation it yields the limonite and wad that are so prominent in the oxidized ores of the district. The pyrite also oxidizes to limonite, and the zinc blende is evidently the source of the zinc in the calamine. The unexpectedly high content of zinc shown by the chemical analyses suggests that part of it may be present as carbonate.

The ores worked in early days averaged 60 ounces or more of silver to the ton. The gold content was practically negligible and never

exceeded 0.05 ounce to the ton. By 1891, near the end of the period of the camp's great productivity, the grade of ore had declined to 30 ounces of silver to the ton. The ore now available ranges from 10 to 15 ounces of silver and 0.01 to 0.02 ounce of gold to the ton. The history of the district, confirmed and enforced by the evidence of the extensive deep workings, shows that the grade and the quantity of ore diminished greatly in depth. It is probable that this diminution was due to a combination of two causes—to a decrease in the original grade of the hypogene ore in depth and to a decrease in the amount by which this hypogene ore was enriched during oxidation. In view of the fact that oxidation was unable to keep pace with the lowering of the water during recent geologic time, it would be useless to prospect for a zone of enriched sulphides at water level.

WALL-ROCK ALTERATION BY THE ORE-DEPOSITING SOLUTIONS.

The solutions that deposited the hypogene ores were able to alter the adjacent wall rocks profoundly. The development of tourmaline is the most noteworthy alteration. The quartz porphyry adjacent to the vein on Mount Potosi is megascopically filled with small radial groups of tourmaline to a distance of 15 or 20 feet from the vein. Under the microscope it can be seen that in addition to the development of tourmaline the feldspar phenocrysts have been altered to compact aggregates of sericite.

The hanging-wall rock of the main vein of the Lucky Hill mine, although resembling to the eye the normal felsite country rock, proves under the microscope to have been completely replaced by exceedingly fine grained dolomite. The gangue of the Baldwin vein of the same mine consists of a breccia of angular fragments of country rock (chert and felsite) cemented by coarsely granular manganiferous ferrodolomite. Although the breccia fragments are clearly outlined against the white carbonate, under the microscope they are found to be largely replaced by dolomite. Tourmaline is an extremely rare accessory constituent in this ore. In the felsite country rock at some distance from the veins tourmaline is common, however, and the microscope reveals the fact that the introduction of this tourmaline, an alkali variety as shown by its deep-blue pleochroism, was accompanied by the development of much sericite and quartz. It is a curious fact that although tourmaline is so abundant in the vicinity of the Lucky Hill mine, the immediate rock of the veins, as already pointed out, was converted into a dolomitic rock in which tourmaline occurs only as a very minor constituent.

The extent of the country-rock alteration and the nature of the new minerals produced indicate that the ore-depositing solutions were active at high temperature. The extensive tourmalinization suggests that these solutions were one of the effects of granite intrusions, for the development of tourmaline is almost invariably connected with the activity of granite magma. Although granitic rocks do not occur in the immediate vicinity of the Candelaria mines, quartz monzonite porphyry is common. Its occurrence testifies to the presence of related plutonic rocks at greater depths, and granitic rocks in fact appear in great volume at the surface a few miles west of the district. The intrusion of these granitic rocks, according to the best evidence available, was essentially contemporaneous with that of the quartz monzonites and granites of the Sierra Nevada, namely, near or soon after the end of the Jurassic period, and it was at this time, therefore, that the hypogene ores of the Candelaria district were formed. Later they became highly oxidized and enriched.

COMPARISON WITH OTHER NEVADA SILVER DEPOSITS.

The Candelaria silver deposits, linked in origin as they are with the late Jurassic or early Cretaceous intrusions of granite, differ notably from those of Tonopah and Comstock, which are of Tertiary age. In harmony with this difference in age and origin is the fact that the Candelaria silver ores were formed under conditions of higher temperature than the Tertiary veins, as indicated by their content of tourmaline. Their tourmaliniferous character, indeed, immediately sets them apart from almost all other Nevada silver deposits. The closest analogues are in the Rochester district, in the Humboldt Range, where the veins carry a tourmaliniferous siliceous silver ore and are associated with a granitic intrusion of post-Triassic, probably late Jurassic age. The Rochester ore is highly siliceous and not manganiferous, like that of Candelaria. It is of commercial grade only where enriched by supergene argentite. Some jamesonite has been found in the district.[8]

In the same range and probably formed during the same metallogenetic epoch as the Rochester deposits is the Sheba vein, which consisted of white quartz carrying argentiferous jamesonite, galena, sphalerite, pyrite, and tetrahedrite.[9] Some of the jamesonite, selected with great care and to all appearances perfectly homogeneous, was found to contain 6.14 per cent of silver.[10]

The Candelaria silver lodes resemble to some extent the deposits of the Arabia district, where the primary sulphide was jamesonite, now almost completely altered to bindheimite. The ores of the

[8] Knopf, Adolph, Ore deposits of the Rochester district, Nev.: U. S. Geol. Survey Bull. —— (in preparation).

[9] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 43, 1909.

[10] Burton, B. S., Contributions to mineralogy: Am. Jour. Sci., 2d ser., vol. 45, pp. 36–38, 1868.

Arabia district are only feebly tourmaliniferous. They also are genetically associated with an intrusive mass of granodiorite of approximately late Jurassic age. On account of the large quantity of bindheimite in the deposits the ore is valuable not only for silver but for lead and antimony and is thus a heavy base ore.[11]

In summary, the Candelaria silver ores were formed during the late Mesozoic metallogenetic epoch which followed the intrusion of the granites at approximately the end of Jurassic time. The silver deposits formed during that epoch in Nevada are most commonly replacement deposits of argentiferous galena in limestone or quartzite.[12] Between the replacement deposits there are transitions to quartz veins carrying silver and lead. The Candelaria ores are practically straight silver ores—that is, valuable for their content of silver only—and although others of the same age and general character are known to occur in Nevada, the tourmaline content of the Candelaria ores, coupled with their manganiferous ferrodolomite gangue, sets them apart from all others.

The commoner and better-known silver deposits of the Tertiary epochs of metallization are invariably precious-metal deposits, contrasting as a group by their absence of heavy argentiferous lead ores with the group of late Mesozoic age. If the comparison is pursued further, the somewhat unexpected conclusion becomes apparent that the Tertiary silver deposits have extended farther in depth and have yielded more silver than the veins of greater age. The explanation of this difference appears to be in part that the older veins, because of the great erosion to which the Nevada region has been continuously subjected since late Jurassic time, are but the roots of the deposits.

MINES.

ARGENTUM MINE.

The Argentum mine is just south of the town of Candelaria, and its numerous workings and dumps stare at one from the steep slope of Candelaria Mountain facing the town. The mine is a consolidation of the Northern Belle and the adjoining Holmes mine, effected in 1884 through the purchase of the Northern Belle by the Holmes Mining Co. at a marshal's sale. It has been the most productive mine in the district, having produced between 1875 and 1893, so it is said, 300,000 tons of $50 silver ore, or about $15,000,000.

The Northern Belle was the first mine developed in the district and was the most productive. The vein was originally located in

[11] Knopf, Adolph, The antimonial silver-lead veins of the Arabia district, Nev.: U. S. Geol. Survey Bull. 660, pp. 249–255, 1918.

[12] Lindgren, Waldemar, in Hill, J. M., Mining districts of the western United States: U. S. Geol. Survey Bull. 507, p. 31, 1912.

1864, but it was abandoned and not relocated until July 1, 1870. The ore was reported to run without sorting $187 a ton.[13] In 1873, adequate capital having been obtained, development was pushed in earnest. By 1875 the Northern Belle Mining Co., which never needed to levy an assessment, had already disbursed $400,000 in dividends. In that year the mine produced 6,982 tons of ore, valued at $544,102, or $77 a ton.[14]

It will be seen that the ore worked in those early days was exceedingly rich. During the census year ending May 31, 1880, there was raised 23,975 tons of ore carrying $1 in gold and $57.83 in silver to the ton. The average yield of bullion from this ore was $49.53 a ton,[15] from which it may be computed that the extraction was 86 per cent. In 1883, the last year of operation of the Northern Belle, 19,574 tons of ore was mined, which yielded $38 a ton.[16]

During its life the Northern Belle produced $10,000,000 and disbursed $2,122,500 in dividends.[17] Its workings had attained a vertical depth of 800 feet, and the grade of ore had declined from $77 to $38 a ton (from 62 ounces to 34 ounces of recoverable silver to the ton).

Although the history of the Northern Belle can thus be reliably determined with some fullness, similar published information concerning its successor, the Holmes or Argentum mine, does not appear to exist for the years after 1884. This lack is somewhat inexplicable, as sworn returns of the yield were required because of the bullion tax imposed by the State of Nevada. The annual output of the Mount Diablo can be followed from year to year in the reports of the Director of the Mint on the production of precious metals, but no output is credited to the Holmes mine until 1891, when it is said to have produced 8,927 tons of ore, yielding $242,022, at a total cost of $235,328.[18]

The underground workings of the Argentum mine are very extensive. The deepest level, the nineteenth, is 1,353 feet vertically below the outcrop of the vein on the summit of Candelaria Mountain, at an altitude of 6,450 feet. Even at this great depth water level was not reached.

The country rock consists of argillite and felsite intruded by serpentine. The wide glory hole on the vein on the summit of the mountains is in argillite. The vein here strikes north at right angles to the strike of the strata and dips east. Some quartz monzonite porphyry, much sericitized, occurs near the vein here, but most of the productive territory of the Argentum vein system is in felsite. The vein system is somewhat complex, and in places as many as three parallel ore shoots were worked. The ore is the highly oxidized manganiferous and ferriferous material common in the district. In depth, however, the vein material becomes less oxidized, and concomitantly the stopes become fewer and fewer. On the seventeenth level drifts on an unoxidized vein in argillite have been run for a long distance and show well the nature of the primary vein filling—curved white carbonate (a ferriferous dolomite) carrying a small amount of pyrite, resinous zinc blende, and minute needles of sulphide, doubtless jamesonite. But this material is not ore. The argillite adjacent to this vein has been rendered black and shiny (graphitic) by shearing.

[13] Nevada State Mineralogist Fourth Bienn. Rept., p. 36, 1873.
[14] Raymond, R. W., Mineral resources of the States and Territories west of the Rocky Mountains for 1875, p. 134, 1877.
[15] Tenth Census, vol. 13, p. 308, 1885.
[16] Director Mint Rept. for 1883, pp. 508–511, 1884.
[17] It is commonly stated that $5,000,000 was paid in dividends, but that is an error. The amount given in the text was obtained by summing up the amounts paid annually, as reported by contemporary authorities.
[18] Director Mint Rept. for 1891, pp. 204–205, 1892.

The Argentum mine is now controlled by the Candelaria Mines Co. Some 5,000 samples have been taken to determine the amount of ore left in the old workings. According to the company, the reserves, including ore in place, fills, and dumps, amount to 381,000 tons, carrying 14 ounces of silver to the ton.

MOUNT DIABLO MINE.

The Mount Diablo mine, next to the Argentum, has been the most productive in the district. It is half a mile from Candelaria, at the head of Pickhandle Gulch. Its immense dump is one of the prominent features of the district.

In 1873 the mine produced 819 tons of ore, from which $63,240 in bullion was extracted. If 10 per cent is allowed for loss during extraction—a moderate allowance—it is found that the ore carried at least 66 ounces of silver to the ton and that the content of gold was almost negligible. During the succeeding decade the output remained small, as the mine had no mill, and the reduction charges of the Northern Belle Co., which owned the mills at Belleville, were regarded as excessive. In 1883, however, 7,848 tons was milled at Belleville, from which $441,518 in bullion was produced. Four dividends were paid, amounting to $50,000.[19] During the next decade the mine continued to produce at the rate of 8,000 tons a year. The last record of this early period is for 1891,[20] when 7,715 tons of ore was produced, from which a gross yield of $186,833 was obtained at a total cost of $173,607. The grade of the ore had fallen one-half, and though the costs had been cut one-half the margin of profit had become small.

[19] Director Mint Rept. for 1883, pp. 510–511, 1884.
[20] Idem for 1891, p. 204, 1892.

The Mount Diablo mine was developed chiefly by a vertical shaft 104 feet deep, whose collar is at an altitude of 6,224 feet, and by an incline dipping 48° N. from the bottom of the vertical shaft. The old workings are very extensive and are in good condition; but I did no more than hastily examine part of them during this reconnaissance. The engineers of the Candelaria Mines Co. have carefully sampled the mine, taking in all 4,500 samples, which have conclusively established that there is no high-grade ore in sight and that the ore left is of very moderate grade.

The country rock consists of argillite interlayered with at least two belts of felsite and cut by dikes of diorite and of quartz monzonite porphyry. At the shaft house the quartz monzonite porphyry is particularly abundant, and on the ridge 400 feet east of the shaft is a dike of the porphyry which is the best preserved (least sericitized and tourmalinized) of its kind in the district.

The ore is the oxidized manganiferous, limonitic, siliceous material typical of the district; it is, however, somewhat more siliceous than the average.

The ore bodies occur as narrow lenses lying en échelon, in places three parallel to one another, in a zone roughly 100 feet wide. The former operators were admirably skillful in finding the large number of scattered pods of ore, and by driving numerous crosscuts in both foot and hanging walls they left unexplored little of the ground within which they worked.

LUCKY HILL MINE.

The Lucky Hill mine is on the second ridge south of Candelaria, a few hundred yards west of the Mount Diablo mine. It is one of the old mines of the district, but not much work had been done on it prior to 1920. According to Mr. E. E. Carpenter, general superintendent of the Candelaria Mines Co., it has produced $250,000. During 1920 all the development work done by the Candelaria Mines Co. was concentrated on this mine.

Two veins occur—the main vein and the Baldwin vein. Both were being actively explored and developed in 1920. The principal opening is an adit 425 feet long, which cuts the main vein at a depth of 180 feet 350 feet from the portal and the Baldwin vein at a depth of 50 feet 110 feet from the portal. The Baldwin vein is further developed by the Baldwin shaft, which slopes 72° N. and attains a vertical depth of 270 feet. From it two levels have been turned off approximately 100 and 200 feet below the adit level. A long crosscut was driven on the bottom level, but it failed to intersect either the Baldwin or the main vein, and this unexpected fact, together with the geology, shows that complex faulting has displaced the veins between the first and second levels. The data to determine

the structural effect of these faults have not yet been obtained, and some of the drifts in which evidence on this vital problem might be obtained have been filled with waste.

The country rock consists of coal-black chert, felsite, and argillite. These beds strike N. 85° E. and dip 70° N. On the surface the cherts appear just south of the main vein; underground they are shown in the end of the main adit and are excellently exposed in the last 200 feet of the south crosscut on the bottom level. The felsite forms the north slope of Lucky Hill; it makes blocky, massive outcrops, in contrast to those of the chert, which are thin bedded, and it weathers to a distinctive dark-brown color. The argillite extends from the lower level up the Baldwin shaft to a point within 20 feet of the first level.

Both veins are in felsite, which forms a homogeneous belt 500 feet or more thick, though containing a minor amount of intercalated chert. Silicified tourmalinized felsite is abundant on the hillside northwest of the Baldwin shaft. A body of quartz monzonite porphyry occurs here also, being best exposed at the powder house, and in places it has been intensely tourmalinized.

The main and Baldwin veins are essentially alike in general features. Both strike roughly east and dip 65°–70° N. The ore is soft and friable, highly oxidized, black where oxide of manganese predominates, yellowish red where limonite predominates, and dull dirty brown where these oxides are evenly disseminated. It is unattractive-looking material, like all the other ore in the Candelaria district, and its value can not be appraised by visual inspection. Some unoxidized vein material was obtained from the west drift on the Baldwin vein; it consists largely of clean white carbonate (a manganiferous ferrodolomite) containing some pyrite and 1 or 2 per cent of felted aggregates of minute needles of jamesonite. This material was not ore, however, and yields on assay only 1.6 ounces of silver to the ton. Truly a remarkable change has been effected by oxidation both in appearance and in content of silver.

The main vein has been largely worked out down to the adit level, where its downward extension is cut off by a reverse fault, which has moved the felsites up over the cherts. On the surface the course of the vein is now indicated by two large open cuts, the east and west glory holes, both about 75 feet long and 250 feet apart.

In the Baldwin vein a shoot of ore at least 200 feet long had been developed on the adit level, which is in places as much as 20 feet wide, carrying 14 ounces of silver to the ton. Its full length had not been determined, and drifting was in active progress at the time of this examination. On the first level the downward extension of this shoot has been cut and is 8 feet wide, 4 feet of which averages 25 ounces to the ton.

According to recent report[21] the ore blocked out amounts to 60,000 tons.

OTHER MINES.

On the summit of Potosi Mountain, in the western part of the district, is exposed a narrow vein striking N. 50° E. and dipping 70° NW. The footwall is chert and the hanging wall quartz porphyry (presumably quartz monzonite porphyry), which contains much tourmaline in the form of small radial aggregates, quite obviously produced by the action of the vein-forming solutions. The ore is a coarse white quartz carrying yellowish-brown bindheimite of pitchy luster. A selected piece of this ore carried 24.8 ounces of silver to the ton and 21.4 per cent of lead.

Somewhat northwest of this vein is the Potosi vein. It strikes N. 70° E. and dips 60° N., conforming to the strike and dip of the country rock—well-bedded argillite. It has been stoped continuously along the strike for 600 feet or more to the surface, over an average width of probably 2 feet. The ore is quartz stained with bindheimite and black limonite.

[21] Nevada Min. Press, May 10, 1921.

COLEMANITE IN CLARK COUNTY, NEVADA.

By L. F. Noble.

INTRODUCTION.

Some deposits of colemanite (hydrous calcium borate, probably $HCa(BO_2)_3+2H_2O$), a mineral that yields borax, have recently been discovered in the Muddy Mountains, Clark County, Nev., in two areas 12 miles apart. One area occupies a part of the mountains that is known locally as White Basin; the other lies near Callville Wash. The White Basin district contains several deposits; the Callville district, so far as known, contains a single deposit, which, however, is by far the largest in the region. The location of the deposits is shown on the accompanying map (fig. 3).

These newly discovered deposits are interesting not only because they are the first economic occurrence of colemanite found outside of California, but because, unlike the California deposits, they occur in rocks whose structure is relatively simple. The large Callville deposit and the inclosing rocks for hundreds of feet above and below it are magnificently exposed, and the deposit itself is regular and persistent over several thousand feet of outcrop. These natural conditions afford an exceptional opportunity to study the origin of the colemanite.

The colemanite in all the deposits occurs in bunchy layers interbedded with whitish shale or thin-bedded limestone that forms part of a series of stratified rocks known as the Horse Spring formation. This formation, which consists of limestone, shale, sandstone, and conglomerate and contains much volcanic ash, is of fresh-water origin and is probably of Miocene age. Some parts of the formation contain deposits of gypsum and magnesite. The colemanite forms bands or zones that are locally called "veins," but these so-called veins are actually beds because they are parallel with the inclosing strata and exhibit bedded structure.

I made a brief examination of the deposits in May, 1921, in company with H. S. Gale, formerly of the United States Geological Survey. The examination was part of a field review of all the important colemanite deposits of California, covering the Ventura, Calico, and Furnace Creek districts.

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