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GEOLOGY AND ORE DEPOSITS

OF THE

YERINGTON DISTRICT, NEVADA

BY

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PREFACE.

By F. L. Ransome.

Yerington is one of the smaller and less productive copper districts of the West, its entire output from the beginning of mining operations being less than a third of the annual output of the mines at Bisbee, Ariz. Nevertheless, its deposits are exceptionally interesting to the student of ore deposition and differ from those of the larger and more productive districts of Utah, Nevada, New Mexico, and Arizona in being of contact-metamorphic origin and only slightly modified by enrichment.

The relation of ore deposition to contact-metamorphic action has been discussed by Mr. Knopf in a keen and suggestive way. He shows that in this district, probably in early Cretaceous time, there were two plutonic intrusions, the first of granodiorite and the second of quartz monzonite. These intrusions effected intense contact metamorphism of the invaded rocks, both igneous and sedimentary. A notable contribution in the report is the recognition of a time interval, marked by dike intrusions and fissuring, between this first metamorphism and the ore deposition, which nevertheless took place at high temperatures and was accompanied by the formation of garnet and other silicates characteristic of contact metamorphism of the pneumatolytic type. It is clearly shown that much iron and silica were introduced into the limestones during the first metamorphism and that some of these same constituents and large quantities of copper and sulphur were added during ore deposition.

The fact that many of the ore bodies are not actually at the contacts between the plutonic rocks and the invaded rocks leads to an interesting discussion of the essential characteristics of contact-metamorphic deposits. The conclusion is reached that mineral composition and associations are of more weight than mere proximity in determining the classification of a deposit.

In describing the relation of enrichment to the adjacent limestone in the Ludwig mine Mr. Knopf makes the important suggestion that supergene sulphide enrichment is likely to be an extremely wasteful process. This conclusion, which accords with that presented in my own paper on the copper deposits of the Ray and Miami districts, Ariz.,[1] indicates that estimates of the thickness of rock eroded from above an ore body in the course of enrichment, based on a comparison between the copper contents of protore and ore, may be far under the mark.

It is impracticable in a brief preface to call attention to all the interesting features in the following pages. The report is an excellent example of a well-balanced, thorough study of a small mining district, in which the essential facts have been discriminatingly observed, the conclusions ably drawn, and the whole presented without superfluous or unrelated detail.

[1] U. S. Geol. Survey Prof. Paper 115 (in preparation).

OUTLINE OF REPORT.

The Yerington district, which next to Ely is Nevada's most productive copper district, is in the west-central part of the State, 50 miles southeast of Reno. Before 1912 it did not produce largely, but since then, to the end of 1917, it has produced 61,200,000 pounds of copper.

The rocks of the district are divided naturally into two strongly contrasted groups, separated by a conspicuous unconformity—an older, Mesozoic group, to which the ore deposits are restricted, and a younger group, consisting of Tertiary volcanic rocks. The oldest rocks, of Triassic age, comprise andesites, soda rhyolite-felsites, and limestone, with subordinate quartzite, shale, and gypsum. They aggregate at least 8,000 feet in thickness, of which volcanic rocks make up 3,200 feet. They were invaded in post-Triassic time, probably early in the Cretaceous, by a medium-grained basic granodiorite and shortly after by a coarse-grained, roughly porphyritic quartz monzonite. These intrusions intensely metamorphosed the rocks they invaded: they caused the andesites and felsites adjacent to them to recrystallize and converted large volumes of the limestone into calcium silicate rocks, among which dense heavy brown garnetites predominate. Probably one-half of the Triassic area consists of rocks made up of garnet, wollastonite, and allied silicates. After this metamorphism numerous dikes and bosses of quartz monzonite porphyry were injected. Faulting then ensued, breaking and displacing the dikes, and along some of the faults formed at this time metalliferous solutions rose and produced the copper deposits to which the district owes its economic importance.

The Tertiary rocks rest with marked unconformity on the Mesozoic rocks. They are dominantly volcanic and are at least 7,000 feet thick. They fall into three major subdivisions, which are separated by two well-marked unconformities. The lowest subdivision consists of quartz latite, rhyolite, and andesite breccia; it is tilted at angles as great as 60°; and it probably is the correlative of the Esmeralda formation, of approximately upper Miocene age. The middle subdivision consists of a series of andesite flows resting in places on the eroded edges of the rhyolites. The uppermost subdivision consists of subangular conglomerate overlain by basalt, which caps the prominent mesas in the southern part of the district. The basalt has been slightly tilted since it was erupted and has been much faulted; in fact, the present relief of the range has resulted largely from post-basaltic faulting.

The principal ore bodies consist of pyrite and chalcopyrite in a gangue of pyroxene, garnet, and epidote. They attain 800 feet in length and 100 feet in width; these dimensions, however, are exceptional and as a rule are more applicable to the ore-bearing zones, in which the ore bodies are commonly small fractions of the associated masses of barren garnet-pyroxene rock. In the Mason Valley mine, for example, masses of barren garnet rock, in places 200 feet thick, underlie the productive part of the ore-bearing zone. The known vertical range of mineralization in the district, in the present stage of development, is 950 feet.

The ore deposits have resulted from the replacement of comparatively pure limestones and are of the contact-metamorphic type. They are clearly related to faulting, and inasmuch as the replacement of the limestone extended outward from fault fissures the ore bodies, as a rule, are lodelike in form. The ore tends to occur on the limestone side of the ore-bearing zone, though this rule is not without notable exceptions. As the ore deposits are situated on or near faults and as these faults commonly separate dissimilar rocks, such as limestone from felsite, andesite, or stratified calc-silicate rocks, it follows from these circumstances, together with the lodelike form and the tendency of the ore to occur on the limestone side of the ore-bearing zones, that the most systematic way of exploring for ore is to drift in the limestone parallel to the ore zone and to crosscut back at intervals to the ore zone.

The ore body at the Bluestone mine, consisting essentially of chalcopyrite and epidote, differs from the others of the district in that it was formed by the replacement not of limestone but of brecciated garnetite and other contact-metamorphic rocks of the first period of metamorphism. Its features serve to emphasize the separateness and distinctness of the two periods of metamorphism distinguishable in the district, both of which occurred, however, during the same general epoch of intrusion—an earlier, widespread metamorphism marked by the addition of the immense quantities of silica and iron to the metamorphosed limestones, and a later, localized metamorphism marked by the addition of silica, iron, copper, and sulphur. The second metamorphism, which produced the ore bodies, acted, as a rule, only on pure limestones (the Bluestone ore body being the one exception)—on limestones that were not silicated by the metamorphism of the first period.

The primary ores of the district are essentially unenriched by later sulphides, supergene covellite and chalcocite being on the whole of minor importance. The production has come largely from ores of this kind from the contact-metamorphic deposits, and the average tenor of the ores has ranged from 2.75 to 6 per cent of copper.

Types of ore deposits other than the contact-metamorphic are sparingly represented in the district and are of subordinate economic importance. They are exemplified by the irregular bodies of rich cuprite ore in quartz monzonite porphyry at the Empire-Nevada mine and by the fissure veins in granodiorite and quartz monzonite porphyry, as at the Montana-Yerington mine.

GEOLOGY AND ORE DEPOSITS OF THE YERINGTON DISTRICT, NEVADA.

By Adolph Knopf.

Part I. GENERAL FEATURES.

GEOGRAPHY.

The Yerington district is in Lyon County, Nev., 50 miles southeast of Reno. (See fig. 1.) It takes its name from Yerington, the county seat, a prosperous agricultural town in Mason Valley. Two smaller towns, of more recent origin and dependent almost wholly on the mining industry, are situated in the district—Mason on the east side of the range and Ludwig on the west side. These two towns are connected by the Nevada Copper Belt Railroad with Wabuska, on the Southern Pacific system, and with the smelter at Thompson, 2 miles from Wabuska.

As used in this report, the term "Yerington district" is restricted to the area shown on Plate I, within which are the chief copper-producing mines of the region. The district includes a small part of the Singatse Range, a northward-trending barren desert range separating Mason Valley on the east from Smiths Valley on the west. D. T. Smith[1] ascertained that the Indian name of the range is "Singatse," but neither this nor any other name appears to be locally known or used. Smith and Ransome termed it the Singatse [illegible], although Spurr[2] had earlier applied to it the name "Smith Valley Range." On the topographic map of the Yerington district recently made by the United States Geological Survey, which forms the base of Plate I, "Singatse Range" is employed, and this name is used here. The range averages 4 miles in width and rises [illegible] 1,500 feet above the valleys. The highest summit, Packhorse, southwest of Ludwig, reaches an altitude of 6,547 feet. The altitude of the range is insufficient to support a scattered growth of pines, such as is common on the summits of the higher ranges of the Great Basin.

The range rises abruptly above the floor of Mason Valley, its front is notched by sharp canyons, and a series of alluvial cones extending from the mouths of these canyons spread over the valley floor. The range is made up of a series of ridges that overlap one another, as is well shown along the road that crosses the range through Mason Pass on the way from Mason Valley to Ludwig, the crossing being made not transversely but at a narrow angle to the trend of the range.

Mason Valley is from 4 to 12 miles wide. A few miles south of the area shown in Plate I the East and West forks of Walker River unite to form the main river, which flows northward through the valley and then southeastward into Walker Lake, 35 miles east of Yerington. The water of the river is largely used for irrigation, and the valley supports a flourishing agriculture. Smiths Valley, on the west side of the Singatse Range, is a broad, arid expanse, at whose north end, northwest of Ludwig, is a playa lake that generally becomes dry early in September.

The climate of the Yerington district is that typical of the Great Basin region. Owing to the aridity and to its moderate elevation, the Singatse Range is without running water—in fact, the range is so dry that there is only one small spring within it.

FIELD WORK.

Field work was begun on July 3 and completed on September 11, 1914. During this work the writer was ably assisted by E. L. Jones, jr.

BIBLIOGRAPHY.

The number of publications on the Yerington district is not large. The only previous systematic account of the geology is that by Ransome, which is based upon a week's reconnaissance devoted mainly to examinations of the mines.

[1] Smith, D. T., Geology of the upper region of the main Walker River, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 3, 1904.

[2] Spurr, J. E., Geology of Nevada south of the fortieth parallel: U. S. Geol. Survey Bull. 208, p. 117, 1903.

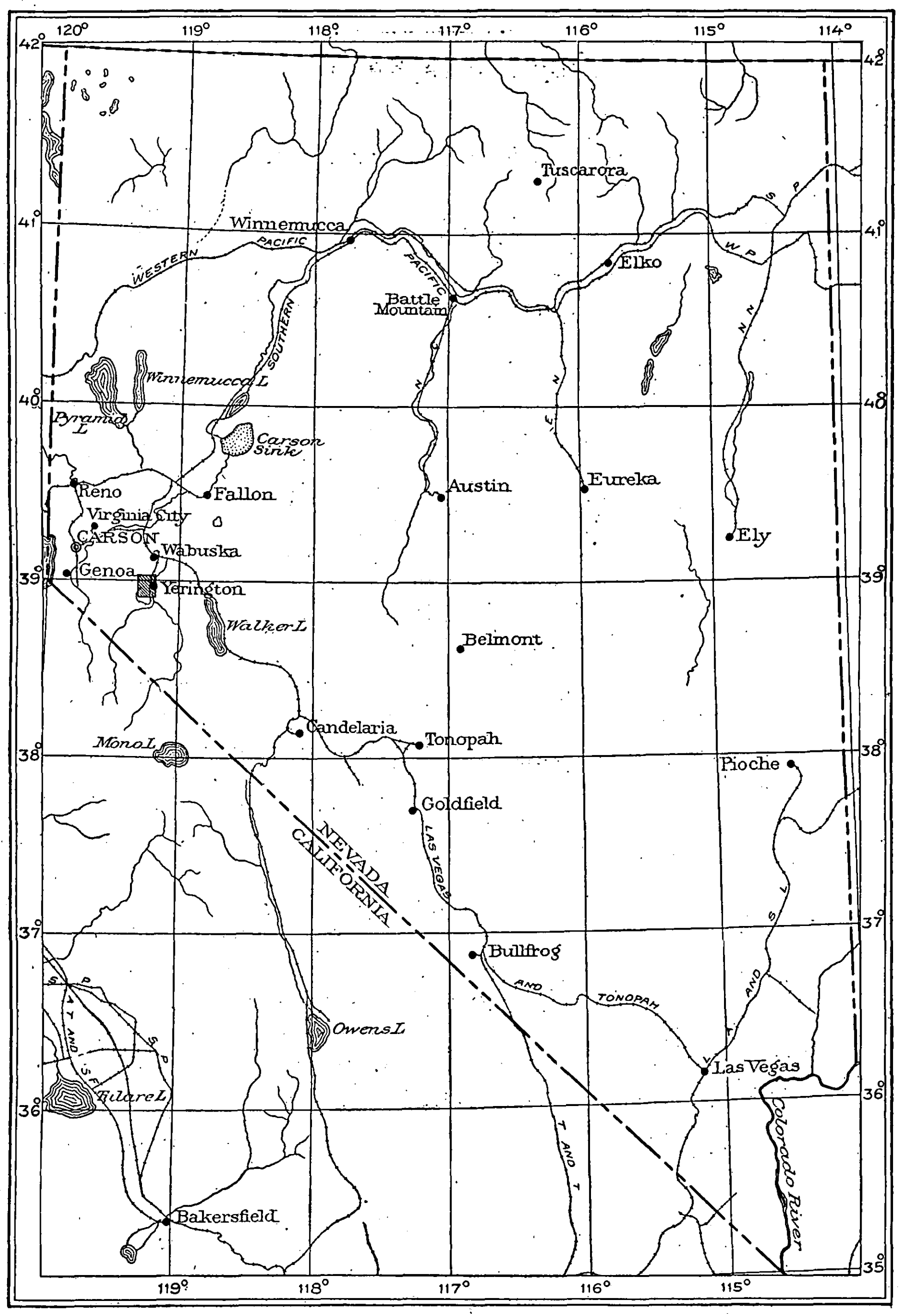


FIGURE 1.—Index map showing the location of the Yerington district, Nev.

1903. Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 117–120.

Gives a few scattered observations concerning mainly the southern part of the Singatse Range.

1905. Smith, D. T., The geology of the upper region of the main Walker River, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 1–32.

The geology of the upper region of the main Walker River, of which the Yerington district is a small part, is described and a reconnaissance map is presented.

1907. Jennings, E. P., The genesis of the copper deposits of Yerington, Nev.: Canadian Min. Inst. Jour., vol. 10, pp. 257–260.

Recognizes clearly the contact-metamorphic origin of the deposits and their dependence on fissuring, but the supporting evidence is not presented convincingly.

1909. Jennings, E. P., The localization of values in ore bodies and the occurrence of shoots in metalliferous deposits: Econ. Geology, vol. 4, pp. 255–257.

Practically a restatement of the earlier paper on the genesis of the Yerington copper deposits.

1909. Ransome, F. L., The Yerington copper district, Nev.: U. S. Geol. Survey Bull. 380, pp. 99–119.

Outlines the broader features of the geology of the district, gives a section across the range, and describes the ore deposits and the principal mines.

1910. Carpenter, J. A., The Yerington copper district: Min. and Sci. Press, vol. 101, pp. 4–9.

This valuable paper deals mainly with the state of development of the principal mines of the district in 1910.

1911. Jennings, E. P., Secondary copper ores of the Ludwig mine, Yerington, Nev.: Canadian Min. Inst. Jour., vol. 11, pp. 463–466.

1912. Rogers, A. F., The occurrence and origin of gypsum and anhydrite at the Ludwig mine, Lyon County, Nev.: Econ. Geology, vol. 7, pp. 185–189.

Gives a section at the mine, showing a bed of anhydrite, 450 feet thick, interstratified between quartzite and limestone. The anhydrite has been hydrated to gypsum to a depth of 400 feet on the hanging-wall side.

HISTORY OF MINING.

Mining in the Yerington district dates back at least as far as 1865, when attempts were made to work the oxidized copper ore at the Ludwig mine. Prior to 1907, however, operations throughout the district were intermittent and never attained much importance, and as a matter of fact the district did not begin to yield much copper until after 1912. The most important of the early activities appears to have been the mining of natural bluestone to supply the reduction works at Virginia City during the period when the great bonanza ore bodies of the Comstock lode were being extracted. The bluestone occurred in the outcrops of the principal ore bodies in considerable quantities, and many thousand tons were mined to furnish the copper sulphate used in the Washoe process of amalgamating the silver ores of the Comstock lode. A smelter was built at Ludwig in the early days, but it was not successful. At the Bluestone mine, on the east side of the range, a smelter was built in 1900, but it was not operated long, and similarly the smelter at Yerington station did not make any notable output. These early attempts were concerned chiefly with the oxidized ores, which were naturally richer than the sulphide ore but occurred in comparatively small quantity. In the absence of transportation facilities the larger bodies of primary ore, essentially unenriched and of low grade, were not attractive.

Interest in the district revived about 1907. Some of the largest deposits were acquired by energetic companies with adequate capital, and a campaign of active exploration and development was begun. The Nevada Copper Belt Railroad, 41 miles long, was built into the district from Wabuska, on the Southern Pacific system; it was commenced in August, 1909, and completed to Ludwig in September, 1911. A smelting plant, eventually increased to a capacity of 1,800 tons a day, was constructed by the Mason Valley Mines Co. at Thompson, 2 miles north of Wabuska. Its situation here at the north end of the arable part of the valley, together with the fact that the prevailing wind is from the south, in large measure precludes the danger of serious difficulty with the agricultural interests of Mason Valley on account of damage by smelter fumes. The plant began operations on January 6, 1912, and a considerable output was soon attained, largely from the ores of the Yerington district. At first a matte containing approximately 40 per cent of copper was produced, which was shipped to the Garfield smelter near Salt Lake City for conversion, but later two converters were added to the plant, and early in 1914 the production of blister copper was commenced.

The smelter was operated continuously until October 20, 1914, when it was shut down, owing to the disastrous effect of the outbreak of the European war on the price of copper. In spite of the recovery of the copper market and the high prices of metals that ruled during 1915, the smelter remained idle, as did also the Mason Valley mine, from which it had drawn a large part of its supply of ore. Elsewhere in the district, however, mining was stimulated by the great rise in the price of copper, and much activity prevailed.

In February, 1917, the smelter again began operations, and a large output was made from the ores of the Bluestone, Mason Valley, and Nevada-Douglas mines.

PRODUCTION.

The production of the Yerington district prior to 1905 is not accurately ascertainable but probably did not exceed 1,000,000 pounds of copper, mainly as natural bluestone and other oxidized ores. The total mine production of copper since 1905, as obtained from the files of the United States Geological Survey, is 61,193,800 pounds. This copper was recovered from or was contained in 886,624 tons of ore, the average yield being therefore approximately 3.45 per cent of copper. The output of gold and silver incidental to the recovery of copper has been insignificant.

Copper produced in the Yerington district, Nev., 1905–1917.

	Mine production.	
	Ore (tons).	Copper (pounds).
1905	1,382	294,000
1906	2,501	869,000
1907	1,074	297,000
1908	360	101,000
1911	120	2,800
1912	239,606	17,058,000
1913	206,558	15,106,000
1914	102,467	7,274,000
1915	4,736	701,000
1916	19,820	3,491,000
1917	308,000	[a]16,000,000

[a] Preliminary estimate.

GENERAL GEOLOGY.

TRIASSIC ROCKS.

CHARACTER.

The oldest rocks of the Yerington district are Triassic andesite, felsite, limestone, quartzite, and subordinate shale. Near Ludwig they include a thick bed of anhydrite, whose outcrop is altered to gypsum. They form a narrow, irregular belt extending across the portion of the range west of Mason. They have been intruded by granodiorite and quartz monzonite, and as a result they have been highly metamorphosed, some by simple recrystallization and others by addition of new material. The limestones especially were altered by pneumatolysis, and as the resultant rocks are composed solidly of garnet or kindred silicates, it has been found necessary to map large areas—in fact, about one-half of the total exposure of Triassic rocks—under a separate symbol as garnetites and allied rocks.

The rocks dip from 70° to 90°; on the east flank of the range they dip 70° W. and on the west flank 70° E. as a rule, but the structure is probably not synclinal, as the rocks differ widely in character and sequence on the two sides of the range. They are cut by many faults, which are of at least three different ages and some of which are of large stratigraphic displacement. These features, combined with the profound contact metamorphism, have rendered it impossible to establish fully the stratigraphic sequence. A thickness of at least 8,000 feet of rock, however, appears to be represented.

The Triassic rocks are a small remnant of a formerly extensive formation; they have been left isolated in an area now occupied mainly by granitic rocks of probably early Cretaceous age and by Tertiary volcanic rocks. They are, however, the rocks of main economic interest, because the limestones of the formation inclose the principal ore bodies of the district.

AGE.

Smith[1] found some evidence indicating that the rocks are of Triassic age, and Jones[2] found Triassic fossils in place near the Ludwig mine.

During the present investigation fossils were found on the south side of the road near the Malachite mine, where they are abundant but poorly preserved and mainly of one species. They occur at two horizons, in black shales interstratified with limestone separated by about 150 feet of felsite, but are more abundant at the upper horizon. The shales are overlain mainly by massive limestone, which includes

[1] Smith, D. T., op. cit., pp. 9–10.

[2] Jones, J. C., The origin of the anhydrite at the Ludwig mine, Lyon County, Nev.: Econ. Geology vol. 7, p. 400, 1912.

some alternations of limestone and felsite. T. W. Stanton reports on the fossils collected here as follows:

9215. Lot B. Malachite mine, Yerington district, Nev.:
Daonella sp.
Daonella? sp.
Triassic.

9217. No. 51–J. Near Malachite mine:
Daonella sp.
Ammonite; imprint too obscure for generic determination.
Triassic.

9218. No. 52–J. Near Malachite mine:
Daonella sp.
Ammonite imprint; possibly a Ceratites.
Triassic.

Imprints of similar fossils were found in shale halfway between the Malachite and Mason Valley mines and in shale 1,500 feet north of the McConnell mine. A well-preserved *Halobia*, a typical Triassic fossil, wholly garnetized, was found in the garnetites west of the McConnell mine. It is concluded from this distribution of Triassic fossils that all the pregranitic rocks of the district are of Triassic age.

VOLCANIC ROCKS.

ANDESITES.

Andesites form a prominent belt extending along the front of the range from Mason southward. They occur also along the summit south of the direct road between Mason and Ludwig and as infaulted blocks near the Western Nevada mine.

The andesites are moderately dark rocks that display some petrographic diversity. The most common variety is probably that carrying abundant phenocrysts of plagioclase and hornblende or pyroxene, both somewhat inconspicuous and blurred through secondary alteration. Some of the andesite differs from the rest because of its numerous large phenocrysts of tabular plagioclase. Both massive porphyries and pyroclastic breccias occur in the andesite series, which is therefore clearly of extrusive origin. Dacite, characterized by numerous large, prominent corroded quartz phenocrysts associated with the feldspars, is intercalated in the andesites in moderate amount.

Under the microscope a typical andesite, from the canyon up which the road to the Malachite mine goes, is found to show the following features: The feldspar phenocrysts are andesine ($Ab_{55}An_{45}$); they are more or less intergrown with amphibole and other secondary minerals, and in consequence most of them no longer stand out sharply from the groundmass. The femic phenocrysts—whether they were hornblende or pyroxene originally is now not ascertainable—have recrystallized to irregular aggregates of light-green amphibole. The groundmass is fine grained and contains evenly scattered through it innumerable prisms of the light-green amphibole and minute grains of magnetite.

The andesites that occur near the intrusive bodies of quartz monzonite have been recrystallized. The effect most obvious on casual inspection is that they have become darker and appear fresher. Moreover, the porphyritic structure has become obscure. In the lower part of the canyon through which passes the road to the Western Nevada mine the andesites have recrystallized so thoroughly that they have a decidedly dioritic appearance, but the retention of pyroclastic structure, as revealed on weather-etched surfaces, still gives a clue to their extrusive origin. Under the microscope the thermally altered andesites are found to consist mainly of plagioclase and hornblende. The hornblende is evenly scattered throughout the rocks, is more or less spongiform, and is evidently secondary. The original porphyritic structure has been obscured partly by the recrystallization of the femic phenocrysts and partly by the growth of multitudes of minute hornblende prisms in the cores of the plagioclase phenocrysts.

The maximum indicated thickness of the andesite series is 2,000 feet. Immediately above the andesites are felsites. As the andesites are intruded by felsite sills, and as extrusive felsites and felsite breccias are interstratified with the overlying fossiliferous Triassic limestones, it is clear that the andesites are the lowest member of the local Triassic section.

SODA RHYOLITE-FELSITE (KERATOPHYRE).

GENERAL FEATURES.

Soda rhyolite-felsites make up an important element in the Triassic section. They are characterized by their light color, aphanitic texture, and obscurely porphyritic habit. As they carry but few phenocrysts and as these are generally inconspicuous, the felsites closely resemble fine-grained sedimentary rocks ranging from cherts to dense quartzites. They resemble also the aphanitic calc-silicate rocks that commonly result from contact-metamorphic action—rocks that are logically to be expected in an area so highly metamorphosed by igneous intrusions as the Yerington district. In the field, therefore, the felsites are generally discriminable with difficulty from a variety of rocks of widely different origins. Fortunately, however, certain of the felsites reveal their volcanic origin either by a conspicuous flow banding or by a breccia structure that is developed by the weathering of exposed surfaces. Notwithstanding the diversity of structure thus locally shown on weathered surfaces, the felsites have the striking peculiarity that on fresh fracture all are of structureless flintlike or cherty appearance.

The main bulk of the felsites lies immediately above the top of the andesites. The greatest thickness is about 1,200 feet, or at least felsites strongly preponderate in a belt of this thickness, as shown along the crest of the ridge extending east from the Mason Valley mine. They occur in smaller thicknesses in the overlying limestone series. Among the more notable of these minor belts is the felsite breccia forming the footwall of the ore-bearing zone at the Mason Valley mine.

The most prominent development of the felsites is the thick belt already mentioned, which extends along the east flank of the range. In this belt they are generally unaltered by dynamic or contact metamorphism. The felsites occurring in the area of highly metamorphosed rocks extending from the McConnell mine to the summit of the range have been recrystallized, and finely flaky biotite has been caused to grow in them, so that their recognition becomes difficult; some, indeed, closely resemble aplite.

PETROGRAPHY.

The felsites include flows, tuffs, breccias, and intrusive rocks. In color they range from snow-white to grayish green. The effusive and pyroclastic members are in the main aphanitic rocks carrying a few obscure inconspicuous phenocrysts of feldspar. Some contain small sporadic corroded crystals of quartz, but such quartz-bearing felsites are comparatively rare. In the intrusive felsites the texture is microcrystalline and the phenocrysts are more common and more readily distinguishable, so that the igneous origin of these rocks is far more easily recognizable.

Under the microscope the massive felsites—that is, the flows and intrusives—all appear to be essentially similar. They show sporadic phenocrysts of albite, or of sodic oligoclase, embedded in a groundmass that is generally cryptocrystalline. Biotite or hornblende appear not to have been present. A secondary mica, probably sericite, occurs as minute fibers in some of the felsites. Further details are presented in connection with the felsites that have been chemically analyzed.

The breccias, which are composed of angular fragments as much as several inches in length, are not as a rule discriminable from the lavas on fresh fracture. This variety of pyroclastic rock is the more common in the region, but near the Mason Valley mine somewhat different explosive products of the felsitic eruptions were found. They occur as thin strata of quartz-feldspar tuff inclosed in the massive brown garnetite that forms the predominant country rock southeast of the office of the mine. The tuff is a white rock made up largely of feldspar but containing quartz particles somewhat larger than the average grain of the rock; the general megascopic effect is that of an aplite porphyry. The clastic origin becomes apparent under the microscope, however, and the rock is seen to be made up of albite, quartz, and sporadic fragments of a trachytoidal volcanic material composed of albite.

The intrusive felsites, as previously mentioned, are sufficiently coarse in grain to be termed microcrystalline. A snow-white felsite of this kind, containing scattered phenocrysts of feldspar, occurs on the divide south of Ludwig; it shows under the microscope crystals of oligoclase-albite, somewhat more sodic than $Ab_{86}An_{14}$, set in a groundmass whose components are well individualized. In this respect it contrasts notably with the extrusive felsites, but otherwise it is quite similar. The groundmass consists of quartz and feldspar, probably albite, forming a mosaic whose structure ranges between allotriomorphic and panidiomorphic granular. Titanite, apatite, magnetite, and zircon occur sparsely, and the secondary minerals epidote and actinolite are present in small amounts, mainly in partial replacement of the phenocrysts.

A rock that is very similar but is rich in phenocrysts of albite—an albitophyre, as it may be called—occurs on the ridge east of the Western Nevada mine.

One complete and two partial analyses of the felsites have been made by R. C. Wells in the laboratory of the United States Geological Survey. They show somewhat greater diversity than was expected but bring out well the highly siliceous, soda-rich character of the lavas and their poverty in iron and magnesia.

Analyses of felsites (keratophyres) from the Yerington district, Nev.

[R. C. Wells, analyst.]

	1	2	3
SiO_2	72.73	77.17	70.18
Al_2O_3	14.42	[a] 13.84	[a] 18.43
Fe_2O_3	.73		
FeO	.94		
MgO	.32		
CaO	.87	1.47	2.55
Na_2O	4.66	6.05	7.46
K_2O	4.50	.38	.44
H_2O-	.36		
H_2O+	.36		
TiO_2	.22		
ZrO_2	.04		
CO_2	.19		
P_2O_5	.07		
MnO	.01		
BaO	.09		
	100.51	98.91	99.06

[a] Includes some Fe_2O_3, etc.

1. Malachite mine, north of road.
2. Mason Valley mine, from cutting on road between office and portal of tunnel No. 3.
3. Douglas mine.

The felsite obtained near the Malachite mine (No. 1) is a flintlike rock of conchoidal fracture, carrying sparse phenocrysts of glassy plagioclase one-tenth of an inch or less in length. Under the microscope it proves to be holocrystalline, probably owing to devitrification. The phenocrysts are seen to be albite near $Ab_{92}An_8$ in composition. Octahedrons of magnetite 0.02 millimeter in size are common, and apatite and titanite are the other accessory minerals. Chlorite (in part possibly pseudomorphous after biotite or hornblende), epidote, and calcite are minor secondary minerals. The groundmass, consisting of irregularly interlocking aggregates, averages 0.005 millimeter in grain. Study of the groundmass immersed in oils of known refractive indices raises some interesting queries. The minimum index of all particles is found to exceed 1.529—in other words, no orthoclase is present, although the subjoined calculation of the chemical analysis of the felsite calls for 27 per cent of orthoclase. Grains whose indices range between approximately 1.530 and 1.536 make up practically the whole of the groundmass; in liquid of index 1.544 a few grains of quartz can be detected, but the amount is totally disproportionate to that calculated from the analysis. The computed composition is given in the following table:

Mineral composition of felsites.

	1	2	3
Quartz	26.60	37.30	19.63
Orthoclase (mol.)	26.78	2.23	2.61
Albite (mol.)	39.45	51.55	63.30
Anorthite (mol.)	1.95	7.23	12.66
Magnetite	1.16		
Titanite	.59		
Apatite	.15		
Calcite	.40		
Chlorite	2.03		
	99.11	98.31	98.20

The felsite from the vicinity of the Mason Valley mine (No. 2) is a dense snow-white rock without phenocrysts; under the microscope it is seen to consist wholly of an intimately interlocking aggregate of minute grains. The refractive indices of all the grains exceed 1.529, and some of the grains have indices exceeding 1.544; hence, in connection with the chemical analysis, it is clear that the felsite consists largely of albitic feldspar plus some quartz.

The felsite from Douglas Hill (No. 3) is also a dense rock without phenocrysts but is characterized by a well-marked banding. In thin section it is found to consist of a closely intergrown aggregate of colorless, untwinned, weakly birefringent grains that average 0.02 millimeter in diameter. Apatite, leucoxene (?), and actinolite in radial groups occur as minor constituents. Examination of the crushed rock in oils of known indices shows that the indices of all particles exceed 1.529 and are notably less than 1.544, the minimum index of quartz. The quartz indicated by the computed mineral composition is therefore not present. The three felsites that have been chemically analyzed and critically examined as to their mineral composition accordingly suggest that sodium-aluminum silicates more siliceous than albite are present, a conclusion similar to that which Mügge reached long ago in his classic studies on the keratophyres of Westphalia.[1]

SEDIMENTARY ROCKS.

The sedimentary rocks consist principally of limestone and quartzite. The larger masses of these rocks have been mapped separately (Pl. I, in pocket). The limestones as a rule are light colored, massive, and coarsely crystalline. Some thinly bedded black limestone, 200 feet thick, occurs east of the Mason Valley mine, however, and extends southward to the Malachite mine. Shale is not common in the district, the principal occurrence being the fossiliferous beds near the south workings of the Malachite mine.

Quartzite is exposed at the upper edge of the alluvium in the town of Ludwig, where it forms the lowermost member of the local Triassic section. It is separated from the overlying rocks by a strike fault. A larger mass, surrounded by granodiorite, occurs on the hill northwest of Ludwig. It is a vitreous quartzite, which the microscope shows is composed wholly of interlocking quartz grains. In the absence of any positive evidence bearing on its age the quartzite is provisionally mapped with the Triassic rocks.

GARNETITES AND ALLIED ROCKS.

CHARACTER AND DISTRIBUTION.

Highly metamorphic rocks—the so-called lime-silicate rocks[2]—make up about half the area underlain by the Triassic. Rocks composed wholly of brown garnet, referred to in this report as garnetites, are most abundant, but many other varieties occur, such as those consisting of epidote, clinozoisite, and vesuvianite, singly or together, or such as those making up the thick white strata composed chiefly of wollastonite, as at the Bluestone and Ludwig mines.

The areas in which rocks of this kind predominate are shown separately on the geologic map (Pl. I). Garnetite and allied rocks, however, also occur to some extent interstratified with the limestone in the areas where limestone prevails.

In places felsite and felsite tuff are intercalated with the calc-hornfelses, and it is accordingly difficult in the field to distinguish these two kinds of rock. The intercalated felsites have not uncommonly been metamorphosed to solid aggregates of fine-grained epidote.

The brown garnetites are well shown on the hill south of the office of the Mason Valley mine. They are heavy, dense, massive rocks composed wholly of microcrystalline garnet. As indicated by its refractive index (1.81), the garnet is a variety halfway between grossularite and andradite. Similar garnetites, still retaining stratification, form the hill west of the McConnell mine. Under the microscope only minute amounts of pyroxene, quartz, and calcite are found to be associated with the preponderant garnet composing the rock. The index of this garnet also proves to be 1.81. A garnetite from this locality, noteworthy in containing a garnetized fossil, was partly analyzed in the laboratory of the Geological Survey.

The analysis given below clearly confirms the optical determination that the garnet is a variety about halfway between grossularite and andradite.

Partial analysis of garnetite from hill near the McConnell mine.

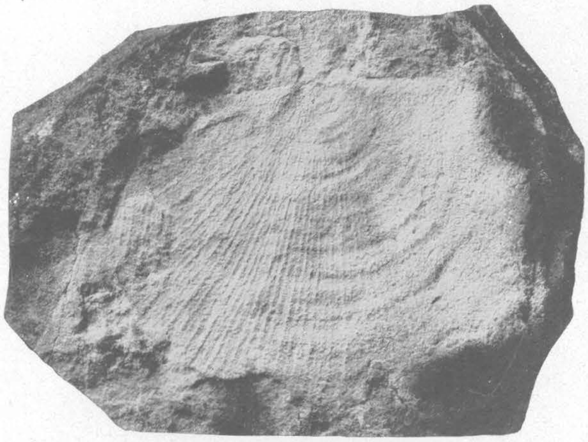
[W. B. Hicks, analyst.]

SiO_2	40.89
Al_2O_3	7.63
Fe_2O_3 (total iron)	15.39
MgO	1.26
CaO	30.61

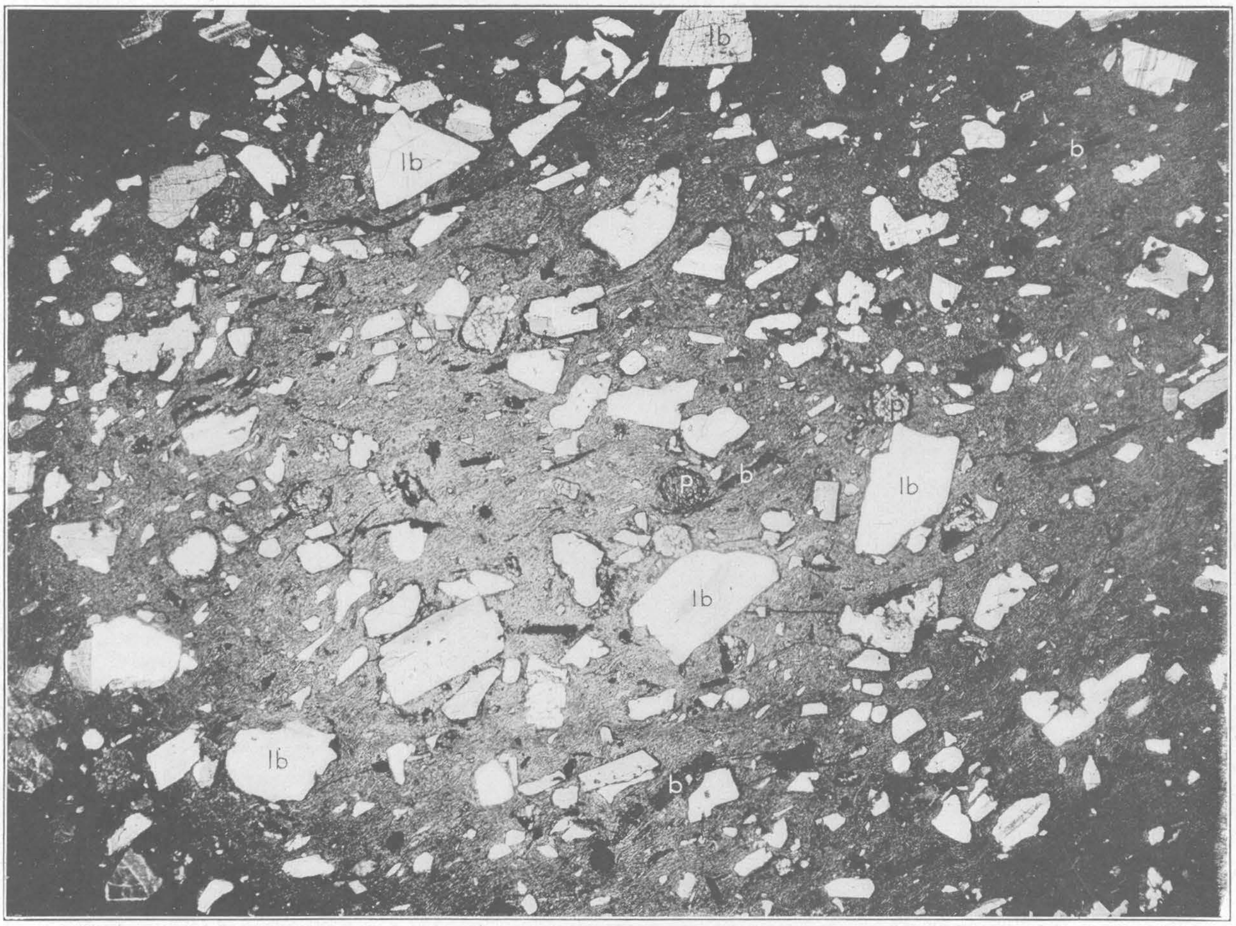
A stadia traverse was made across the strike of the rocks on Douglas Hill, and specimens

[1] Mügge, O., Untersuchungen ueber die "Lenneporphyre" in Westfalen und den angrenzenden Gebieten: Neues Jahrb., Beilage Band 8, p. 616, 1893.

[2] There is no wholly satisfactory name for rocks of this kind. Flett and others of the Geological Survey of Great Britain call them calc-silicate hornfelses; the writer has elsewhere (Tungsten deposits of northwestern Inyo County, Cal.: U. S. Geol. Survey Bull. 640, p. 233, 1916) suggested that this term be shortened to calc-hornfelses.



A. GARNETIZED HALOBIA.



B. PHOTOMICROGRAPH OF LATITE VITROPHYRE.

lb, Labradorite; p, pyroxene; b, biotite.

were taken from those rocks that differed perceptibly to the unaided eye; the specimens were examined microscopically and the accompanying section (fig. 2) was drawn. It is probable that if more specimens had been collected, more varieties of lime-silicate rocks would have been discriminated microscopically. At the base of the section is a much brecciated quartzite (*a*); above this is the coarse limestone (*b*) that incloses the Ludwig lode; and above this are lime-silicate rocks and felsites, aggregating more than 1,500 feet in thickness. Although these rocks are highly metamorphic, they are well stratified and retain their general aspect of sedimentary rocks. The fine-grained rock near the base of the belt of white lime-silicate rocks (*c*) consists chiefly of wollastonite, with accessory plagioclase ($Ab_{73}\,An_{27}$), diopside, and pyrite. The faintly banded aphanitic hornfels (*e*) resembles to the eye exactly the banded felsites of the region; under the microscope, however, it proves to consist largely of slender fibers of tremolite scattered through a feebly birefringent granular aggregate, which probably consists of plagioclase, as its maximum refractive index, determined by the immersion method, is 1.544. The uppermost belt of black hornfelses (*f*) on casual examination resembles a series of thin-bedded black limestones, but on closer inspection it is found to consist of heavy aphanitic rock. In thin section such rock is seen to be made up largely of vesuvianite, of index 1.71, and epidote of a pale variety near clinozoisite. The black color of the rock is due to very abundant and finely disseminated carbonaceous matter. This belt of black rocks is overlain by felsites (the felsite whose analysis is given in column 3, on p. 15, came from this belt) and aphanitic hornfelses. A hornfels of this belt—a heavy even-grained aphanite of grayish-green color—proves in thin section to consist of vesuvianite, diopside, and quartz, which is partly idiomorphic against the other two minerals. Near the top of the section there occur garnetites which are composed solidly of microcrystalline garnet; as determined by the immersion method, the refractive index of the garnet is 1.75, showing that the garnet is nearly pure grossularite.

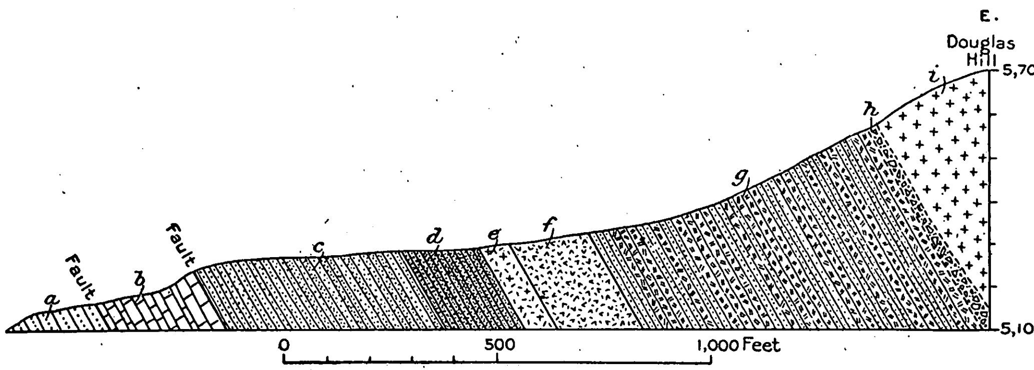


FIGURE 2.—Geologic section extending N. 71° W. from the summit of Douglas Hill, Nev. *a*, Quartzite, highly brecciated; *b*, limestone; *c*, white lime-silicate rocks; *d*, black lime-silicate rocks; *e*, aphanitic tremolite rock, probably including some felsites; *f*, black epidote vesuvianite rocks; *g*, felsites, lime-silicate rocks, and garnetites; *h*, fault breccia cemented by andradite; *i*, andradite rock.

ORIGIN OF THE METAMORPHIC ROCKS.

The fact that the appearance of normally stratified rocks is preserved by the dense aphanitic wollastonite rocks and garnetites suggests that large amounts of silica, ferric oxide, and possibly other substances were added during metamorphism and that the volumes of the original strata have remained unchanged. This conclusion appears to be confirmed by the discovery of a completely garnetized fossil in the stratified garnetites near the McConnell mine.[1] This fossil was identified as *Halobia* sp. by T. W. Stanton, who commented on its preservation in undistorted form. (See Pl. II, *A*.) The petrographic description and chemical analysis of the garnet matrix of the *Halobia* is given on page 16, and from these it appears that the garnet is a variety high in the andradite molecule. Mani-

[1] Fossils preserved intact in silicated contact-metamorphic limestones are not uncommon. Lindgren (Mineral deposits, p. 671, 1913) says that "at Tres Hermanas, N. Mex., near the contact with granite porphyry, Spirifers and Fenestellas have been perfectly preserved in the garnetized rock." Goldschmidt (Die Kontakt-metamorphose im Kristianiagebiet, p. 327, 1911) found that in some of the contact-altered limestones thick-walled brachiopod shells have been completely altered to wollastonite.

festly the garnetization of the *Halobia* and its matrix took place without change in volume or increase of porosity; and it must therefore have involved the addition of large amounts of ferric iron, silica, and probably alumina to the metamorphosed limestone from an extraneous source. In view of the considerable areal extent of rocks of this kind in the Yerington district, this great accession of material becomes one of the most noteworthy features of the geology of the district.

Inclosed in the lime-silicate rocks are irregular masses of limestone, which, as the field evidence discloses, are residual from interbedded strata that were not wholly replaced by silicates. Incomplete replacement of this kind is well shown in a belt of thin-bedded black limestone 200 feet thick near the Mason Valley mine. (See fig. 7, p. 53.) The northern extension of the belt is completely metamorphosed to silicates, but toward the south the silicates diminish abruptly and finger out irregularly in stringers penetrating the unaltered limestone.

Along the contact of the massive limestone belt and the calcium silicate rocks southwest of Douglas Hill blocks and slabs of unsilicated limestone are commonly inclosed in rocks composed solidly of silicates; that this relation is not due to faulting that occurred after the period of silication is shown by such features as the corroded and embayed boundaries of the limestone blocks and by the tonguelike masses of silicates penetrating the limestone. Along this contact there occur also breccias of limestone in which the limestone fragments are surrounded by networks of tremolite fibers.

The widespread profound metamorphism described in the preceding paragraphs occurred shortly after the intrusion of the granodiorite and quartz monzonite, and, as pointed out in detail on page 43, it almost wholly preceded the intrusion of the quartz monzonite porphyry. It led to the development of large masses of aphanitic or microcrystalline silicate rocks. It is referred to in this report as "the metamorphism of the first period" to distinguish it from the later, more localized, and widely different metamorphism accompanying the formation of the copper ores of the district.[1]

[1] A similar relation between regional contact metamorphism and later deposition of contact-metamorphic ore occurs in the Darwin district, Cal. (See Knopf, Adolph, The Darwin silver-lead mining district, Cal.: U. S. Geol. Survey Bull. 580, pp. 1-18, 1915.)

GYPSUM.

A bed of gypsum 450 feet in maximum thickness and sufficiently large to be shown on the geologic map (Pl. I) occurs near the Ludwig mine. It is underlain by quartzite and is overlain by limestone about 170 feet thick, which separates it from the Ludwig lode. These geologic relations are shown in figures 9 (p. 59) and 10 (p. 60). A small mass of intrusive granodiorite lies within 200 feet of the main outcrop of the gypsum bed.

The origin of the gypsum has aroused considerable interest. Ransome[2] suggested that it resulted from the alteration of limestone by acid solutions derived from the oxidizing sulphides of the Ludwig ore body. Later development work at the mine showed, however, that the gypsum passes into anhydrite in depth, and Rogers[3] established conclusively that the gypsum originated from the anhydrite by hydration. It was assumed by Rogers that the anhydrite was originally formed during the evaporation of an inland sea. Jones,[4] however, advanced the hypothesis that the anhydrite resulted from the dehydration of a bed of gypsum originally laid down during the deposition of the Triassic rocks. He based his explanation on the fact that the Triassic at other places in Nevada where it has not been affected by intrusive igneous rocks contains interstratified beds of gypsum; but at Ludwig, where the Triassic is cut by granodiorite, anhydrite occurs, which is very probably therefore metamorphosed gypsum. If gypsum is heated at atmospheric pressure to 130° C. it loses all its water and becomes converted into anhydrite; at higher pressures the temperature of dehydration would be raised, in accordance with the law of Le Chatelier. Now the rocks associated with the anhydrite have been profoundly altered by thermal metamorphism, as is described on pages 16–17 and shown in figure 2, and this leaves little doubt that the anhydrite, if originally gypsum, was heated to a temperature high enough to effect its dehydration, notwithstanding its burial to con-

[2] Ransome, F. L., The Yerington copper district, Nev.: U. S. Geol. Survey Bull. 380, pp. 112-113, 1909.

[3] Rogers, A. F., The occurrence and origin of gypsum and anhydrite at the Ludwig mine, Lyon County, Nev.: Econ. Geology, vol. 7, pp. 185-189, 1912; see also Notes on the occurrence of anhydrite in the United States: School of Mines Quart., vol. 36, pp. 128-130, 1915.

[4] Jones, J. C., The origin of the anhydrite at the Ludwig mine, Lyon County, Nev.: Econ. Geology, vol. 7, pp. 400-402, 1912.

siderable depth. Obviously, however, no decisive evidence can be adduced in this area of intrusion, metamorphism, and faulting to establish whether the bed was originally laid down as gypsum or as anhydrite.

The deposit was formerly utilized as a commercial source of gypsum, as is described on page 62.

CORRELATION OF THE TRIASSIC ROCKS.

The Triassic rocks of Nevada were divided by Hague into two formations. The lower of these was called the Koipato and was described as consisting of quartzites and "felsitic porphyroids," aggregating roughly 6,000 feet in thickness. The porphyries were thought to be metamorphic sedimentary rocks. It was shown by Ransome,[1] however, that the Koipato is dominantly of igneous origin. "It consists of volcanic flows, mostly rhyolitic but including also andesitic lavas, associated with tuffs, conglomerates, grits, and limestones." The later work of Jones[2] and Schrader[3] in the recently discovered Rochester district, in the Humboldt Range, has confirmed this statement and has shown the wide textural variety of rhyolites included in the Koipato formation.

One of the more coarsely crystalline "porphyroids" from Cottonwood Canyon, in the Humboldt Range, was analyzed for the Fortieth Parallel Survey,[4] as follows:

Analysis of rhyolite from the Humboldt Range, Nev.

[M. R. Woodward, analyst.]

SiO_2	74.74
Al_2O_3	14.14
Fe_2O_3	.79
CaO	1.51
MgO	.39
Na_2O	.92
K_2O	5.29
Loss on ignition	1.88
	99.66

This analysis shows that the rhyolite is a normal potassic variety, and in this respect it differs very considerably from the soda-rich rhyolites in the Triassic of the Yerington district.

The Star Peak formation overlies the Koipato and consists, as determined by Hague, of "broad alternating zones of quartzites and limestones," roughly estimated as 10,000 feet thick. According to Ransome, the stratigraphy and lithology of the formation are in need of detailed study. The formation is of Middle and Upper Triassic age, as established by Gabb, Meek, Hyatt and Smith, and J. C. Merriam. The Triassic of the Humboldt Range also contains thick lenses of gypsum,[5] such as occur also in the Yerington district.

The Triassic rocks of Nevada, as will be seen from the foregoing statements, attain a great thickness, possibly as much as 16,000 feet, of which 6,000 feet is dominantly of igneous character. The locality nearest to the Yerington district at which Triassic fossils occur is in the Pine Nut Mountains, 15 miles northwest of the district. Here Whitney[6] and later Spurr[7] found fossils in shaly limestone, but not much is known about the rocks of this locality. The Triassic probably occurs, according to Hill,[8] at many places in western Nevada. In eastern California, in the Inyo Range, the Triassic appears in large volume; it includes here at least 4,500 feet of andesitic lavas, tuffs, and breccias.[9] The igneous rocks are interleaved with marine limestones whose fauna has been carefully studied by J. P. Smith and determined to be of Middle Triassic age. Lindgren[10] has assembled the information showing that the Triassic period was one of volcanic activity along the whole Pacific coast from Inyo County, Cal., to the Alaska Range.

CRETACEOUS (?) ROCKS.

GENERAL RELATIONS.

The Triassic rocks, after being folded, were invaded by a succession of igneous rocks, which, named in the order of their intrusion, are basic granodiorite, quartz monzonite, aplite, and quartz monzonite porphyry. These post-

[1] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 32, 1909.

[2] Jones, J. C., Geology of Rochester, Nev.: Min. and Sci. Press, vol. 106, pp. 737-738, 1913.

[3] Schrader, F. C., The Rochester mining district, Nev.: U. S. Geol. Survey Bull. 580, pp. 334-338, 1915.

[4] U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 722, 1877.

[5] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, p. 295, 1904.

[6] Whitney, J. D., California Geol. Survey, vol. 1, p. 459, 1865.

[7] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, pp. 122-123, 1903.

[8] Hill, J. M., Some mining districts in northeastern California and northwestern Nevada: U. S. Geol. Survey Bull. 594, p. 20, 1915.

[9] Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, pp. 87-88, 1914.

[10] Lindgren, Waldemar, Igneous geology of the Cordilleras, in Problems of American Geology, pp. 250-252, Yale University, 1915.

Triassic intrusives are presumably of early Cretaceous age, like those of the Sierra Nevada, not many miles to the west.

The granodiorite and quartz monzonite are areally the most important. Although no great interval of time separated their intrusions, these two rocks are chemically distinct, the quartz monzonite being much more siliceous and considerably lower in iron, magnesia, and lime. If they were derived from a common magma this implies a notable differentiation, but no trace of the hypothetically resultant basic differentiate occurs in the district.

The invaded sedimentary rocks were intensely metamorphosed as a result of the intrusions, but whether this metamorphism is due to the granodiorite or to the quartz monzonite, or in part to both, could not be determined. It is certain, however, that the quartz monzonite porphyry, the last member of the intrusive sequence, was injected after the metamorphism was effected. This matter, which is important in the genesis of the ore deposits, is discussed in detail on pages 43–44.

MAJOR INTRUSIONS.

GRANODIORITE.

Granodiorite is the oldest granular intrusive rock in the district. It is most widely exposed in the area northeast of Ludwig, extending across the range to Mason Valley, and is quite homogeneous throughout its area. It is a gray medium-grained equigranular rock, showing no megascopic quartz, and resembles a diorite.

Under the microscope plagioclase ($Ab_{67}An_{33}$) is seen to be the dominant constituent; it occurs as tabular crystals which are alined roughly parallel, thus giving the granodiorite a distinctive structure. Hornblende and biotite, occurring in about equal quantities, are the ferromagnesian minerals. Microcline and quartz are subordinate components, the quartz being perhaps just sufficiently abundant to warrant naming the rock a granodiorite. The accessory minerals are magnetite, which is relatively abundant, titanite, apatite, and xenotime (?). In the following table is given an analysis of the granodiorite, made on a specimen from an altitude of 5,540 feet on the road west of the Bluestone mine, together with analyses of the quartz monzonite that intrudes the granodiorite.

Analyses of granodiorite and quartz monzonite from the Yerington district, Nev.

	1	2	3
SiO_2	57.90	68.35	67.70
Al_2O_3	16.38	14.71	15.95
Fe_2O_3	3.02	1.69	1.53
FeO	3.66	1.47	1.14
MgO	3.13	1.11	1.23
CaO	6.33	3.11	2.70
Na_2O	4.10	4.28	4.83
K_2O	2.52	3.54	3.74
H_2O-	.18	.31	.19
H_2O+	.89	.46	.36
TiO_2	1.12	.57	.23
ZrO_2	None.	None.	....
CO_2	.08	.14	....
P_2O_5	.42	.20	([a])
MnO	.09	.04	([a])
BaO	.06	.06	....
SrO	.08	.07	....
	99.96	100.11	99.60

[a] Undetermined.

1. Granodiorite. George Steiger, analyst.
2. Quartz monzonite. George Steiger, analyst.
3. Quartz monzonite. D. T. Smith, analyst; California Univ. Dept. Geology Bull., vol. 4, p. 20, 1905.

The chemical analysis confirms the deduction drawn from the mineral composition that the rock is a basic end member of the granodiorite group; indeed, the rock might equally well be termed a tonalite or diorite. The rock closely resembles the granodiorite from Donner Pass, in the Sierra Nevada.[1]

QUARTZ MONZONITE.

GENERAL FEATURES.

Quartz monzonite appears in large volume southeast of Ludwig and occupies the entire width of the range. It probably makes up much of the range south of the mapped area, for it is prominently exposed in the lower part of the canyon of West Walker River, where this stream cuts through the range.

The intrusive relation of the quartz monzonite to the granodiorite is clearly shown northwest of the Bluestone mine, where apophyses of quartz monzonite penetrate the granodiorite. The contact between the two rocks is sharp: the quartz monzonite maintains its character unchanged within half an inch of the boundary, but here it has a salic selvage, narrow dikes of which cut the granodiorite. This absence of contact chilling leaves

[1] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, p. 273, 1900.

little doubt that the quartz monzonite was intruded soon after the granodiorite.

The quartz monzonite is a coarsely granular aggregate consisting of plagioclase, orthoclase, quartz, hornblende, and biotite. It is characterized especially by large imperfect crystals of pearl-gray orthoclase, which give it a rude subporphyritic aspect. The plagioclase is white and contrasts plainly with the pearl-gray orthoclase; it is easily seen that the two kinds of feldspar occur in about equal quantities, and as a rule the rock is therefore readily recognizable as a quartz monzonite. It differs from the granodiorite most obviously in its coarser grain, its roughly phenocrystic orthoclase, and its megascopic quartz. Areally the quartz monzonite is nearly uniform in structure and mineral composition. The most noteworthy departure from this uniformity is in the tips of the apophyses that penetrate the lime-silicate rocks southeast of Ludwig; here the quartz monzonite grades into coarse pegmatite, which commonly shows local development of graphic structure and is in places slightly tourmaliniferous.

Under the microscope the potassium feldspar of the quartz monzonite proves to be mainly perthitic microcline. The characteristic plaid twinning of microcline is rather unequally developed, and some of the feldspar resembles orthoclase but is doubtless microcline, in conformity to the rule that microperthite is an "unmixed" solid solution in which the orthoclase has inverted to microcline during the "unmixing."[1] The plagioclase is an oligoclase of the composition $Ab_{75}An_{25}$, a composition found to prevail in specimens from widely separated localities. Quartz is prominent, and biotite and hornblende in about equal amounts are the dark minerals. Myrmekite (a peculiar intergrowth of quartz and microcline) is a subordinate constituent, and magnetite, titanite, apatite, and zircon are the accessory minerals. Epidote is a minor secondary constituent.

A chemical analysis of the quartz monzonite is given in column 2 on page 20; it fully confirms the mineralogic evidence in showing that the quartz monzonite differs notably in composition from the granodiorite. The content of potassa is somewhat lower than the megascopic evidence suggested, but this discrepancy appears to be due to the fact revealed by the microscope that the potassium feldspar is microperthitic. The specimen analyzed was obtained near Mickey Pass, and for comparison an earlier analysis of a specimen obtained by D. T. Smith about 1½ miles southwest of this locality is given (column 3); it agrees closely with the later analysis.

[1] Warren, C. H., A quantitative study of certain perthitic feldspars: Am. Acad. Arts and Sci. Proc., vol. 51, p. 151, 1915.

In chemical composition the granodiorite and quartz monzonite of the Yerington district resemble those of the Sierra Nevada, especially in their dominantly sodic character.

SCAPOLITIC ALTERATION.

The quartz monzonite is profoundly scapolitized at two localities—one west of the McConnell mine and the other on the 6,225-foot hill east of Ludwig. The second occurrence is the more noteworthy of the two. The quartz monzonite of this locality, which is several hundred feet from the contact, is traversed by a system of scapolite and epidote veins, and the intervening rock is scapolitized and epidotized on a large scale. The rock contains veinlike masses as much as 2 feet wide that consist solidly of white scapolite, which is in radial columnar groups attaining 8 inches in length. The adjoining wall rock, where it is not highly epidotized, resembles a coarse-grained gabbro, but under the microscope it proves to consist of scapolite, pyroxene, epidote, quartz, titanite, and apatite. Scapolite predominates; it is subhedral, and its refractive indices as determined by immersion in oils (ω 1.55 and ϵ slightly less than 1.54) show that it is practically a pure sodium scapolite. None of the original minerals of the quartz monzonite remain, except some quartz, and even this is in greatly reduced amount.

The scapolitic and epidotic alteration, it is clear, did not take place around blocks of sedimentary rock engulfed in the quartz monzonite but was determined in large measure by a system of steeply dipping joints along which the metamorphosing solutions flowed.

MINOR INTRUSIONS.

APLITE.

Aplite is not common in the district. It is practically absent from the granodiorite and quartz monzonite areas but occurs as sporadic dikes in the metamorphic rocks which they invaded. In places it is difficult to distinguish in the field aplites from felsites that have been thermally metamorphosed; and for this reason the amount of aplite shown in Plate I to occur southwest of the Bluestone mine is possibly too large. Although aplite occurs in the district, pegmatite does not, except for the very minor amount in the ends of the quartz monzonite apophyses. The aplite that cuts the large apophysis of quartz monzonite penetrating the granodiorite north of the Bluestone mine is a snow-white fine-grained rock wholly devoid of dark minerals. It is rudely porphyritic through the occurrence of quartz in small subhedral phenocrysts. Microscopically it proves to consist of orthoclase, oligoclase, and quartz. An aplite dike occurring in the garnetites and wollastonite rocks near the Bluestone mine is found under the microscope to be composed of albite and quartz.

QUARTZ MONZONITE PORPHYRY.

OCCURRENCE AND CHARACTER.

Dikes and stocks of quartz monzonite porphyry are common in the district. They cut all the pre-Tertiary rocks, inclusive of the aplites that followed the quartz monzonite intrusion. The dikes are particularly abundant in the granodiorite northeast of Ludwig, where they are noteworthy for their branching and gangliform character. They range from varieties so highly crowded with phenocrysts as to closely resemble granitic rocks to porphyries having an aphanitic groundmass. The porphyries of the stocks and the larger dikes are the most nearly granular, but even in dikes that are only 10 feet wide and traverse calc-silicate rocks the phenocrysts predominate over the groundmass.

A common feature of all the dikes is that the orthoclase occurs as large porphyritic crystals of pearl-gray color. Plagioclase phenocrysts are numerically more abundant but are much smaller. Hornblende is the sole ferromagnesian mineral; it is usually altered, commonly to epidote. Many of the plagioclase phenocrysts also are pseudomorphously altered to epidote; in fact, no material was found in any of the many dikes of the district that was wholly free from epidotization and as alteration of this kind is commonly associated with the copper metallization, it arouses the suspicion that the dikes afforded paths of escape for mineralizing solutions.

A certain range of chemical composition of the porphyries is indicated by the range in the abundance of quartz phenocrysts in different dikes. In some the prevalence of rounded dihexahedrons of quartz is the most obvious macroscopic character; in others, however, quartz phenocrysts are so rare that they can be found only after the most searching inspection. These differences suggest that the varieties practically devoid of quartz phenocrysts may be granodiorite porphyries that were injected shortly after the intrusion of the granodiorite and before the intrusion of the quartz monzonite; and that those dikes rich in quartz phenocrysts are quartz monzonite porphyries that were injected after the intrusion of the great mass of quartz monzonite. The crucial test of this hypothesis is in the intersection of the two kinds of porphyries, but although dikes are common in the district none were found to intersect. Furthermore, as there appears to be a gradation in degrees of prevalence of quartz phenocrysts in different dikes, it was felt to be rather too fine a distinction for field use to attempt to discriminate between granodiorite porphyries and quartz monzonite porphyry, and so all were mapped as quartz monzonite porphyry.

The porphyries differ from the granodiorite and quartz monzonite in the absence of biotite and, as shown by the microscope, in the absence of magnetite, which is an abundant accessory mineral in the granular rocks. They thus show an impoverishment in iron and magnesian minerals, indicating that at the time they were injected the parent magma had begun to differentiate, as indeed is indicated by another line of evidence, in that the porphyry dikes intersect aplite dikes that followed the intrusion of the quartz monzonite.

PETROGRAPHIC DETAILS.

Two porphyries, representing the extreme varieties in respect to the abundance of quartz phenocrysts, have been selected for special description. One of these was obtained from a mass of porphyry intrusive into the quartz monzonite southeast of Mickey Pass. It is a white rock that on casual inspection appears to be coarsely granular but on closer observation is seen to be highly porphyritic, a feature most apparent from the abundant corroded dihexahedrons of quartz. It carries sporadic large phenocrysts of orthoclase, innumerable striated crystals of glassy plagioclase, and lesser amounts of hornblende. The individual crystals of orthoclase are from 8 to 27 times as large as the individual plagioclase crystals, but as the phenocrysts of plagioclase far outnumber those of orthoclase the amounts of orthoclase and plagioclase present are roughly the same. At the contact with the quartz monzonite this almost granular porphyry has a notably chilled border. The resulting porphyry is characterized by its smaller phenocrysts, which amount to roughly half the bulk of the rock, and its aphanitic groundmass. Under the microscope the normal porphyry is found to carry phenocrysts of orthoclase, oligoclase, quartz, and hornblende in a groundmass that forms not over 15 per cent of the bulk of the rock. The orthoclase contains idiomorphic inclusions of plagioclase and titanite, as well as irregular patches of quartz suggestive of the "unmixing" of an originally homogeneous solid solution; the oligoclase dominates numerically and has the composition Ab_{70} An_{30}; the quartz crystals are magmatically corroded; and the hornblende is pale green, reedy, and anhedral. The groundmass is an irregular intergrowth of quartz and oligoclase, the oligoclase being in places poorly idiomorphic. Titanite and apatite are the accessory minerals; titanite is the more abundant and occurs as crystals nearly as large as the hornblende prisms.

The other porphyry selected for special description occurs in the hanging-wall country rock of the Ludwig lode. It carries scattered crystals of pearl-gray orthoclase ranging from 12 to 15 millimeters in length, innumerable plagioclase crystals averaging about 4 millimeters, and euhedral prisms of hornblende 10 millimeters long. So well does the groundmass blend with the rest of the rock that the general effect is that of a somewhat porphyritic monzonite. When examined under the microscope, however, phenocrysts and groundmass are found to be sharply contrasted and, as measured by the Rosiwal method, to be roughly equal in amount. The plagioclase, as in the other porphyry, is an oligoclase of the composition Ab_{70} An_{30}; some of the crystals are completely altered to epidote. The porphyry contains sporadic individuals of quartz which are highly corroded and very small, not exceeding 0.6 millimeter in length. The groundmass is an imperfect micrographic intergrowth of quartz and orthoclase. Titanite and apatite, occurring as comparatively large crystals, are the accessory minerals. Although this porphyry is macroscopically widely different from the other one, the microscopic analysis appears to minimize the difference in chemical composition that would be assumed to exist between them: In one the quartz is all in the groundmass and in the other it is mainly in the phenocrysts.

TERTIARY ROCKS.

THE SECTION IN GENERAL.

The Tertiary period is represented in the Yerington district by three major subdivisions, which are separated by two well-marked unconformities. The rocks are probably all younger than middle Miocene. The lowest member consists chiefly of rhyolite with some intercalated fluvial and lacustral sediments tilted at angles of 15° to 65°; the middle member consists of andesite; and the upper member consists of basalt in horizontal sheets capping a conglomerate. The Yerington section is thus dominantly volcanic, and it aggregates roughly 7,000 feet in thickness. The columnar section is shown in figure 3.

CONGLOMERATE AT THE BASE OF THE TERTIARY SECTION.

At the base of the Tertiary section there is generally a conglomerate resting on granodiorite. It consists of cobbles and of boulders as much as 6 feet in diameter, all of which are well rounded but are unsorted and unstratified. These features suggest that the conglomerate is probably of fluvial origin. Although consisting mainly of andesite cobbles, it contains sporadic boulders of granitic rocks and siliceous sediments. Boulders of granodiorite 6 feet in diameter were seen. The conglomerate is at most 150 feet thick. It is persistent enough to be mapped, and its distribution is shown on Plate I (in pocket).

LATITE SERIES.

LATITE VITROPHYRE.

A series of lavas, characterized by their columnar structure and dark-red or brown color on weathered surfaces, overlie the conglomerate. The basal member of this series is a highly distinctive flow of black porphyritic glass, which attains a maximum thickness of 100 feet. It rests on the conglomerate where that member is present, but elsewhere it lies directly on the granodiorite. It occurs at widely separated localities and invariably in the same stratigraphic position and is consequently a good horizon marker.

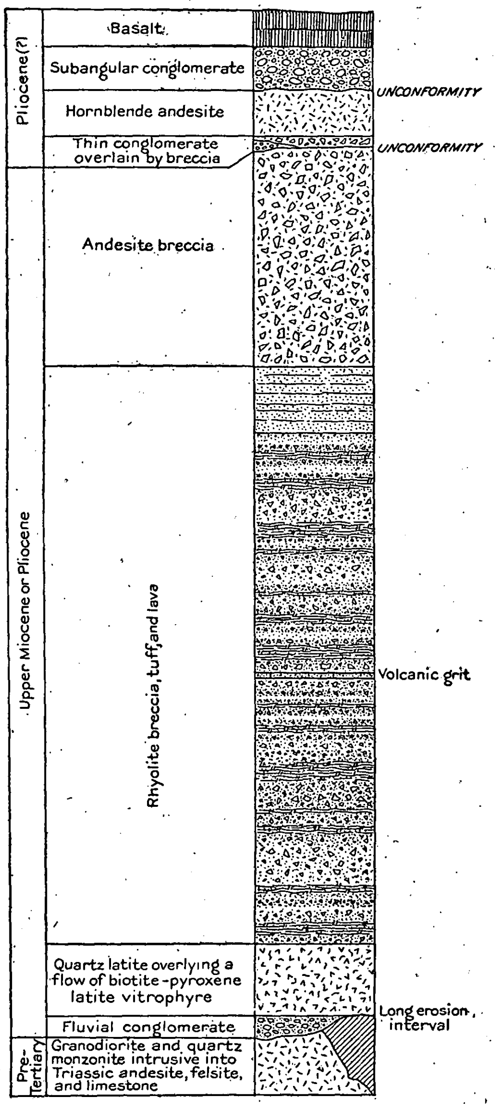


FIGURE 3.—Columnar section of the Tertiary rocks in the Yerington district.

The glass flow has at some localities an excellent columnar structure. The columns, which doubtless originally stood vertical, now dip at angles of about 30° E. as a result of the westward tilting of the latite series. The glass flow attains its greatest thickness, roughly 100 feet, near the Montana-Yerington mine; toward the south it gradually decreases in thickness, and west of Mason it is only 6 to 8 feet thick. On account of its thinness the glass flow has been mapped with the overlying series of quartz latites.

The vitrophyre is strikingly fresh, being coated only with a thin film of decomposition products. It consists of a black lustrous glass carrying numerous crystals of plagioclase and splendent foils of biotite. Under the microscope the vitrophyre shows a marked fluidal structure, which in its swirls incloses many phenocrysts, mainly of plagioclase, biotite, and pyroxene. The plagioclase, of the composition $Ab_{50}An_{50}$, predominates; it is generally more or less angular, but some of it is partly embayed. Sanidine occurs sparsely in some thin sections but fails in others, and it is evidently a rare constituent of the vitrophyre. Biotite, commonly bent, is the chief ferromagnesian mineral. Both augite and an orthorhombic pyroxene, which is either bronzite or enstatite, occur. Hornblende, magnetite, and apatite are accessory minerals. The glass is highly flow streaked, deep-brown glass alternating with light, almost colorless streaks, as may be partly seen in Plate II, *B;* it is completely isotropic, and its index is found by the immersion method to be 1.50. The microscope fully confirms the megascopic impression that the rock is ideally fresh.

The analysis of a specimen obtained northeast of Mason, given below in column 1, was made in the laboratory of the Geological Survey:

Analyses of lavas from the Yerington and Tonopah districts.

[George Steiger, analyst.]

	1	2
SiO_2	66.03	71.71
Al_2O_3	14.98	14.00
Fe_2O_3	1.65	1.06
FeO	1.67	.51
MgO	.99	.43
CaO	2.62	2.25
Na_2O	3.60	3.21
K_2O	4.34	4.41
H_2O-	.44	.44
H_2O+	2.46	1.38
TiO_2	.48	.28
ZrO_2	None.	....
CO_2	.07	....
P_2O_5	.11	.07
MnO	.07	....
BaO	.11	....
SrO	.08	....
	99.70	99.75

1. Biotite-pyroxene latite vitrophyre, Yerington district.
2. Dacitic rhyolite, Brougher Mountain, Tonopah.

The high potassa content is probably the most noteworthy fact disclosed by the analysis and shows that the vitrophyre falls into the latite group; the silica, however, is somewhat higher than in typical latites, corresponding rather with that of the rocks in recent years termed quartz latite. As only a small part of the potassa is contained in the biotite and the amount of sanidine in the vitrophyre is insignificant, the bulk of the potassa is locked up in the glass groundmass.

The analysis of the vitrophyre corresponds more closely with that of the Brougher dacitic rhyolite (column 2), as Spurr terms it in his latest report on the geology of Tonopah,[1] than with that of any other lava in that district.[2] It agrees closely in lime, soda, and potassa, but the Brougher rock, which in the nomenclature here employed would be called quartz latite, is somewhat higher in silica.

QUARTZ LATITES.

A distinctive series of lavas overlies the glass flow or, where the glass is absent, the conglomerate at the base of the Tertiary section. These lavas are characterized by their brown color and well-marked columnar structure. They are highly porphyritic, containing numerous crystals of plagioclase, quartz, and biotite; in the field they were therefore called dacites. In some of the lower flows the quartz phenocrysts are sparse or lacking, and consequently some of these flows resemble andesites. Toward the top of the series the quartz phenocrysts become abundant and sanidine appears and becomes prominent; in short, there is a complete gradation into the rhyolites of the overlying series. The boundary between them and the rhyolites drawn on the geologic map (Pl. I) is therefore purely arbitrary.

The lavas of this group are best shown along the east front of the range, in the northern part of the area mapped. The columnar structure is especially conspicuous here, and as the lavas weather dark red and brownish red the series, viewed in the large, is of basaltic aspect. The columns, of which part are hexagonal and part are of other perimeters, are 10 feet long and dip 15° E. The lavas aggregate several hundred feet in thickness here, 500 feet being probably the maximum, but they thin toward the south; near Mason only the basal glass flow is left, and this itself, as before noted, is but a few feet thick. They occur, however, on the west flank of the range.

A specimen taken from a flow immediately above the biotite-pyroxene latite vitrophyre proves microscopically to be a porphyry whose groundmass is a glass of markedly fluxional structure. Plagioclase ($Ab_{60}An_{40}$) predominates among the phenocrysts. Biotite is common. Quartz phenocrysts are rare, and sanidine in large sporadic crystals is still less common. In the flows higher in the sequence the microscope verifies the observation that the quartz and sanidine phenocrysts are abundant and shows that plagioclase is rare. In view of these features the lavas are called quartz latites.

RHYOLITE.

Rhyolite is the dominant Tertiary volcanic rock of the district. It makes up a thick series of tuffs, breccias, and lavas in which the pyroclastic members predominate. They are light-colored rocks, white, ash-gray, and pink being the principal colors. As a rule they are conspicuously porphyritic and carry numerous phenocrysts of quartz, sanidine, and biotite. They are quite uniform in mineral composition, and save a few scattered phenocrysts of plagioclase they carry none but the three minerals mentioned.

The rhyolites dip 15°–65° W., averaging about 45° W., and they trend nearly parallel to the range. Their attitude is readily determinable, as thin well-bedded volcanic grits are interstratified with them from place to place. A thin layer of such grits, containing considerable silicified wood, occurs 1,800 feet above the base of the rhyolites in the section west of Mason, and a belt of grits, 430 feet thick, occurs at the top of the section, near the Bluestone mine. The upper belt contains a conglomeratic bed 30 feet thick made up of a great variety of pebbles, including quartz and andesite, which range from angular to well rounded. The thickness of the rhyolite series, including the upper belt of grits, is about 4,000 feet.

Besides the grits mentioned, some thin lenses of coarse conglomerate, indicative of stream washes, are intercalated in the rhyolites. One of the more notable of these occurs at about

[1] Spurr, J. E., Geology and ore deposition at Tonopah, Nev.: Econ. Geology, vol. 10, p. 746, 1915.

[2] Spurr, J. E., Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, p. 57, 1905.

the horizon of the lower grit; it consists of well-rounded cobbles and boulders 6 feet in maximum diameter. The boulders comprise andesite, quartzite (or felsite?), and granite. Much rhyolite occurs between the boulders, but this is in angular fragments. These features clearly indicate the filling of a stream channel, in which the fragments that have been carried some distance from their sources, as is obviously true of the andesite, granite, and quartzite, are well rounded, whereas the material of local derivation is likely to be angular.

A conspicuous member of the rhyolite series is the tuff that forms the ridge just west of the Mason Valley mine. It is made up of fragments of rhyolite and crystals of quartz, sanidine, and sporadic biotite in a dense matrix which the microscope shows is composed largely of glass sherds. The structure is typically vitroclastic, as defined by Pirsson.

ANDESITE BRECCIA.

A coarse andesite breccia overlies the rhyolites conformably near the Bluestone mine. Above the grits near the top of the rhyolite series is a white rhyolite tuff overlain by a biotite andesite tuff. The andesite tuff is a light-gray rock containing numerous dark porphyritic fragments (probably andesite), angular crystals of plagioclase (labradorite), and biotite flakes, commonly in unbroken hexagonal crystals. The matrix proves under the microscope to be composed of finely comminuted glass sherds. Like other vitroclastic rocks in the district, it is firmly lithified.

The coarse andesite breccia, comprising fragments as much as several feet in diameter, rests above the biotite andesite tuff. It makes up the main part of the formation, which attains a thickness of 1,400 feet. The formation occurs only in a small area between the Mason Valley and Bluestone mines; originally it was doubtless somewhat thicker, as its upper limit is the strong fault that has brought the Tertiary rocks down against the Triassic. Locally, however, some rhyolite overlies it, but as shown in the lower tunnel of the Bluestone mine, 130 feet from the portal, this contact is highly sheared and slickensided, so that the relation of the overlying rhyolite to the andesite breccia is obscure.

The andesite of the breccia is a gray highly porphyritic variety, the phenocrysts forming half its bulk. Hornblende in stout prisms is the most conspicuous component to the unaided eye, but under the microscope the feldspar (labradorite) is seen to dominate strongly. The groundmass is glassy and contains innumerable minute crystals of feldspar. Biotite occurs sparingly together with the hornblende in some of the andesite.

HORNBLENDE ANDESITE.

A succession of andesite flows rests in places on the eroded edges of the rhyolites. These flows dip 25° E., whereas the underlying rhyolites dip 45° W. They are probably best exposed on the east scarp of the 5,995-foot hill northeast of Ludwig; the section here consists of a basal breccia, about 100 feet thick, overlain by five thin sheets of columnar lava. On the southwest side of the 6,100-foot peak the basal breccia is underlain by a thin conglomerate, as shown by the occurrence of well-rounded cobbles. The thickness of the andesite series appears not to exceed 300 feet.

A distinctive andesite predominates. It is a gray lava characterized by numerous slender prisms of hornblende in roughly parallel orientation and averaging 0.2 inch in length. It carries no feldspar phenocrysts. Under the microscope the hornblende phenocrysts are seen to be embedded in a holocrystalline fluidal groundmass composed largely of feldspar prisms near $Ab_{50}An_{50}$ in composition, together with subordinate augite and accessory magnetite and apatite. This rock may be termed a hornblende andesite, to distinguish it from other andesites in the district, though that term is commonly given to andesites carrying both plagioclase and hornblende phenocrysts.

The hornblende andesite occurs as dikes in many of the rocks of the district. It cuts the quartz monzonite porphyry near Yerington station, is intruded along a fault separating quartz monzonite from limestone in the McConnell mine, and is fairly common as thick dikes cutting the rhyolites.

CONGLOMERATE.

The next younger member of the Tertiary sequence is a mass of loosely cemented gravel or conglomerate, represented chiefly by the deposits occurring beneath the basalt-capped mesas southwest of Mason. They comprise a wide variety of rocks, including much rhyolite, and are subangular and poorly sorted. Their greatest thickness is 300 feet.

A body of similar material occurs east of the Mason Pass road, not far from the Martha Washington prospect. It is composed largely of subangular fragments of different varieties of andesite; granitic rocks are fairly common, but rhyolite is scarce. Boulders as much as several feet in diameter occur in it. Prospect pits show it to be unshingled, unsorted, and unstratified.

BASALT.

Basalt is the youngest igneous rock in the district. It caps the high mesas in the southern part of the area mapped and is generally underlain by gravels. It forms a superposed succession of nearly horizontal flows, which aggregate 200 feet in thickness. It has been slightly tilted since it was erupted and has been much faulted; in fact, the present relief of the range has resulted largely from postbasaltic faulting.

The basalt is a dark rock showing to the unaided eye sporadic small phenocrysts of pyroxene only. Microscopically it proves to be composed essentially of calcic labradorite and augite. The labradorite predominates; the larger crystals are euhedral, but as there is a continuous gradation between these and the smallest the structure approaches the seriate porphyritic. The augite is in two generations, the earlier crystals as phenocrysts, about the size of the largest feldspars, and the later as small prisms and grains lying interstitially between the smaller feldpsars. Olivine occurs sporadically in small grains, but most of it has altered to iddingsite. Magnetite is a minor accessory mineral.

CORRELATION OF THE TERTIARY ROCKS.

The andesitic detritus in the fluvial conglomerate at the base of the local Tertiary section shows that the eruption of the volcanic rocks now occurring in the Yerington district had been preceded in earlier Tertiary time by the eruption of an andesitic series.

The rhyolites, including the underlying quartz latites and the glass flow and the conformably overlying andesite breccia, probably correspond in age to the Esmeralda formation, which consists of lacustral beds, tuffs, and intercalated terrestrial deposits. They appear to represent a phase of the Esmeralda formation that accumulated in an area where volcanic aggradation predominated. The age of the Esmeralda formation has recently been shown by Merriam [1] to be approximately upper Miocene. The correlation proposed is suggested (1) by the similarity of stratigraphic relations: the rhyolites are younger than a preexisting andesite series, as is true of the Esmeralda formation, which overlies unconformably a series of andesitic lavas and is itself unconformably overlain by later lavas; [2] (2) by a certain amount of lithologic resemblance: much rhyolite tuff and andesite (latite) tuff occur in the Esmeralda; [3] (3) by the fact that the degree of tilting and amount of faulting of the two formations are of the same order; and (4) by the paleontologic evidence.

No fossils were found in the rhyolitic series during the present examination, but some fragments of vertebrate bones had been obtained by Smith [4] 10 miles east of Yerington, in rocks that he regarded as belonging to the same formation. The fossils were originally reported on by W. J. Sinclair,[5] who pronounced them to be "probably late Miocene or Pliocene." Since this determination was made knowledge of the Great Basin faunas has increased greatly, and it seemed desirable to review the evidence in the light of the new information. Prof. J. C. Merriam has kindly reexamined the original collection and reports as follows: [6]

> The collection consists of a few fragments and the greater part of an ankle bone. The fragments are indeterminable. The ankle bone represents a large camel, which seems to me to be specifically different from the large species represented by an ankle bone from the Cedar Mountain or Esmeralda beds. One could not safely state more than that the formation from which these bones came is somewhere between middle Miocene and middle Pliocene.

QUATERNARY DEPOSITS.

The Quaternary deposits consist of gravel, sand, and silt. The gravel is angular and unsorted and occurs in a series of alluvial

[1] Merriam, J. C., Tertiary vertebrate fauna from the Cedar Mountain region of western Nevada: California Univ. Dept. Geology Bull., vol. 9, pp. 165-172, 1916.

[2] Buwalda, J. P., Tertiary mammal beds of Stewart and Ione valleys in west-central Nevada: California Univ. Dept. Geology Bull., vol. 8, p. 348, 1914.

[3] Turner, H. W., Contribution to the geology of the Silver Peak quadrangle, Nevada: Geol. Soc. America Bull., vol. 20, pp. 254-255, 259, 1910.

[4] Smith, D. T., California Univ. Dept. Geology Bull., vol. 4, p. 8, 1905.

[5] Idem, p. 10.

[6] Letter of Nov. 9, 1916.

cones along both flanks of the range; laterally it grades into the silts of the valley bottoms. Thick deposits of clean sand of obscure origin occur toward the heads of some of the canyons, notably in Sand Canyon, where sand is present up to altitudes of 5,600 feet. These deposits are now deeply dissected.

No Lahontan beach lines occur in the district. The elevation of the Lahontan beach around Walker Lake, as determined from the position shown on Plate XV of Russell's monograph[1] and from the altitudes in the Hawthorne quadrangle, is approximately 4,250 feet, which is somewhat lower than Russell's own estimate—4,378 feet.[2] As the lowest altitude in the mapped area of the Yerington district is 4,350 feet, the absence of strand lines conforms with the probabilities.

GEOLOGIC STRUCTURE.

The geologic structure of the district is rather intricate in detail. This is especially true of the area underlain by the Triassic limestones and associated rocks—the area that is of main economic interest. The Triassic consists of steeply tilted rocks, greatly faulted, extraordinarily metamorphosed, and intruded by numerous igneous rocks. Upon the eroded surface of these older rocks rests a series of Tertiary rocks, dominantly of volcanic origin. These are of broadly simple structure, though examination soon discloses that they conceal a rather eventful tectonic history. (See Pls. I and III.)

Three periods of faulting at least can be recognized—one accompanying the intrusion of the Cretaceous igneous rocks, and two in the Tertiary; of these the last is postbasaltic.

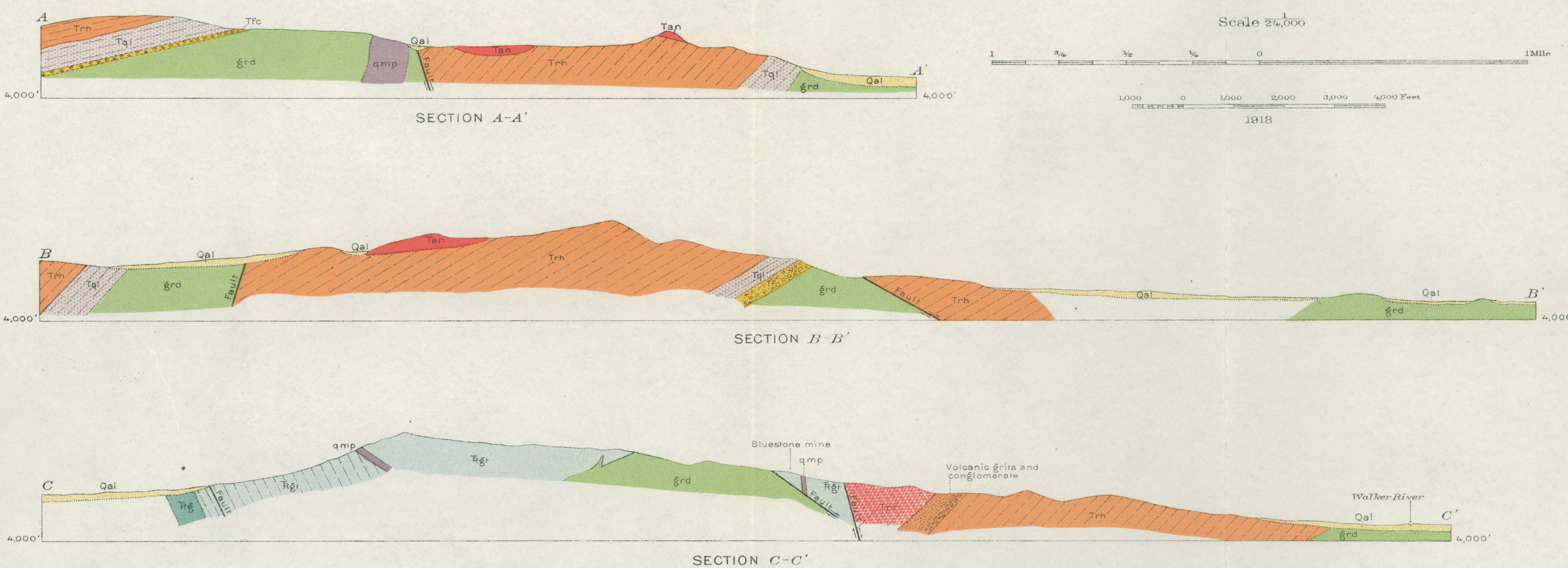
The earliest faulting that can be dated approximately is that which occurred soon after the intrusion of the quartz monzonite porphyry dikes, though it is probable that some faulting accompanied the intrusion of the granodiorite and quartz monzonite. Many of the dikes are broken by faults, and along some of these faults contact-metamorphic silicates have formed, as is well shown, for example, near the boarding house at the Malachite mine, where masses 20 feet wide composed of garnet, epidote, and lamellar pyroxene occur along the fault contact between limestone and felsite. The silicates replace both limestone and felsite but mainly the limestone. Contact-metamorphic silicates occur along other faults, many of which were first recognized during the field work by the fact that the porphyry dikes abut against them. It is noteworthy that the ends of some of the dikes abutting upon the faults have been profoundly epidotized or garnetized. Copper-bearing minerals occur in some of the belts of silicates along the faults, and such faults were thus places of ore deposition; but this phase of the matter is discussed in more detail elsewhere in this report. The development of garnet and allied silicates, minerals that form only at relatively high temperatures, proves, then, that these faults were formed shortly after the injection of the dikes that they displace.

The displacement can rarely be determined, as the severed ends of the dikes on opposite sides of the faults as a rule can not be found. This would appear to indicate that the faults are generally of considerable magnitude. Some, in fact, clearly represent large displacements, inasmuch as rocks widely separated stratigraphically have been brought into contact, as near the Western Nevada mine, where andesite has been brought against massive limestone.

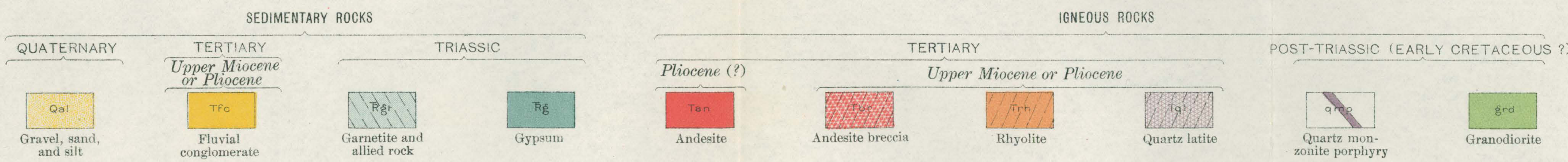
During the Tertiary period faulting occurred on a large scale, certainly at two different times and probably at three different times. The earliest faulting coincided with the tilting of the rhyolites. It was during this deformation that the rhyolites were faulted down against the pre-Tertiary rocks. As shown by the structure sections in Plate III, these faults involve vertical displacements of 5,000 to 10,000 feet; but owing to the lack of close, detailed study of the rhyolite area north of Mickey Pass it can not be affirmed that displacements of this total magnitude were effected along single fault surfaces. One of the most prominent faults of this set is well shown at the Mason Valley and Bluestone mines, and it is cut by the lowermost tunnel of the Bluestone mine, where it dips 75° E. Its throw is undoubtedly several thousand feet. The faults of this age strike not only parallel to the range but also at right angles to its trend; they dip from 25° to 75°.

[1] Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, 1885.

[2] Idem, p. 101.



GEOLOGIC SECTIONS ACROSS THE YERINGTON DISTRICT, NEVADA



A.Hoen & Co.Lith.Baltimore, Md.

The fault that separates the granodiorite from the garnetites at the Bluestone mine and continues to the Western Nevada, where it separates the quartz monzonite from the metamorphic limestones, probably was formed at about this time. It is certainly younger than the faults that displace the porphyry dikes, as it cuts off these faults.

Faulting occurred also after the extrusion of the hornblende andesite. A small mass of andesite along the west flank of the range north of Ludwig has been faulted against the rhyolites; at one place the fault surface forms a cliff face, 15 feet high and 50 feet long, trending N. 35° E. and dipping 75° W. (See Pl. III, section B–B′.) This displacement may mark a separate epoch of faulting but may possibly coincide with that discussed in the next paragraph.

Severe faulting took place after the basalts were erupted. The present relief of the portion of the range south of Mason is rather obviously due to postbasaltic faulting. The basalt that caps the range is broken by a series of step faults forming a succession of treads; the base of the lowermost, just south of Sand Canyon, is at an altitude of 5,000 feet, the base of the middle tread at 5,500 feet, and the base of the highest at 5,800 feet.

Sand Canyon is a rift valley resulting from the downfaulting of a block between two parallel faults trending at right angles to those that have determined the front of the range. The faults are about 1,000 feet apart, and the rocks lying between them are extremely brecciated.

Although the postbasaltic faults are mainly normal faults, such as those along the front of the range south of Sand Canyon, just described, reverse faulting has occurred to some extent. This is best shown near the McConnell mine, and the fault plane itself is well exposed in the upper tunnel (fig. 4). It is sharply defined, dipping 54° W.; the basalt, which forms the footwall, is considerably shattered near the fault plane, and the overlying limestone is highly brecciated for more than 20 feet from the fault plane. The mine workings disclose that the dip slip is at least 150 feet.

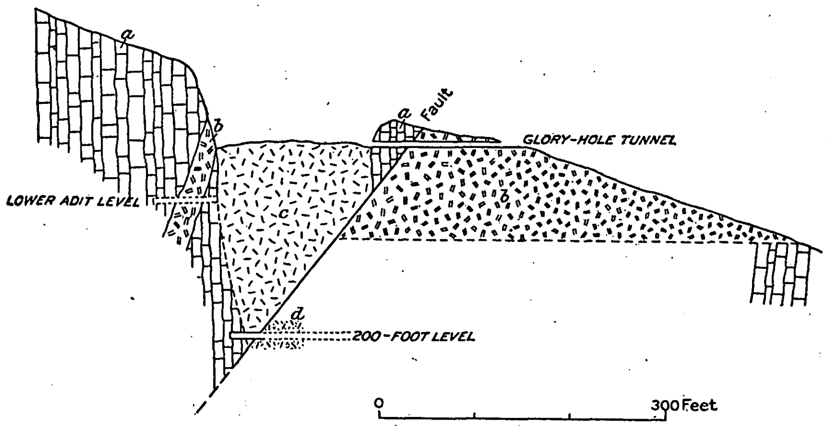


FIGURE 4.—Section through the glory-hole tunnel of the McConnell mine. *a*, Limestone; *b*, basalt; *c*, garnet rock and ore; *d*, Triassic andesite.

EPITOME OF THE GEOLOGIC HISTORY OF THE DISTRICT.

The oldest geologic records of the district date back to the Triassic period. At this time 4,000 feet of andesitic and dacitic lavas, breccias, and tuffs were erupted, which were succeeded by a peculiar series of soda-rich felsite lavas and tuffs. Marine conditions then prevailed, and limestones mainly were laid down, interrupted, however, by occasional eruptions of felsite. At one time during the Triassic a bed of gypsum, as much as 450 feet thick, was deposited.

These rocks were folded, probably in the beginning of Cretaceous time, and were intruded, probably early in the Cretaceous, by large masses of granodiorite and quartz monzonite. These intrusions were followed by others that brought in minor amounts of aplite and considerable amounts of quartz monzonite porphyry. Faulting occurred during and immediately after this epoch of intrusion, and as a sequel to the intrusive activity the ore bodies were formed.

A long period of erosion then ensued, during which the Triassic rocks were in places entirely removed and the granitic rocks were laid bare over wide areas. Volcanic eruptions followed, probably in the later part of the Miocene, and buried the fluvial deposits that had accumulated on the surface eroded upon the older rocks. The relief of this surface on which the Tertiary rocks accumulated appears to have been moderate, though on account of the small exposures and the profound faulting to which the rocks of the region have been subjected this conclusion is not firmly established. At any rate, the streams that flowed on this surface appear to have been powerful, as is indicated by the well-rounded boulders, 6 feet in diameter, occurring in their gravels.

The volcanic activity began with the effusion of a distinctive flow of black glass, a latite vitrophyre; this flow was succeeded by quartz latites, which are especially characterized by their columnar structure; and upon these were piled about 4,000 feet of rhyolites and 1,400 feet of andesite breccia. From time to time during the general period of eruptive activity fluvial and lacustral conditions prevailed; the most noteworthy of these interruptions led to the deposition of 430 feet of lake beds, which occur at the top of the rhyolites and underlie the andesite breccia. This succession of rocks, beginning with the vitrophyre at the base of the section and including the andesite breccia at the top, appears to correspond to the Esmeralda formation, which is now believed to be of late Miocene age.

After the deposition of these rocks a period of pronounced diastrophism set in, the most vigorous in this part of Nevada during Tertiary time. The rhyolites were tilted at angles of 25° to 65° and were greatly faulted, the rocks being displaced stratigraphically to the extent of thousands of feet. Erosion ensued, and subsequently andesites were erupted, now resting at low angles upon the worn edges of the rhyolites. This eruptive outburst was extremely moderate and is represented by only a few hundred feet of lava.

After the andesitic extrusion erosion again began. Rather extensive deposits of gravels accumulated, in places as much as 300 feet thick; their unsorted, subangular character suggests that they are of fanglomerate origin. Eruptive forces, the final manifestation of volcanism in the district, once more became active, and a series of basalt flows was poured out. The basalts, although nearly horizontal, have been considerably faulted, and this period of vigorous diastrophism is held to mark the beginning of Quaternary time. The faulting that took place at that time blocked out the Singatse Range largely as we see it now. Since this faulting the deep canyons opening out upon Mason Valley have been excavated, and the material thus derived has built up a series of alluvial cones fronting the range.

Part II. THE ORE BODIES.

GENERAL FEATURES.

The main ore bodies of the Yerington district are copper-bearing deposits characterized by a gangue of either pyroxene, garnet, or epidote or a mixture of these minerals. Chalcopyrite is the chief copper-bearing mineral; pyrite is commonly associated with it, but no other primary sulphides occur in the district.

The deposits belong to the contact-metamorphic group. The primary ore is essentially unenriched by later sulphides, for supergene covellite and chalcocite, although occurring locally, are as a rule not abundant.

Ore bodies of this kind have yielded the bulk of the metal output. The average tenor of the ore mined has ranged from 2.75 to 6 per cent of copper, with gold and silver present in traces only. Among the representatives of this group are the ore bodies of the Bluestone, Mason Valley, Ludwig, Douglas Hill, Casting Copper, and McConnell mines.

Other types of the copper deposits are sparingly represented in the district and as a whole are of minor economic importance. They are exemplified by the irregular bodies of rich cuprite ore in quartz monzonite porphyry at the Empire-Nevada mine and by the fissure veins in quartz monzonite and quartz monzonite porphyry.

MINERALS OF THE ORE DEPOSITS.

PRIMARY MINERALS.

Actinolite.—A finely fibrous amphibole is common in some of the ore bodies, notably in that of the Mason Valley and to a lesser extent the McConnell and Western Nevada mines. Under the microscope it is pale green and feebly pleochroic, and it is therefore identified as actinolite. In some of the ore of the Mason Valley mine pyrite is molded around fibers of tremolite, or the tremolite "cuts" the pyrite; which of these two explanations is the correct one it is impossible to decide, though the former appears the more probable.

Albite.—Albite was detected microscopically as a minor component of some of the gangue in the Bluestone mine, where it occurs together with pyroxene, garnet, epidote, calcite, pyrite, tremolite, and apatite.

Andradite.—The garnet associated with the ores proves invariably to be an andradite. It varies widely in color, from pale amber to amber-brown, grayish green, and resin-yellow. Crystals of very different shades occur close together in the same hand specimens, and conformably with what Goldschmidt found in the Christiania district, color proves not to be a reliable index as to whether the garnet is grossularite or andradite. The garnets as a rule are partly faceted, the dodecahedral habit being almost universal, but trapezohedral faces are occasionally to be found.

To determine approximately the composition of the garnets, numerous specimens were examined by the immersion method; they were found to have refractive indices ranging from 1.83 to 1.87. Those of index 1.86 predominate, corresponding to a garnet in the grossularite-andradite series containing about 80 per cent of the andradite molecule. Under the microscope the garnets are commonly found to show a wide range of optical anomalies. The garnets may either be divided into six birefringent sectors or the narrow outer zones may be birefringent, which is probably the most common type, or they may show a highly complex structure. The maximum birefringence is 0.009.

The garnet rock of the Casting Copper mine consists largely of resin-yellow garnet. Under the microscope the deep-yellow garnet, whose refractive index is 1.86, is found to be completely isotropic. A paler garnet, whose index is 1.83, is also present, in part peripheral to the deeper-colored garnet and in part interstitial. It is complexly built, is strongly birefringent, and in places has a well-marked parting. Accessory minerals are calcite, quartz, chlorite, apparently primary, magnetite, and apatite.

Apatite.—Apatite is an accessory mineral in all the contact-metamorphic ores. It occurs as small euhedral prisms embedded in the silicates and in the quartz. It is more abundant at the Bluestone mine than elsewhere in the district.

Biotite.—An extremely close grained black rock occurring in the footwall of the Mason

Valley mine proved to be a felsite tuff whose clastic structure has been veiled by the metasomatic development of finely flaky biotite.

Calcite.—Calcite is common as in interstitial filling in the contact-metamorphic ores. The garnet, pyroxene, and allied silicates, as well as the quartz and albite, are invariably idiomorphic against it.

Chalcopyrite.—Chalcopyrite is the sole primary copper-bearing mineral found in the Yerington district and as such is the ultimate source of all the copper in the primary, oxidized, and enriched ores that are mined in the district. The chalcopyrite that is inclosed in an andradite gangue alters commonly during oxidation directly to copper pitch ore. In ore enriched by supergene sulphides chalcopyrite has altered to covellite or chalcocite, while the associated pyrite has remained intact.

Chlorite.—Chlorite has been noted as a minor constituent of the ores of the McConnell and Western Nevada mines.

Epidote.—The silicate epidote occurs most abundantly at the Bluestone mine, where it forms the larger part of the gangue. It has originated there principally through replacement of garnet and pyroxene rocks formed during the epoch of metamorphism following the quartz monzonite intrusion. Epidote is also a minor constituent in the pyroxenic and garnetiferous ores of the district, in which it is coeval with the other silicates. The intense pleochroism and high refractive indices indicate that the epidote in these deposits is a variety high in ferric iron.

Garnet.—Garnet is extremely common. Two varieties may be distinguished—a fine-grained massive variety commonly near grossularite in composition and a coarse-grained variety commonly showing crystalline facets and near andradite in composition; the latter is the variety associated with the ores, as described in preceding paragraphs.

Hematite.—Finely micaceous hematite is associated with the chalcopyrite in the Montana-Yerington vein.

Magnetite.—Magnetite is a rare constituent of the Yerington ores and as a rule is detected only with the microscope.

Pyroxene.—Garnet and pyroxene are the chief gangue minerals of the contact-metamorphic ore. The relative proportions of the two vary widely, however, in different deposits; in the Mason Valley ore body the gangue is principally pyroxene, and in the Douglas Hill ore body it is almost wholly andradite. The pyroxene is a grayish-green variety of lamellar habit. It is coarsely crystalline and commonly forms radial groups 2 or 3 inches in diameter, though some as much as 10 inches across are occasionally found.

A carefully selected specimen of pyroxene from the 300-foot level of the Mason Valley mine was analyzed by R. C. Wells in the laboratory of the Geological Survey. Microscopic examination showed it to contain a small amount of calcite and a trace of pyrite. Calculation of the analysis discloses that the pyroxene is a variety almost exactly halfway intermediate in composition between diopside and hedenbergite. Its extinction angle is 45° and its maximum refractive index as determined by the immersion method is 1.71.

Analysis of pyroxene from the Mason Valley mine.

[R. C. Wells, analyst.]

SiO_2	50.59
Al_2O_3	.11
Fe_2O_3	1.18
FeO	13.05
MgO	9.19
CaO	23.03
Na_2O	.15
K_2O	.16
H_2O-	.71
H_2O+	.58
TiO_2	.13
ZrO_2	.02
CO_2	1.52
P_2O_5	Trace.
S	.02
Cr_2O_3	None.
V_2O_3	Trace.
MnO	.26
BaO	None.
	100.70

Computed composition of material analyzed.

Diopside ($CaMgSi_2O_6$)	44.73
Hedenbergite ($CaFeSi_2O_6$)	45.74
Alkali pyroxenes:	
$K_2O.Al_2O_3.4SiO_2$	.44
$K_2O.Fe_2O_3.4SiO_2$	.50
$Na_2O.Al_2O_3.4SiO_2$	.93
$MgO.Fe_2O_3.SiO_2$	1.04
Calcite	3.50
Quartz	2.04
Titanite	.40
Pyrite	.04
	99.36

Pyrite.—Pyrite and chalcopyrite are the only two primary sulphides in the district. Their relative proportions vary widely in different deposits: In the Mason Valley mine, for example, the pyrite averages about twice the chalcopyrite in amount, but in the Douglas Hill mine it occurs in not more than traces.

Quartz.—Quartz occurs from place to place as a minor constituent of the contact-metamorphic ores. It incloses idiomorphic garnet, pyroxene, epidote, and apatite.

Tourmaline.—Tourmaline is an accessory epigenetic mineral in the biotitized felsite tuff occurring in the footwall of the Mason Valley ore body.

Zircon.—Zircon is found as a residual mineral in the silicified, garnetized, and pyritized dikes of quartz monzonite porphyry that occur in some of the ore bodies, notably the Ludwig lode.

SECONDARY MINERALS.

Azurite.—The blue copper carbonate azurite occurs rarely in the oxidized ores of the district.

Brochantite.—Brochantite, the basic sulphate of copper, occurs as small glassy emerald-green prisms in vugs in the oxidized ore of the Douglas Hill mine.

Chalcanthite.—Chalcanthite, or bluestone, as it is generally known in the district, formerly occurred in minable quantities in the outcrops of most of the ore bodies. It is still common in the outcrops at the Bluestone mine, where it forms networks of veinlets traversing oxidized gypsiferous material. The veinlets have a cross fibrous structure.

Chalcedony.—Chalcedony occurs in small quantity in the siliceous gossan of the Ludwig lode.

Chalcocite.—As a supergene sulphide chalcocite is found in small quantity in the district. It has formed almost wholly at the expense of chalcopyrite and is generally associated with gypsum. In polished sections it proves to be a porous blue variety. Rogers [1] has presented a photomicrograph of a polished section showing chalcopyrite from the Ludwig mine partly altered to chalcocite.

Chrysocolla.—The term chrysocolla is here used to designate the bluish-green opal-like substance that occurs in the oxidized ores of the district—a hydrous copper silicate, evidently of colloidal origin. Under the microscope it is found that probably several different minerals are grouped under the term "chrysocolla" and that the original colloid has generally become crystalline. Some chrysocolla from the Douglas Hill mine proves to be a cryptocrystalline aggregate having a refractive index of 1.47 and a barely perceptible birefringence. Other chrysocolla, however, forms brightly birefringent spherulites, whose fibers are elongated optically positively and whose indices are both below 1.54. The copper pitch ore, which is regarded as of colloidal origin like the chrysocolla, except that ferric hydrate was precipitated along with the copper and silicon hydrates, is an isotropic substance; in this respect the relation between chrysocolla and copper pitch ore resembles that between chalcedony and ferriferous opals, in that the entangled ferric compound has prevented the crystallization of the colloid.[2]

Under high powers of the microscope the chrysocolla, especially that occurring in embayments in andradite, shows a brecciated structure, consisting of multitudes of curved fragments, which have evidently resulted from the bursting of colloidal membranes by osmotic forces.[3]

Copper.—Native copper occurs sparingly in the oxidized ores of the district. In the Ludwig mine it is intimately associated with cuprite in ore from the 600-foot to the 800-foot levels.

Copper pitch ore.—A brown or brownish-red substance of pitchy luster and conchoidal fracture is common in the oxidized ores of the district. It is locally spoken of as "copper oxide" but is perhaps better termed copper pitch ore, a substance which Von Kobell long ago showed is a mixture of chrysocolla and limonite. Mixtures of cupric and ferric hydroxides are also included under this term. According to present conceptions copper pitch ore is doubtless a colloidal complex of hydroxides of copper, iron, and silicon and is of variable composition. Copper pitch ore from the Greenwood prospect reacts strongly for copper

[1] Rogers, A. F., Min. and Sci. Press, vol. 109, p. 683, 1914.

[2] Liesegang, R. E., Geologische Diffusionen, p. 100, 1913.

[3] Liesegang, R. E., Ein Membrantrümmer-Achat: Centralbl. Mineralogie, 1912, pp. 65–67. Knopf, Adolph, Wood tin in the Tertiary rhyolites of northern Nevada: Econ. Geology, vol. 11, pp. 657–661, 1916.

and iron; examined in oils it proves to be a completely isotropic substance having a refractive index of 1.68. It is a clear deep brown, but it is so strongly colored that only the minutest particles and the edges of the larger grains are translucent.

Covellite.—Covellite is common, though not abundant, as a supergene sulphide which has been precipitated largely at the expense of the original chalcopyrite in the ore. It has developed in part parallel to what is probably the pyramidal cleavage of chalcopyrite. Under high powers of the metallographic microscope the plates of covellite are seen to have exceedingly irregular edges.

Cuprite.—Cuprite is most abundant in the ore of the Empire-Nevada mine, forming small masses in fractured quartz monzonite porphyry. It is disseminated through the veins and bodies of copper pitch ore of the Ludwig mine, which are inclosed in the limestone footwall of the lode. It extends down in this mine to the lowest level at a vertical depth of 675 feet.

Gypsum.—Gypsum is extremely common in the oxidized ores, occurring not only in veinlets but also in plates thoroughly disseminated through the ores. During the replacement of calcite by chrysocolla the calcite near the advancing chrysocolla becomes filled with plates of gypsum, as is well shown at the Ludwig mine, but the chrysocolla itself is free from gypsum, showing that the gypsum has but a transient existence in this process.

The clear transparent variety of gypsum called selenite is common in the Ludwig mine; it occurs down to the 600-foot level, where it forms in the vugs in the quartzose ore of the "selenite stope" fine prisms as much as 8 inches long.

Libethenite.—Libethenite, a hydrous phosphate of copper, was noted by Ransome[1] to occur sporadically in the oxidized ore of the Ludwig mine in crystalline aggregates resembling malachite. Smith[2] had earlier discovered this mineral at the Blue Jay mine, east of the town of Yerington, and Schaller[3] has described the crystals found.

Malachite.—The copper carbonate malachite occurs in all the oxidized ores in small amounts but is distinctly subordinate to the copper silicates, the chrysocolla and the copper pitch ore.

Opal.—A small amount of opal was found microscopically to occur in the siliceous outcrop of the Ludwig lode.

CONTACT-METAMORPHIC ORE DEPOSITS.

GEOLOGIC ENVIRONMENT.

COMPOSITION OF THE ROCKS INCLOSING THE ORE DEPOSITS.

The principal copper deposits of the district, characterized by their pyroxene, garnet, or epidote gangue, have, with one notable exception, been formed by the replacement of limestones. The Bluestone ore body, the exception alluded to, consists essentially of chalcopyrite in an epidote gangue and was produced by the replacement of brecciated garnetite and allied silicate rocks.

The limestone beds in which the ore bodies developed are shown in the following paragraphs to have been relatively pure calcite rocks. Their chemical composition is a matter of some theoretical interest. Lindgren and others have presented evidence to show that ore bodies of this type have commonly formed in limestones of extreme purity. Leith and Mead,[4] however, consider the evidence thus adduced to be doubtful and inadequate, inasmuch as the specimens chosen for analysis represented only single strata, and they emphasize the fact that to obtain evidence of conclusive value samples must be taken across the full width of the ore zones.

Analyses of the limestone in the ore-bearing zone of the Mason Valley mine of the Yerington district are available that in large measure meet Leith's requirement. The limestone was used as smelter flux and hence was carefully analyzed for lime and silica but less carefully for other constituents. A glory hole 200 feet long, 60 feet wide, and 75 feet deep was opened up. The limestone is mainly in beds ranging from 5 to 10 feet in thickness but includes some thinly banded varieties. The beds strike north and dip 70° or more westward; the longer axis of the glory hole is parallel to the strike of the strata. In column 1 of the subjoined table is given an average of seven analyses of limestone from the stope, and in column 2 an average of four analyses of limestone from the "new stope"

[1] Ransome, F. L., U. S. Geol. Survey Bull. 380, p. 113, 1909.
[2] Smith, D. T., California Univ. Dept. Geology Bull., vol. 4, p. 31, 1905.
[3] Schaller, W. T., U. S. Geol. Survey Bull. 262, pp. 140-143, 1905.
[4] Leith, C. K., and Mead, W. J., Metamorphic geology, p. 148, 1915.

situated in the immediate hanging-wall country rock of the ore-bearing zone; from this stope limestone flux is now being obtained. The individual analyses do not vary widely from the average figures.

Analyses of limestone from Mason Valley mine.

	1	2
CaO	46.9	48.5
MgO	2.3	.6
SiO_2	9.1	5.7
Al_2O_3	4.0	2.2
Fe_2O_3	1.1	2.3
CO_2 (theoretic)	39.4	38.7
	102.8	98.0

In these analyses, according to the smelter manager, the lime and silica were carefully determined, as these are the constituents of importance in calculating the furnace charge, and the determinations of the other oxides are of nominal value only. The defective summations of the analyses are doubtless due to this imperfect determination of the minor constituents.

The analyses concur in showing that the limestones of the ore-bearing zone and of the hanging wall are relatively pure; they are slightly siliceous but are low in magnesia, alumina, and iron.

Two specimens of limestone obtained from the south end of the ore zone on the No. 3 level of the Mason Valley mine were analyzed in the laboratory of the United States Geological Survey. The great ore lens on the south end of this level extends obliquely across strata of limestone of different colors, ranging from light bluish white to dark gray or black. These beds carry a few fibers of tremolite and sporadic cubes of pyrite. The limestone represented by column 1 of the subjoined table, taken 20 feet from the edge of the ore body, is a dark-gray, almost black crystalline limestone; under the microscope it proves to consist preponderantly of calcite grains, with accessory tremolite and pyrite. The limestone represented by column 2, taken from rock immediately adjoining the solid andradite of the periphery of the ore body, is a light-gray, rather dense limestone; under the microscope it proves to consist essentially of calcite and a few scattered fibers of tremolite.

Analyses of limestone from Mason Valley mine.

[W. C. Wheeler, analyst.]

	1	2
CaO	52.12	51.63
MgO	.84	3.17
SiO_2	3.04	1.80
Al_2O_3	1.39	.14
Fe_2O_3 (total)	.64	.17
CO_2 (theoretic)	41.87	44.02
	99.90	100.93

These analyses show that the two specimens selected are somewhat purer than the average as found by the smelter determinations. The analyses are of the same general purport, however, and confirm the statements made as to the essentially nonmagnesian character of the limestone of the ore-bearing zone and their low content of silica, alumina, and iron.

The ore bodies at the other mines in the district have formed in coarse calcite rocks, which without doubt are of the same general character as the limestones analyzed.

RELATION OF THE ORE DEPOSITS TO FAULTING AND BRECCIATION.

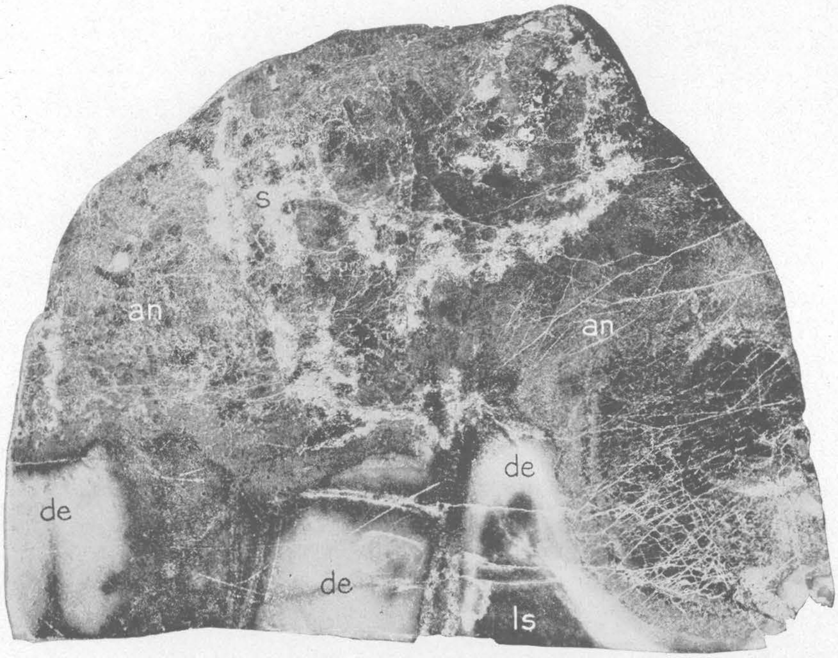
The ore deposits are situated on or near fault contacts. Commonly the faults separate dissimilar rocks, such as limestone from felsite, andesite, or stratified calc-silicate rocks. That the faulting occurred before the ore bodies were formed is established by the following structural relations: (1) The faults displace the quartz monzonite porphyry dikes, and the severed ends of the dikes and the fault drag from the dikes have been metamorphosed by the ore-forming solutions: the brecciated quartz monzonite porphyry at the Bluestone ore body, which is an epidote-chalcopyrite deposit, is profoundly epidotized and pyritized; and the porphyry inclosed in the Ludwig lode is garnetized, silicified, and pyritized. (2) The calc-silicate rocks, such as the fine-grained grossularite rocks near the Douglas Hill mine, have been brecciated, and the shattered mass has been recemented by the coarsely granular andradite that was formed at the time the ore was deposited; at the Casting Copper mine a series of thin-bedded black garnetites and allied rocks abut at an angle of 45° upon a belt of crystalline limestone, the garnetites were broken along the contact, and the angular black fragments are inclosed in the yellow andradite that forms the gangue of the ore body. These significant structural relations, pointing to the considerable faulting that intervened between the time of intrusion of the quartz monzonite and the deposition of the ores and proving the dependence of ore deposition on fissuring, will now be considered in some detail.

The relation of the ore deposits to faulting and brecciation is shown most strikingly at the Douglas Hill and Casting Copper mines; nor is elsewhere shown so clearly the distinctness of the ore-forming mineralization as a separate event that took place after the metamorphism accompanying the intrusion of the quartz monzonite. The mineralogically complex series of calc-silicate rocks on the west flank of Douglas Hill has been described; toward the top of the hill these rocks consist of exceedingly dense fine-grained garnetites, composed almost wholly of a nearly pure grossularite, as shown by its index of 1.75. The summit of the hill consists of an immense mass of andradite in which the ore occurs as irregular lenses. This great body of andradite resulted from the replacement of a massive limestone lying above the stratified series of aphanitic garnetites. The footwall of the ore zone is a belt of remarkable breccia about 20 feet thick. This breccia is composed of sharply angular fragments of the aphanitic garnetites inclosed in a cementing matrix of coarse, euhedral yellow garnet. The index of this garnet proves to be 1.87 and determines the garnet to be a nearly pure andradite. The garnets of the two periods of metamorphism show, then, in this grossularite hornfels cemented by andradite their maximal possible contrast. The andradite cement carries a little interstitial quartz, apatite, and chalcopyrite.

The dependence of ore deposition on fissuring and the evidence of two distinct periods of garnetization are clearly shown at the Casting Copper mine. The ore-bearing zone lies along the fault contact of a stratified series of black garnetites striking at an angle of 45° against massive limestone, as is shown in figure 12 (p. 63). The garnetites are dense, heavy fine-grained rocks. Under the microscope they are seen to be composed wholly of garnet, which is clouded with carbonaceous inclusions, a feature that accounts for their black color. The massive limestone has been solidly replaced by coarsely granular resin-yellow andradite for over 400 feet along its contact with the stratified garnetites. The garnetites were shattered along the contact, and the angular fragments of dense black rocks that resulted therefrom are now outlined by the thin veinlets of euhedral yellow andradite that traverse the breccia.

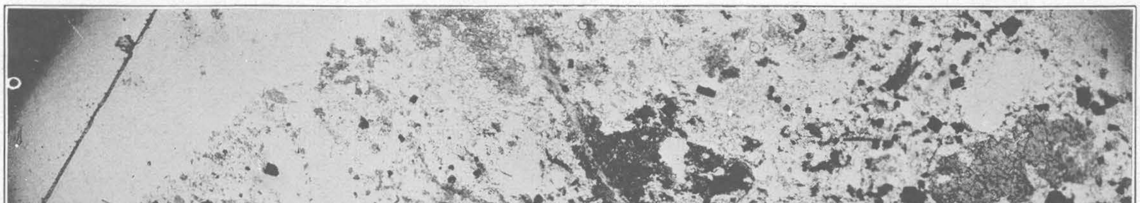
Some of the ore deposits, as the Bluestone, Mason Valley, and Western Nevada, are situated at the contact of the Triassic rocks with the quartz monzonite or the granodiorite. This contact, however, proves to be faulted; in fact, the granodiorite at the Mason Valley mine is a narrow fault wedge lying between the ore zone and Tertiary rhyolites to the north. The time of the faulting, except that it is later than the intrusion of the quartz monzonite porphyry dikes, is unknown, as is also the amount of displacement. The other garnetiferous ore deposits of the district are at some distance from the large intrusive bodies; that farthest distant—the Douglas Hill, which is characterized by its extraordinarily extensive mass of andradite—is 2,500 feet from the nearest surface exposure of quartz monzonite.

The limestones adjoining the faults along which the ore-forming solutions rose were shattered, and there is some evidence that the shattering facilitated or governed the replacement of the limestone by the mineralizing solutions. In the Ludwig ore body, which is lodelike in form, the limestone was extremely broken and crushed by dynamic disturbance, forming breccias as much as 80 to 100 feet thick. The garnetiferous quartz-pyrite ore, carrying coarse calcite as a minor component, forms a large low-grade shoot 50 to 100 feet wide. Toward the footwall side of the ore body, where it grades into unreplaced limestone and where the mineralizing activity was presumably less intense, the result of the selective action of the solutions becomes apparent. Here the finely crushed limestone that formed the matrix of the larger angular fragments of the breccia was replaced by pyrite, and thus a limestone breccia cemented by pyrite resulted. In the same way the brecciated condition of the quartz monzonite porphyry occurring in the Bluestone ore body has been strikingly emphasized by the selective



A. SPECIMEN SHOWING JUNCTION OF UNREPLACED LIMESTONE WITH PORTION WHOLLY REPLACED BY ANDRADITE.

an, Andradite; s, sulphides (chalcopyrite and pyrite); ls, limestone; de, decarbonized limestone.



B. GARNETIZED, SILICIFIED, AND PYRITIZED PORPHYRY FROM THE LUDWIG MINE.

g, Garnet; ep, epidote; py, pyrite.

replacement of the more finely crushed portion of the breccia. It was further emphasized by the fact that the sulphides form margins around the larger fragments of the breccia.

The replacement of fractured and brecciated limestone by andradite and sulphides is recognizable along the periperhy of the large ore lens at the south end of the ore zone of the Mason Valley mine. The andradite and sulphides have replaced a dark-gray fine-grained limestone; the junction between wholly replaced and unreplaced limestone is sharp; and the only change shown by the limestone is that where it adjoins the replaced rock it is bordered by a white band less than half an inch wide. The limestone has evidently been decarbonized in this band, but its grain has not been coarsened. (See Pl. IV, *A*.) At the McConnell mine, also, there is some evidence that the replacement by the mineralizing solutions progressed along fractures. However, it is difficult to obtain proof in many of the deposits in this district, as in others, that replacement by garnet, pyroxene, and allied silicates was governed by the fractured condition of the limestone in which they have developed. The conclusion to be drawn from this general lack of positive evidence is probably that the replacement of limestone by garnet and allied silicates is commonly so thorough that it has obliterated the evidence of the premineral fracturing. There has consequently been a general tendency to regard ore deposits of this kind as having originated at high temperatures and pressures from solutions permeating the limestone by diffusion or through microscopic fractures.

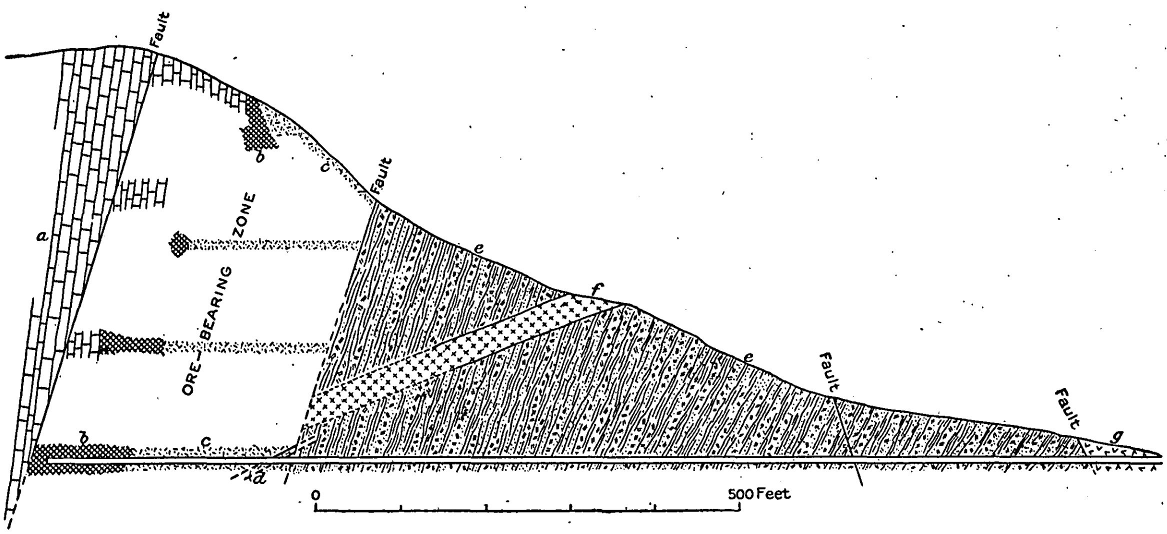


FIGURE 5.—Geologic section through tunnel No. 4, Mason Valley mine. *a*, Limestone; *b*, ore; *c*, garnetiferous rock; *d*, basic dikes; *e*, lime-silicate rocks with intercalated felsites; *f*, quartz monzonite porphyry; *g*, Tertiary rhyolite.

From the preceding discussion it appears that the chief ore deposits were localized by the ascent of the ore-forming solutions along fault fissures. The presence of limestone obviously appears to have favorably influenced the precipitation of ore. The main ore bodies are in the limestone adjoining the faults, but concomitantly with the deposition of the ore large bodies of garnet and pyroxene were formed, which in amount greatly exceed the ore. To find the bodies of ore in this unprofitable envelope is one of the main problems of mining in the district. As a rule, not without important exceptions, however, the ore tends to occur in the marginal portion of the contact-silicate rock where this borders the limestone. This tendency shows most clearly in the ore bodies of the Mason Valley (fig. 5) and Casting Copper mines. That ore is most likely to occur on the limestone side of the contact-metamorphic copper deposits at Mackay, Idaho, has been recognized by Umpleby;[1] and in a later paper by the same writer[2] this rule is shown to apply to a considerable number of other contact-metamorphic deposits. The Yerington district broadly supports the rule.

[1] Umpleby, J. B., The genesis of the Mackay copper deposits, Idaho: Econ. Geology, vol. 9, p. 321, 1914.

[2] Umpleby, J. B., The occurrence of ore on the limestone side of garnet zones: California Univ. Dept. Geology Bull., vol. 10, pp. 25-37, 1916.

FORM AND DIMENSIONS OF THE ORE DEPOSITS.

The ore deposits that occur in fault zones tend to approximate lodes in form. This tendency reaches its maximum in the Ludwig ore body, which is dimensionally a typical lode. As the deposits are the result of the replacement of limestone by contact-silicates, however, they are likely to depart from the typical lode form from place to place because of irregular embayments and protuberances that extend into the adjoining limestone. Even where the lode form is well developed the copper content is as a rule distributed erratically through the garnet or pyroxene mass that makes up the main bulk of the lode. Consequently some of the lodes or deposits are better designated ore-bearing zones.

The ore bodies are commonly small fractions of the masses of garnet-pyroxene rock. As already pointed out, the ore tends to occur on that side of the garnet-pyroxene bodies which adjoins the limestone. On this side the ore generally grades abruptly into limestone; on the opposite side it grades into lean pyritiferous garnet rock and from this into barren garnet rock. Such masses of barren garnet rock, in places as much as 200 feet thick, underlie the productive part of the ore zone in the Mason Valley mine. The occurrence of the ore toward the limestone side of the silicate masses is well shown in the Mason Valley mine (fig. 5), in the Casting Copper mine, and in the McConnell mine (fig. 8). On the other hand, lenses of ore are erratically distributed throughout the great mass of andradite on Douglas Hill (see fig. 11), and this distribution appears not to be governed by any rule.

The ore bodies of the district attain 800 feet in length and 100 feet in width. These are maximal dimensions, and the average are much smaller, owing to the lenticular habit of the individual bodies within the ore-bearing zones. As representative of the dimensions of a large lens of good-grade ore may be cited the principal ore body of the Casting Copper mine, a large lens 120 feet long, 175 feet high, and 20 feet wide.

The greatest vertical depth attained in the district is 678 feet, at which large bodies of low-grade ore, carrying less than 3 per cent of copper, have been developed. In general, however, exploration in depth has been disappointing, and some of the deposits appear definitely to have been bottomed. Although most of the deposits attain their maximal dimensions of primary ore at or near the present surface, others have been found in depth to be much larger than was indicated by the surface exposures; of these the Mason Valley is the most conspicuous illustration, showing at its state of development in 1914 the largest and most continuous bodies of primary ore at depths of 300 to 400 feet below the surface.

The known vertical range of cupriferous mineralization in the district is 950 feet. The two points that fix the measure of this range are the summit of Douglas Hill, whose altitude is 5,600 feet, and the bottom level of the Ludwig mine, whose altitude is 4,650 feet; they lie so close together that it is practically certain that this difference in altitude has not been changed by postmineral faulting. The vertical range of 950 feet is, then, a minimal measure of the vertical distance through which the ore-forming solutions were able to deposit pyrite and chalcopyrite together with andradite and allied silicates.

Concerning the persistence in depth of similar deposits Lindgren[1] wrote in 1905:

> Although cases may be easily conceived in which the deposits would continue in depth and length for several thousand feet, it is far more common to find them irregular and spotted in their mineralization, so that while there is no genetic reason why they should not be continuous to the greatest depth attainable by mining they will as a matter of fact often give out when least expected. * * * Few mines on contact deposits have been worked at a greater depth than a few hundred feet.

This still remains essentially true, except that mining in recent years has made known a few deposits of greater persistence in depth than was known in 1905. The contact-metamorphic copper deposits on Hetta Inlet, southeastern Alaska, have a known vertical range of 700 feet;[2] at Mackay, Idaho, the range is 900 feet;[3] and the Marble Bay deposit on Texada Island, at present the deepest worked contact-metamorphic ore body in the world, is worked at a depth of 1,160 feet, where good ore is exposed.[4]

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[1] Lindgren, Waldemar, Ore deposition and deep mining: Econ. Geology, vol. 1, p. 37, 1906.
[2] Knopf, Adolph, U. S. Geol. Survey Bull. 480, pp. 99, 101, 1911.
[3] Umpleby, J. B., Econ. Geology, vol. 9, p. 313, 1914.
[4] McConnell, R. G., Texada Island, British Columbia: Canada Geol. Survey Mem. 58, p. 48, 1914.

METAMORPHISM BY THE ORE-FORMING SOLUTIONS.

MINERAL TRANSFORMATIONS.

The ore-forming solutions in their ascent traversed limestone, quartz monzonite porphyry, felsite, and the rocks formed during the first period of metamorphism, such as garnetite and quartz-pyroxene hornfels. They metamorphosed the limestone most profoundly and extensively, but they also metamorphosed strikingly the other kinds of rocks, causing new minerals to grow in them similar to those developed in the limestones.

The limestones have been replaced mainly by garnet, pyroxene, and sulphides. The garnet is invariably a calcium-iron variety near the andradite end of the grossularite-andradite series. Some of the andradite, notably that in the Casting Copper mine, is of pronounced zonal structure, and quantitative examination shows that the peripheral zone of such garnet is somewhat nearer grossularite in composition than the core is, a feature possibly indicating that the ore-forming solutions changed slightly during the course of ore deposition. The pyroxene, as shown by the analysis on page 32, is halfway intermediate between diopside ($CaMg(SiO_3)_2$) and hedenbergite ($CaFe(SiO_3)_2$). The garnet rocks associated with the ore bodies are relatively coarse grained, and the garnets are more or less faceted, and in both these respects they differ obviously from the dense aphanitic or microcrystalline garnet rocks of the first period of metamorphism. The pyroxene is invariably lamellar and forms coarse radial aggregates that are as much as 10 inches across. The replacement of the limestone by this hedenbergitic pyroxene indicates that the ore-forming solutions carried abundant ferrous iron, as well as ferric iron indicated by the development of andradite in the limestone.

Among the accessory minerals formed during the replacement of the limestone are magnetite and apatite. The magnetite occurs only at the Mason Valley mine as a macroscopic component and there only in minute amount; elsewhere in the district it occurs only as a rare microscopic component. The practical absence of magnetite and hematite—minerals generally common in the contact-silicate ores—distinguishes the Yerington ores from those of the same type occurring in other districts. Apatite is a fairly common accessory mineral in the ores formed by the replacement of limestone, but it is detectable only with the aid of the microscope.

The quartz monzonite porphyry dikes show three different modes of alteration under the action of the mineralizing solutions—actinolitization, epidotization, and silicification accompanied by garnetization. All three processes were accompanied by pyritization.

Actinolitized porphyry is known to occur only as a narrow dike in the ore zone of the Mason Valley mine. It is a white, highly porphyritic rock carrying finely disseminated pyrite. Under the microscope the main change that was effected in the porphyry is seen to be the development of hairlike actinolite throughout its groundmass. The actinolite forms numerous sheaves and brushlike aggregates, averaging 0.2 millimeter in length, and further occurs as countless minute fibers of various sizes down to the limit of the resolving power of the microscope. Narrow veinlets of clear glassy plagioclase traverse the porphyry, occupying fractures that have not displaced the phenocrysts, and the new feldspars in the veinlets have the optical orientation of the plagioclase phenocrysts in which they are inclosed.

In the process of epidotization, the results of which are seen mainly in the Bluestone and Malachite mines, the porphyry was almost completely replaced by epidote, the quartz phenocrysts alone remaining intact. Where the porphyry has been less profoundly altered, the feldspar and hornblende phenocrysts have been pseudomorphously replaced by the epidote.

The quartz monzonite porphyry was most strikingly transformed by the solutions that deposited the garnetiferous ore of the Ludwig lode. The porphyry was fractured; through the passages thus formed flowed solutions that deposited andradite, epidote, pyroxene, quartz, calcite, pyrite, and chalcopyrite; and from these veinlets the porphyry was thoroughly metamorphosed, chiefly by the growth of quartz, garnet, and pyrite at the expense of the pyrogenic minerals. Only the quartz phenocrysts, usually rounded by magmatic corrosion, have survived intact; in fact, the transformation of the porphyry has commonly been so thorough that the quartz crystals alone give clues that the resultant siliceous pyritic rock was derived from porphyry.

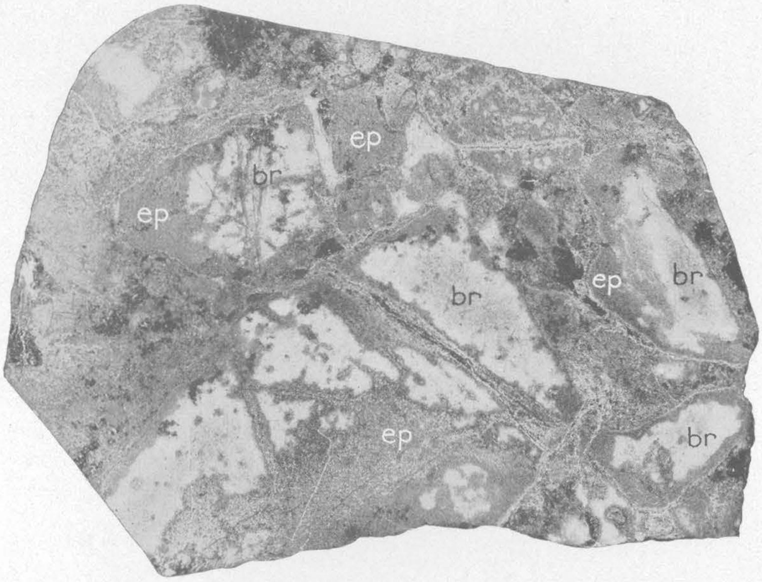
The altered porphyry, whose content of intact quartz phenocrysts clearly indicates its igneous origin, proves under the microscope to consist largely of quartz. The quartz phenocrysts are generally unchanged; the smoothly rounded outlines of the magmatically corroded crystals remain intact, even though some of the crystals are surrounded by broad aureoles of quartz optically continuous with that of the phenocrysts. Some, however, are partly replaced by pyrite, which is common as euhedral crystals throughout the rest of the rock. The orthoclase and plagioclase phenocrysts have been so thoroughly replaced by quartz that no traces of them remain. Garnet, sharply idiomorphic as a rule, occurs scattered throughout the rock, especially in quartz areas of coarser fabric than the rest of the groundmass, as shown in Plate IV, *B*. Deep-brown mica in finely foliated aggregates is present as a subordinate constituent. Apatite, besides occurring as large sporadic prisms, obviously residual from the porphyry, also occurs in innumerable minute needles, suggestive of addition by metasomatic action. Titanite occurs in a few large crystals, as in the unaltered porphyries, and zircon is a minor accessory mineral.

In the more highly metamorphosed porphyries much epidote and pyroxene appear along with the garnet, and in proportion as these minerals become abundant the resulting rock becomes increasingly difficult to distinguish from metamorphosed limestone.

The flow-banded felsite that forms the hanging wall of the Ludwig lode in depth has been partly replaced by garnet, pyroxene, epidote, pyrite, and calcite. The footwall felsite tuff of the Mason Valley ore zone has been altered somewhat differently. Much finely flaky biotite has been developed in the tuff, so that it has become a fine-grained black rock. Tourmaline occurs as a minor accessory mineral, and this is the only known occurrence of pneumatolytic minerals associated with the ore deposits of the district. The andesite in the footwall of the Mason Valley ore zone is altered by the metasomatic growth of pyrite, epidote, chlorite, and biotite.

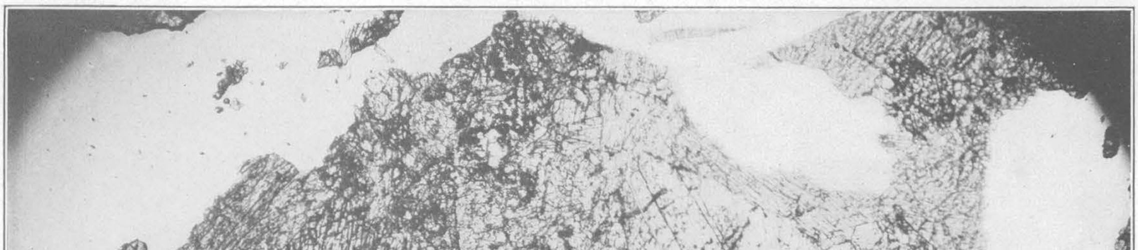
There remains to be described the metasomatism effected by the ore-forming solutions in the limestones previously metamorphosed by the quartz monzonite intrusion—that is, the metasomatic alteration of grossularite hornfels, or other garnetites, and of quartz-pyroxene hornfels. Alteration of this kind has taken place on the largest scale in the Bluestone ore body.

The Bluestone ore deposit differs from the others of the district in that the ore originated through the replacement not of limestone but of previously formed calc-silicate rocks. The ore body is situated along a fault that displaces a quartz monzonite porphyry dike, and the ore has developed through the replacement of the adjacent shattered and brecciated calc-silicate rocks—grossularite hornfels and quartz-pyroxene hornfels. The introduction of the ore minerals chalcopyrite and pyrite was accompanied by the growth of epidote at the expense of the preexisting minerals. The epidotization of the brecciated porphyry has already been described. The epidotization of the brecciated garnetite is well illustrated in Plate V, *A*, where the angular fragments, bordered by epidote, are excellently shown; in the actual specimen the dark green of the epidote, of course, emphasizes strikingly the extent to which this mineral has invaded and replaced the angular fragments of the breccia. The replacement so obvious macroscopically is still more evident under the microscope. The replaced rock is found to be composed mainly of garnet whose refractive index of 1.80 indicates a composition near grossularite; pyroxene is a subordinate component. Other breccia fragments consist of a finely granular assemblage of quartz and pyroxene, a rock of the kind here termed quartz-pyroxene hornfels. The garnet shows the replacement by epidote, but it is traversed by veinlets of epidote, adjoining which it is irregularly altered to epidote; in places certain zones of the garnet are pseudomorphically altered to epidote. Chalcopyrite also occurs as a replacement of garnet and is invariably accompanied by epidote. Subordinate components of the ore are quartz and calcite; apatite is a minor but constant accessory mineral. The epidote is rarely idiomorphic except in the veinlets that constitute the cement or binding of the ore-bearing breccia.



A. GARNETITE BRECCIA IN WHICH THE FRAGMENTS HAVE BEEN PARTLY REPLACED BY EPIDOTE, BLUESTONE MINE.

ep, Epidote; br, fragments of brecciated garnetite.



B. GANGUE OF COPPER ORE, IN WHICH ANDRADITE IS INTERSTITIAL BETWEEN PYROXENE CRYSTALS, WESTERN NEVADA MINE.

an, Andradite; pyr, pyroxene.

COMPOSITION OF THE ORE-FORMING SOLUTIONS.

The metamorphism effected by the ore-forming solutions shows that they were charged with silicon, ferrous and ferric iron, magnesium, copper, sulphur, and phosphorus. What else they carried remains unknown; that they carried boron, for instance, is shown by the metasomatic occurrence of tourmaline in the footwall of the Mason Valley ore zone, but the small amount of tourmaline may mean either that the solutions were unsaturated with respect to this mineral or that the temperature conditions were unfavorable, probably too low, for its formation. The solutions were manifestly deficient in calcium, as they removed immense quantities of calcite. In what form the bulk of this calcite was dissolved must remain unknown. That it may in part have been carried as calcium chloride is a reasonable hypothesis, in view of the intensive scapolitization shown at some localities by the quartz monzonite, although, on the other hand, it must be confessed that no scapolite is known to be associated with the ore deposits. For every molecule of calcite removed as chloride a molecule of carbon dioxide would be set free, and, proportionally to the pressure existing at the point of replacement, would aid in the removal of the calcite as bicarbonate.

The solutions appear, further, to have been deficient in sodium and potassium, as is shown by the complete obliteration of the feldspars in the quartz monzonite porphyry and by the fact that no sericite has been developed in this rock. Biotite, however, has locally been formed in small quantities.

It is of some interest to compare the composition of the ore-forming solutions as deduced from their action on limestone with their composition as deduced from their action on quartz monzonite porphyry, both kinds of rock occurring in the same ore body. From the metasomatic replacement of the limestone by andradite, pyrite, chalcopyrite, quartz, and apatite, it would be concluded that the solutions were highly charged with silicon, ferrous and ferric iron, copper, and sulphur and contained sufficient phosphorus to develop accessory apatite; moreover, they must have become highly charged with calcium, derived from the immense quantities of calcite that they dissolved. From the study of the silicified porphyry, essentially a pyritic quartz aggregate, the most obvious deductions would be that the solutions were rich in silicon and sulphur, that they contained sufficient phosphorus to cause the development of accessory apatite, and that they were deficient in aluminum, ferric iron, calcium, magnesium, and alkalies. From the study of the garnetized and epidotized porphyry it would be concluded that the composition of the solutions was like that indicated by the alteration of the limestone, with the important exception that in reacting with the porphyry the solutions, instead of removing calcium, have added large amounts of this element to the porphyry. The physical-chemical deduction from this comparison appears to be that the solutions were saturated with garnet, but undersaturated with respect to other calcium compounds, such as the chloride; hence, the same solutions were able to replace both limestone and porphyry, although the one replacement meant a subtraction of calcium and the other an addition of calcium.

PARAGENESIS.

The sulphides and associated silicates—pyroxene, andradite, amphibole, and epidote—broadly considered, were formed essentially at the same time. Under the microscope sequential relations between the silicates are occasionally observable, in that certain minerals appear to have continued to grow after others had stopped. But such relations, clear enough in the small areas of certain thin sections, do not appear to be supported by any broadly significant evidence in the ore deposits themselves, and they are therefore regarded as evidence of minor vagaries in the general course of ore deposition. The sulphides appear to have formed continuously throughout the period during which the gangue minerals were being deposited. The details on which these conclusions are based are given in the following paragraphs.

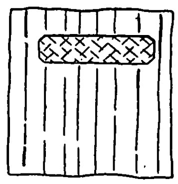


FIGURE 6.—Inclosure of an idiomorphic cross section of lamellar pyroxene in a clinopinacoidal section of pyroxene.

The radial and spherulitic pyroxene not uncommonly shows under the microscope idiomorphic sections of one crystal that are inclosed in idiomorphic sections of another crystal, as illustrated in figure 6. The relations shown in the figure are clearly explicable as having resulted from unequal rates of growth of two different pyroxene crystals growing from contiguous spherulitic centers; had the mineral whose cross section is shown been other than pyroxene, however, it would according to usage somewhat common in the study of ore deposits be said to "cut" and replace the pyroxene shown in clinopinacoidal section.

The pyroxene in a specimen from the Western Nevada mine is sharply idiomorphic, and the associated andradite lies interstitially between the pyroxene crystals (Pl. V, *B*); from this relation it follows that in this particular specimen the andradite continued to grow after the pyroxene had ceased to grow. Garnet appears to have replaced the earlier-formed pyroxene to a slight extent; but the main bulk of the evidence, both the field and the microscopic, points to the essential contemporaneity of the pyroxene and garnet.

Epidote, which is rare except in the Bluestone ore body, is clearly syngenetic with the pyroxene and garnet that were deposited by the ore-forming solutions. In the Bluestone ore, however, it has clearly replaced the garnet and pyroxene of the first epoch of metamorphism. The replacement is strongly indicated by megascopic evidence, which shows it to have followed the faulting and brecciation of the replaced rock, and this megascopic evidence is confirmed by the microscope. It is manifest, therefore, that the replacement of the garnet and pyroxene by epidote and sulphides in the Bluestone ore records an event in the genesis of the deposit that is of real geologic significance.

Actinolite is most common in the Mason Valley ore deposit, where it occurs irregularly distributed through the pyroxenic gangue. It does not appear to have originated as a result of the introduction of the sulphides, nor is there any structural evidence, such as faulting or brecciation of the previously formed ore, to show that its origin was connected with any change in the conditions of ore deposition of broad geologic significance.

The sulphides occur inclosed in garnet, in pyroxene, or in the calcite that in places lies interstitially between the silicates. As the silicates strongly predominate in the ores of the district, it is clear that on the whole the sulphides are more closely associated with the silicates than with the calcite. It is further apparent that the sulphides have not replaced interstitial calcite, because the silicates are invariably idiomorphic against calcite, and consequently, if the sulphides did replace calcite that was formerly interstitial they should be molded around idiomorphic garnet and pyroxene; as a matter of fact, however, such a relation is rarely or never found. If the sulphides replaced interstitial calcite in the garnet-pyroxene masses (the calcite being therefore essential to their precipitation), it is very remarkable that no sulphides have been deposited in the limestone beyond the border of the silicate masses. This failure of the sulphides to occur in the favorable limestone environment beyond the silicate masses is therefore highly significant, and it strongly supports the other evidence of the essential contemporaneity of sulphides and silicates.

The chalcopyrite is almost invariably anhedral; the pyrite, however, is generally euhedral. Cubes of pyrite are inclosed in the chalcopyrite, and as seen under the microscope they show no sign of fracturing or brecciation. The proportion of chalcopyrite to pyrite differs widely in different deposits; in some pyrite is nearly absent, whereas in others it is more than twice as abundant as the chalcopyrite. The sulphides are more closely associated in some deposits with the pyroxene and actinolite, as in the Mason Valley ore body, and in others with the andradite, as in the Douglas Hill deposit. The sulphides are not uncommonly embedded in pyroxene, which shows no trace of alteration to actinolite, so that it is clear that the pyroxene was not altered to actinolite as a result of the introduction of the sulphides. In the Bluestone deposit, which differs from the others of the district in that the ore has replaced garnetite and related hornfelses instead of limestone, the sulphides that were formed by the metasomatic replacement of garnet and pyroxene are invariably accompanied by epidote, which also has replaced the garnet and pyroxene. This paragenetic relation clearly implies that if during the introduction of the sulphides the pyroxene was actinolitized the sulphides would probably not be inclosed in the unaltered pyroxene.

Fibers and prisms of amphibole project into or are inclosed by chalcopyrite, but whether this means that the amphibole "cuts" the sulphide or that the sulphide is later than the amphibole and has grown around it is not clear. From similar relations observed in ore from Arizona Tolman[1] concludes that the amphibole is later than the sulphide it "cuts," but this conclusion appears to be not more probable than the reverse conclusion. It is likely that the pyrite bears the same relation to the tremolite that the pyroxene in cross section seen in figure 6 bears to the clinopinacoidal section in that figure.

The facts that veinlets composed of prisms of quartz, dodecahedrons of garnet, and sulphides break across the structure of stratified garnetites; that veinlets of quartz, calcite, sulphides, garnet, pyroxene, and epidote traverse quartz monzonite porphyry; and, to take an example on a larger scale, that the Ludwig lode, whose gangue, although consisting essentially of calcite and subordinate quartz, nevertheless contains notable quantities of andradite all show that the deposition of the silicates, persisted until quartz and calcite were deposited simultaneously with them. If, then, in the final stage of ore deposition the silicates, sulphides, quartz, and calcite were deposited together, it is improbable that the silicates would have been replaced by sulphides, quartz, or calcite in any of the earlier stages of deposition.

TIME OF ORE DEPOSITION.

The earliest plutonic rock to invade the district was the granodiorite, a medium-grained rock. This was followed by the quartz monzonite, a coarse-grained rock, areally the most widespread rock in the district. Aplite succeeded the quartz monzonite and was in turn followed by an extensive injection of quartz monzonite porphyry dikes. Faulting then took place, displacing many of the dikes, and the metalliferous solutions rose along the faults and formed the ore deposits.

It is therefore important to consider closely the relation of the ore deposits to the porphyry dikes and to the whole sequence of intrusive rocks, for a long lapse of time evidently occurred between the consolidation of the parent magma and the deposition of the ore. The intrusion of the granodiorite and the quartz monzonite profoundly metamorphosed the rocks of the district. It was at this time, as was previously shown, that the garnetites and calcium-silicate hornfelses were produced. After this metamorphism the quartz monzonite porphyry dikes were injected, cutting all the preexisting rocks of the district—limestones, calcium silicate rocks, granodiorite, and quartz monzonite. The relation of the dikes to the metamorphosed limestones—the calcium silicate rocks—is of considerable interest. Where the porphyries traverse the garnetites and other calcium silicate rocks they show chilled contact selvages. For example, one of the prominent dikes southeast of Ludwig splits irregularly into branches and incloses masses of dense, aphanitic quartz-pyroxene hornfels. The porphyry is bordered by a notably chilled selvage, 8 inches wide, within which it is aphanitic and carries small phenocrysts of feldspar and quartz, although the normal rock is so crowded with large crystals as to be almost granitic in habit. Another dike, which is more than 100 feet thick, has a chilled margin several feet wide bordering the garnetite it traverses. These observations indicate that the calcium silicate rocks were at a temperature low enough to chill the porphyries at the time of intrusion, but whether this means a long interval between the time of the metamorphism when the calcium silicate rocks originated and the intrusion of the dikes is an open question, in view of the lack of quantitative data on the physics of such phenomena.

Although it is firmly established that the ore deposition took place after the intrusion of the porphyry dikes, yet the question can be raised whether the dikes are all of one pulse of intrusion. May not a particular set of dikes—that is, a series of granodiorite porphyries—have followed the irruption of the granodiorite, and another series the irruption of the quartz monzonite? If this has happened, it is conceivable that the faulted and mineralized dikes are granodiorite porphyries and that their mineralization ensued contemporaneously with the quartz monzonite intrusion and prior to the injection of the last set of porphyry dikes. Although it can not be positively affirmed that there is not a series of granodiorite porphyries distinct from a later series of quartz monzonite porphyry dikes, yet, inasmuch as dikes petrographically like those cutting the quartz mon-

[1] Tolman, C. F., jr., Observations on certain types of chalcocite and their characteristic etch patterns: Am. Inst. Min. Eng. Bull. 110, p. 409, 1916.

zonite were highly mineralized during the period of ore deposition, manifestly the ores were formed after the last of the porphyry dikes had been injected. This is most clearly shown at the Ludwig mine. Here the two extreme variants of the porphyry dike series are present. A thick dike of porphyry, characterized by its almost granitoid habit and lack of quartz phenocrysts, cuts the hanging-wall country rock, terminating against the hanging-wall fault. In the lode itself occurs an aphanitic porphyry whose quartz phenocrysts are its most prominent features; it carries also large phenocrysts of orthoclase and similar crystals of plagioclase, and it is clearly a quartz monzonite porphyry similar to those porphyries rich in phenocrysts of quartz that are known to cut the quartz monzonite. This porphyry has been garnetized, silicified, and pyritized in many places so thoroughly as to be almost beyond recognition. There is little doubt, therefore, that the deposition of the garnetiferous ores—the contact-metamorphic ore bodies—occurred after the injection of the quartz monzonite porphyry dikes. No intrusions genetically related to the quartz monzonite magma succeeded the injection of the quartz monzonite porphyry dikes. If the ores are genetically connected with the quartz monzonite magma, as they are believed to be, then their deposition was the last manifestation of its hypogene energy, which was postponed until long after the consolidation of the quartz monzonite now exposed to view.

ORIGIN AND CLASSIFICATION.

The genesis of the ore deposits, although anticipated in the previous descriptions, will now be recapitulated and attention will be called to the theoretical bearing of certain features of the ore bodies.

Granodiorite, followed by quartz monzonite in far larger amount, invaded the region probably in early Cretaceous time. These intrusions profoundly metamorphosed the invaded rocks: they caused the andesites and felsites adjacent to them to recrystallize and in part to become schistose, and they transformed the limestones into aphanitic or microcrystalline rocks composed mainly of garnet or wollastonite. Dense, heavy garnetites probably predominate among the limestones thus metamorphosed, and the pseudomorphic replacement of an undistorted *Halobia* in typical rock of this kind indicates that the garnet resulted not from recrystallization of the impurities in the limestone but from the accession of new material, principally silica and iron. In view of the extent of the metamorphosed limestone, it is evident that silica and iron were added in large quantities, but notwithstanding this large addition, no copper or sulphur were added at this time. In places the quartz monzonite is traversed by veins of scapolite as much as 2 feet thick and is itself extensively altered to scapolite near the veins; but this scapolitization is the only record that chlorine or any other pneumatolytic agent was active at this stage in the igneous history of the district. The intrusion of the quartz monzonite was succeeded by that of aplite in minor amount and by the injection of numerous quartz monzonite porphyry dikes. Faulting then ensued, as is shown by the dislocation of the dikes, and along certain of the fault fissures metalliferous solutions rose and formed the ore bodies of contact-metamorphic type. A long interval of time, therefore, separated the intrusion of the quartz monzonite and the formation of the ore. During this interval the consolidating quartz monzonite magma differentiated to some extent, as the aplite and the porphyry series prove; the porphyries, however, do not differ greatly from the parent magma, being only somewhat more salic.

The ore deposits, as shown by the minerals composing them, were formed at high temperatures. As the component garnets are generally birefringent, it is probable, from some experimental work by H. E. Merwin, that the temperatures did not, however, exceed 600° C.[1] The ore-forming solutions were therefore at high temperatures, but whether they were gaseous or liquid can not be positively affirmed because of lack of data on the concentrations of the various constituents in the solutions. Doubtless water strongly predominated. The critical temperature of pure water is 370° C.; the presence of the gaseous constituents CO_2 and H_2S would lower the critical temperature,[2] but the presence of the difficultly volatile com-

[1] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 108, 1915.

[2] Nernst, W., Theoretische Chemie, 7th ed., p. 115, 1913.

pounds would raise the critical temperature.[1] What was the balance between these two opposing effects in the ore-forming solutions under discussion no one can tell, but the probable strong predominance of water makes it likely that their critical temperature was near 370° C. If, as appears probable, a higher temperature than this prevailed during the synthesis of the garnet and pyroxene, the solutions were therefore gaseous. The physical condition of such solutions has been a matter of considerable discussion among geologists, but that it is of any geologic significance does not seem to have been shown. As long ago as 1879 Hannay and Hogarth determined that substances would act above their critical temperatures as solvents for difficultly volatile compounds, and confirmatory evidence has been since accumulating.[2] The geologically important substance water has, however, not yet been experimentally investigated in this regard, but the geologic evidence leaves little doubt that water conforms in its behavior with the substances experimentally investigated and is a solvent above its critical temperature.

A notable feature of the ore-forming metamorphism is that some ore bodies, or large portions of them, consist almost wholly of pyroxene plus some sulphide, whereas others consist essentially of andradite. A mass that is composed of diopside-hedenbergite (a silicate of calcium, magnesium, and ferrous iron containing 50 per cent of silica) must differ widely in chemical composition from a mass composed of andradite (a silicate of calcium and ferric iron containing 36 per cent of silica). That these widely differing bodies of silicate rock have formed within the same limestone strata appears to oppose insuperably any attempt to apply the theoretical views of Leith [3] to account for the silicate masses of the Yerington district. If, in accordance with these views, the deposits had resulted largely from elimination of the calcite in the limestones and recrystallization of the residual impurities, then the chemical composition of the various silicate masses throughout the district should show a considerable degree of uniformity. It is perhaps hardly necessary to apply this test to the "recrystallization hypothesis" in its applicability to the Yerington district, because so many features of the ore deposits absolutely negative its adoption, even as a tentative explanation. Probably the most powerful single argument against the recrystallization hypothesis as applied to this district lies in the facts that all the impurities in the limestones recrystallized during the first epoch of metamorphism (and even during this recrystallization much iron and silica were added to the recrystallized limestones) and that the ore bodies and their great masses of associated garnet and pyroxene were formed by replacement and, with one exception, by the replacement of relatively pure limestones. The single exception, the Bluestone ore body, affords if possible, even stronger evidence against the applicability of the recrystallization hypothesis, as the ore of this deposit was formed by the replacement of brecciated garnetite and quartz-pyroxene hornfels.

The significance of such iron-bearing silicates as andradite and hedenbergite in contact-metamorphic deposits has been amply emphasized in recent years. It appears to have been first recognized by Lacroix,[4] who described a contact deposit of magnetite—a deposit that, he says, is of a high theoretic importance, as it strongly indicates the accession of substance from the granite magma. The silicates accompanying the magnetite are iron-bearing varieties. Lacroix says:

> The garnet is not grossularite but melanite; the pyroxene is not light-colored diopside but a diopside near hedenbergite; and the amphibole, instead of being faintly tinted in pale green in thin section, is extremely deep green and is a highly ferriferous hornblende.

Later work, especially by Kemp and Lindgren, has abundantly confirmed Lacroix's estimate of the theoretic importance of these paragenetic relations.

Probably the most noteworthy fact connected with the occurrence of the andradite in the Yerington district, aside from its general association with the ores, conformably with what is now recognized as the rule that the garnet of contact-metamorphic ore deposits is generally andradite, is that along certain faulted contacts the andradite forms the binding material of breccias made up of angular

[1] Boeke, H. E., Grundlagen der physikalischen-chemischen Petrographie, pp. 261-263, 1915.

[2] Idem, pp. 261-263.

[3] Leith, C. K., Recrystallization of limestone at igneous contacts: Am. Inst. Min. Eng. Trans., vol. 48, pp. 209-214, 1915.

[4] Lacroix, A., Le granite des Pyrénées et ses phénomènes de contact: Services carte géol. France Bull. 71, pp. 9-11, 1900.

fragments of grossularite rock or allied contact rocks formed during the first period of metamorphism.

The distribution of the "contact deposits" throughout the district independent of close proximity to the intrusive rocks is due to the thermal history of the district. The long interval separating the initial intrusion of the granodiorite from the final injection of the quartz monzonite porphyry dikes caused the invaded rocks to become highly heated and temperature gradients to flatten.[1] Conditions had therefore become favorable to the development of "contact deposits" at considerable distances from the igneous contact. Superimposed upon this favorable condition was another, possibly even more favorable in this respect, namely, that the ore-forming solutions ascended along fault channels, thereby extending to long distances from the igneous contacts the temperature conditions necessary to form garnet, pyroxene, and allied silicates. The maximum distance from the nearest visible granular igneous rock at which an andradite mass has formed is 2,500 feet.

As the ore bodies originated at high temperatures, they are clearly linked genetically to the igneous intrusion, but whether they were deposited by magmatic emanations or by meteoric waters stimulated by the heat of the intrusion the evidence does not show so clearly. The structural complexity of the rocks, however, would appear to have been unfavorable to the establishment of a systematic circulation of meteoric waters. The conclusion is thus reached that the ore deposits are causally connected with igneous rocks, if not consanguineous, and that they were not formed until considerable time had elapsed after the intrusion of the quartz monzonite. Furthermore, it follows that if the deposits were formed by magmatic solutions, as is regarded the more probable, the two distinct periods of metamorphism, which have been discussed under the designations "metamorphism of the first period" and "ore-forming metamorphism," show that material was supplied by the magma or magmas at two separate and distinct times; during the first metamorphism the addition of material was rather widespread in its scope, and during the later, which was characterized especially by the addition of copper and sulphur, it was rather localized and resulted in ore deposition.

At this point the questions arise: Are the pyroxenic and garnetiferous copper deposits of the Yerington district properly called contact-metamorphic ore bodies? What, in fact, are the distinctive features of contact-metamorphic ore deposits? Three criteria for distinguishing deposits of this kind are generally recognized as valid—(1) that the deposits commonly occur in limestone at or near its contact with an intrusive igneous rock; (2) that the sulphides are associated with contemporaneously formed oxides, chiefly of iron; and (3) that the metalliferous minerals are associated with contact-metamorphic silicates, among which garnet, pyroxene, epidote, and amphibole predominate.

When actual usage is examined, however, it is found that the third criterion—the presence of "contact" silicates—is the sole diagnostic feature. Visible nearness to an irruptive rock is not necessary, though opinions will differ as to what constitutes "nearness." For example, the copper deposits of Phoenix, British Columbia, consisting of chalcopyrite, pyrite, and hematite in a gangue of epidote and andradite, are from 1 to 2 miles distant from the nearest exposure of the granodiorite batholith to which they are genetically related;[2] but this distance appears to be the greatest at which ore bodies of this kind are known to occur. Moreover, according to Lindgren,[3] "Some ore deposits of the contact-metamorphic type occur at a distance from any intrusive rock to which their origin could be attributed"—a statement of itself clearly implying that ore deposits of the contact-metamorphic type are recognizable otherwise than by their nearness to intrusive masses. Of the seven types of deposits that Lindgren groups under the contact-metamorphic class many representatives are known in which the sulphides are not associated with magnetite or hematite. The one distinctive feature of the contact-metamorphic group, then, is the association of metalliferous minerals with contact silicates. These silicates are as a rule characterized chemically by the dominance of calcium among the positive radicles; they are the mineral witnesses of the fact that the ore deposits containing them were formed

[1] Daly, R. A., Igneous rocks and their origin, pp. 198-199, 1914.

[2] LeRoy, O. E., The geology and ore deposits of Phoenix, Boundary district, British Columbia: Canada Geol. Survey Mem. 21, p. 67, 1912.

[3] Lindgren, Waldemar, Mineral deposits, p. 675, 1913.

at high temperature in a limestone environment.

Contact-metamorphic ore deposits may be regarded as a special facies of one of the two forms of contact metamorphism recognized by petrologists, namely, as a facies of pneumatolytic contact metamorphism, as distinguished from normal contact metamorphism such as is typified by the classic example of Barr-Andlau. The special facies is of course due to the occurrence of sulphur and of heavy metals such as copper in the metamorphosing solutions. Now, the characteristic features of pneumatolytic contact action are that it takes place after the normal metamorphism has been effected and that it is localized along fractures and fissures, instead of forming a continuous aureole of metamorphic rock encircling the intrusive rock. These relations have long been specially emphasized by Lacroix,[1] Rosenbusch,[2] and other petrologists and may be considered as well-established laws of petrology. They are particularly well illustrated in the Christiania region, as recently described by Goldschmidt.[3] In this region the pneumatolytic contact metamorphism produced numerous argentiferous zinc-lead ore deposits having a gangue of andradite and fluorite. These deposits are situated along faults, the fault at Glomsrudkollen, for example, having a throw between 1,000 and 2,000 meters.[4]

Among economic geologists there appears to be some hesitation to classify the deposits of this kind that occur along fissures as typically contact metamorphic. According to Krusch,[5] where fissure fillings have resulted from contact-metamorphic agencies, the distinction between contact deposits and fissure deposits becomes difficult. That the attempted distinction is rather artificial is shown, for example, by a consideration of the geologic relations of the contact-metamorphic sphalerite deposit at Glomsrudkollen, just referred to. The ore of this deposit consists of sphalerite, pyrrhotite, and pyrite in a gangue of fluorite and andradite, and it is localized along the fault of large throw previously mentioned. It occurs where the fault traverses limestone, but where the fault traverses granite or quartz porphyry greisen occurs, consisting of muscovite, quartz, pyrite, and locally much specular hematite. In short, the greisen and the contact-metamorphic ore bodies were formed by the same solutions; they are therefore genetically coordinate, but this close kinship is not denoted by the terminology usually employed; and this leads again to the previously expressed conclusion that the distinguishing features of contact-metamorphic ore deposits result from their formation at high temperature in a limestone environment, and that the sole criterion diagnostic of these deposits is the presence of contact silicates, which are generally of calcic composition.

From the foregoing discussion it appears necessary to conclude that the Yerington deposits are clearly members of the contact-metamorphic class. The special features of broader import as to the theories of ore deposition that they illustrate exceptionally well are (1) the long time that intervened between the formation of the ore deposits and the consolidation of the magma on which they are genetically dependent; (2) the great amount of material, principally iron and silica, that was added to the sedimentary rocks during this interval, without traces of ore deposition; and (3) the genetic dependence of the contact-metamorphic ore on fault fissures, along which the fractured or brecciated limestone has been metasomatically replaced by garnet, pyroxene, and sulphides.

OXIDATION AND SULPHIDE ENRICHMENT.

The ores in general are not oxidized extensively or to great depths. Residual sulphides, in fact, commonly occur in the outcrops of the oxidized ores. Enrichment by supergene sulphides has not been important. The bulk of the copper output of the district has come from primary ores. Water level has not been reached in any of the mines except the Ludwig, where it was struck at a vertical depth of 500 feet.

The notable features of the oxidized ores are the prevalence of gypsum, chalcanthite (bluestone), chrysocolla, and copper pitch ore. Chalcanthite was formerly abundant enough to be mined to supply the amalgamating mills of the Comstock lode; it is even now common

[1] Lacroix, A., Le granite des Pyrénées et ses phénomènes de contact: Services carte géol. France Bull. 71, pp. 62-67, 1900.

[2] Rosenbusch, H., Mikroscopische Physiographie der massigen Gesteine, 4th ed., vol. 2, pt. 1, pp. 123-127, 1907.

[3] Goldschmidt, V. M., Die Kontaktmetamorphose im Kristianiagebiet, pp. 70, 86, 108, 1911.

[4] Idem, p. 88.

[5] Krusch, P., Die Classification der Erzlagerstätten von Kupferberg in Schlesien: Zeitschr. prakt. Geologie, Jahrg. 1901, p. 228.

in the oxidized ores yet remaining, especially of the Bluestone mine. Its prevalence is of course a direct result of the existing arid climate. The oxidized ores are permeated with gypsum, which in places forms plates as much as an inch in diameter and a quarter of an inch thick. Narrow veinlets of gypsum are also common. The gypsum in the oxidized ores was derived from the action of sulphuric acid on the interstitial calcite of the gangue and probably to some extent from the action of the acid on the andradite, which, as Bergeat [1] has shown, is easily decomposed by dilute sulphuric acid. Its prevalence proves that throughout the history of the ore bodies the downward movement of oxidizing water has been sluggish—so sluggish as to be unable to remove so soluble a compound as gypsum. This imperfect lixiviation in the zone of oxidation is clearly due to the general imperviousness of the massive garnet-pyroxene ores.

Chrysocolla and the related copper pitch ore are relatively abundant among the oxidized compounds. Their prevalence is due to two factors; first, the andradite, easily decomposable by weak sulphuric acid, furnished abundant colloidal silica, and, second, the rapid neutralization of the sulphuric acid (in which chrysocolla and copper pitch ore are readily soluble) by the calcite and the andradite of the ore allowed their ready precipitation.

The ores have not been notably enriched by secondary (supergene) sulphides, and moreover, the zone of enrichment is not sharply separated from the zone of oxidation. The supergene sulphides occur as a rule as soft, sooty bluish-black or black material. They have formed chiefly at the expense of the chalcopyrite originally present, and in some ore this action has gone so far that the chalcopyrite has wholly disappeared, leaving the pyrite essentially intact. This selective replacement is common throughout the district and is perhaps the most noteworthy feature of sulphide enrichment that the district exemplifies. Covellite and chalcocite are the two sulphides formed during enrichment. They are invariably associated closely with gypsum, which not only occurs as plates intergrown with them but also penetrates them in veinlets. It is found as far down as enrichment extends.

[1] Bergeat, Alfred, Der Granodiorit von Concepcion del Oro im Staate Zacatecas (Mexiko) und seine Kontaktbildungen: Neues Jahrb., Beilage Band 28, p. 534, 1909.

The covellite, as may be seen on polished sections of ore, has tended to replace the chalcopyrite along crystallographic directions, forming triangular and rhombic patterns, obvious even to the unaided eye.[1] Possibly these directions are those of the pyramidal cleavage (201) of the chalcopyrite, which Dana says is sometimes distinct; but etching with potassium cyanide failed to bring out the cleavage, so that this supposition is unverified. In general, however, the covellite traverses the chalcopyrite in networks of minute veinlets; it is from some of these that branches extend parallel to the supposed cleavage.

Chalcocite, like the covellite of the district, has formed chiefly at the expense of the primary chalcopyrite. It was more abundant at the Ludwig mine than in any other deposit of the district.

The conditions of oxidation and sulphide enrichment in the Ludwig lode differ rather markedly from those prevailing in other deposits of the district. These differences have resulted from its lode form, its siliceous character, and its greater perviousness, due to postmineral shattering. Owing to this combination of circumstances the lode has been oxidized and leached down to water level, at a vertical depth of about 500 feet. Below the leached zone is the chalcocitized zone, at its maximum not much over 100 feet in vertical extent and averaging much less than this. In view of the large quantity of highly leached gossan above water level, the amount of chalcocite formed was disproportionately small. This meager enrichment is explicable as due to the fact that the lode, which dips 70° E., is underlain by limestone. The acid copper-bearing solutions formed by the oxidation of the primary pyrite and chalcopyrite flowed in large measure into the footwall, their ingress into which was facilitated by the postmineral faulting and shattering. Once in this calcitic environment the acid was neutralized and the copper was precipitated as carbonates, copper-pitch ore, chrysocolla, and cuprite. The ore thus deposited shows a rather well defined layering parallel to its inclosing walls, and much of it plainly fills solution cavities in the limestone. On the other hand, the local replacement of

[1] A. F. Rogers (Secondary sulphide enrichment of copper ores with special reference to microscopic study: Min. and Sci. Press, vol. 109, p. 684, fig. 5, 1914) has described a similar replacement of chalcopyrite by covellite in ore from the Rambler mine, Wyo.

limestone by chrysocolla is remarkably well shown. In conclusion, the relations shown at the Ludwig mine suggest that had not the lode been underlain by limestone large amounts of copper would have been dispersed and not reprecipitated and so would have been lost beyond recovery, and that therefore the process of supergene sulphide enrichment is likely to be extremely wasteful of copper.

FISSURE VEINS AND OTHER DEPOSITS.

In addition to the contact-metamorphic deposits a few fissure veins and related deposits occur in the district, but none of them have yet attained economic prominence. The only fissure vein that was being worked in 1914 was the Montana-Yerington, in which the ore bodies occur in a crushed and foliated zone in granodiorite. The ore consists chiefly of chalcopyrite with minor amounts of euhedral pyrite, associated with finely disseminated plates of specular hematite. At the Empire-Nevada mine scattered bunches of cuprite ore in quartz monzonite porphyry are being worked, but the primary sulphides from which these have been derived have not so far been disclosed.

In the granodiorite hills east of the town of Yerington, an area not shown in the map accompanying this report, occur a group of fissure veins in which chalcopyrite and pyrite are associated with specular hematite in a gangue of quartz. Representative of these are the New Yerington and the Butte & Yerington; at the Black Rock prospect the chalcopyrite is inclosed in quartz that carries much magnetite intergrown with specularite.

A few narrow quartz veins are inclosed in the quartz monzonite in the southwest corner of the mapped area, a few miles south of Ludwig. They carry pyrite and chalcopyrite and in one a minor amount of galena—the only occurrence of a primary sulphide in the district other than pyrite and chalcopyrite—but the value of these ores is in their gold content.

Part III. MINES AND PROSPECTS.

MINES AND PROSPECTS ON CONTACT-METAMORPHIC DEPOSITS.

BLUESTONE MINE.

The Bluestone mine, the oldest in the district, is 1½ miles west of Mason, at an altitude of 5,400 feet. In the seventies it supplied natural bluestone to the amalgamating mills on the Comstock lode. Later a small smelter was built near the mine and was run for a time on oxidized ore, but the high cost of fuel, which had to be hauled from the railroad at Wabuska, soon brought operations to a close. In recent years work has been restricted mainly to exploration and development of the ore. In 1917 the mine became productive, supplying 1,000 tons of ore a day to the smelter at Thompson.

The mine is opened by two adits. The lower or main adit, whose portal is at an altitude of 5,151 feet, entering from the east, undercuts the ore-bearing zone at a depth of 300 feet, 780 feet from the portal. The principal development, however, is on the upper or 100-foot level, which connects with the surface through an adit entering from the west at an altitude of 5,370 feet. This level consists of an irregular network of drifts and crosscuts intersecting the ore body. Considerable work has also been done on the 200-foot level, but comparatively little on the three levels or sublevels below this. The total development work aggregates about 7,000 linear feet.

The rocks in the vicinity of the Bluestone mine consist principally of highly metamorphosed limestones, the so-called calc-silicate hornfelses, which on the west have been faulted against granodiorite. Two thick dikes of quartz monzonite porphyry intersect the lime-silicate rocks, and an aplite dike occurs a short distance north of the mine.

The details summarized in the preceding paragraph will now be presented. White lime-silicate rocks, interstratified with beds of white marble, make up the north end of the ridge extending north from the mine. They strike N. 85° E. and dip 70° N. They consist largely of wollastonite, with subordinate diopside and tremolite. Underlying these are darker-colored lime-silicate rocks, mainly dense fine-grained garnetites, which constitute the country rock in the immediate neighborhood of the mine. Associated with them, however, are a few strata of quartzite-like appearance, which are found under the microscope to be composed of quartz and pyroxene. These lime-silicate rocks form a belt about 1,000 feet wide at the mine, which is bounded on both sides by faults—one on the west separating it from granodiorite and one on the east separating it from rhyolite. (See Pl. III, section C–C′.) Both fault contacts are well shown in the main adit; that between the rhyolite and lime-silicate rocks is 210 feet from the portal and dips 77° E., and that between the lime-silicate rocks and the granodiorite is near the face of the adit and dips 35° E. These faults converge northward, causing the lime-silicate belt to narrow abruptly in that direction.

One of the quartz monzonite porphyry dikes is fairly well exposed at the "head frame shaft." It is at least 50 feet thick, is highly shattered, and locally is so thoroughly epidotized as not to be easily recognizable. It is cut off by a transverse fault and displaced somewhat over 100 feet to the east. This fault appears to have been the principal channel along which ore-forming solutions ascended.

The ore body in plan, as shown on the 100-foot level, is roughly elliptical. The major axis, which trends about N. 30° W., is 400 feet in length, and the minor axis is 200 feet in length. The area thus circumscribed is, however, not uniformly mineralized, and parts of it are in fact of too low grade to be ore. The northwest end of the ore-bearing area coincides with the fault along which the quartz monzonite porphyry dike has been displaced, and here the ore formed a rich lodelike shoot, as stoped out in drift 106.

The ore-bearing zone is separated on the footwall side from the barren country rock by a well-defined fissure, locally known as "the footwall," which trends N. 15° W. and dips 35° E., steepening to 45° on the 200-foot level. The ore does not, however, extend everywhere to the footwall. Toward the hanging wall the copper content gradually diminishes, but some of the hanging-wall country rock is said to average 0.75 per cent of copper for 200 feet beyond the limits of the commercial ore. The country rock of the footwall zone, of the hanging-wall zone, and in fact in all barren portions of the mine differs in appearance from that of the ore-bearing parts in that the barren rock is composed of silicates that are lighter colored than the epidote that is characteristically associated with the ore. As verified under the microscope the barren rock is made up chiefly of fine-grained massive garnet.

The ore consists of chalcopyrite inclosed in a gangue consisting predominantly of finely granular epidote with subordinate quartz and calcite. Owing to the prevalence of epidote the ore is of dark-greenish color, a feature that distinguishes the ore-bearing rock from the barren garnetite. The chalcopyrite occurs as grains and irregular small masses; pyrite is absent from the main ore body but appears in the low-grade material of the hanging-wall country rock. The ore shows in places an obscure breccia structure, which is due to the fact that such ore is composed of angular fragments of garnetite, of quartz-pyroxene hornfels, or of porphyry, which have been cemented by chalcopyrite, epidote, quartz, and pyroxene. The breccia structure is particularly well displayed near drift 121, where the quartz monzonite porphyry dike has been crushed and the angular fragments thus produced have been epidotized and surrounded by sulphides. The breccia structure has in this way been strikingly emphasized. That the epidotization and the deposition of chalcopyrite took place together is obvious; and if in other parts of the mine the breccia structure is generally less evident than in drift 121 it is probably due to the obliteration of the garnetite fragments through replacement by epidote. Some of the ore, however, incloses fragments of garnetite, and when examined under the microscope clearly shows not only that epidote along with the other minerals fills the fracture, but that the epidote has grown at the expense of the garnet, invading and destroying it. The end result of intensive action of this kind was chalcopyrite-epidote ore.

The outcrop of the Bluestone ore body was largely covered with soil and hence inconspicuous. The barren capping is thin, however, nowhere exceeding 10 feet. The surface workings disclose notable quantities of bluestone and gypsum. Both of these minerals ramify through the oxidized material in veinlets characterized by cross-fiber structure. Unaltered nuclei of chalcopyrite, however, are present in the oxidized ore, and in general the depth to which oxidation has progressed is inconsiderable, in few places extending to the 100-foot level. Enrichment by supergene sulphides is unimportant; sporadically the chalcopyrite has been in part altered to steely chalcocite, but in general the small amount of enrichment that has occurred has produced only sooty films on the chalcopyrite.

The Bluestone ore body attains its maximal dimensions on the 100-foot level; it is considerably smaller on the 200-foot level, and in the lower workings the metallization, which is mainly pyrite, is clearly confined to narrow fissures traversing dense, massive garnetite. The quantity of ore blocked out is estimated by the manager as 1,000,000 tons, averaging 2.5 per cent of copper.

MASON VALLEY MINE.

HISTORY AND DEVELOPMENT.

The Mason Valley mine is 1½ miles west of Mason. Between 1870 and 1875 the mine furnished considerable bluestone to the mills on the Comstock lode. No large output of copper ore was made, however, until after the mine was acquired by the Mason Valley Mines Co. Active development by this company began in March, 1907, but copper was not produced until after the smelter, built by the company at Thompson, 16 miles from the mine, was blown, on January 6, 1912. The development work done by the company aggregated 23,107 feet at the end of 1914.

The mine yielded 98,912 tons of ore in 1912, 114,854 tons in 1913, and 75,038 tons in 1914. The total production aggregates 288,900 tons, which averaged 2.75 per cent of copper. An estimate of the ore reserves available in 1910 was made by the company's engineer as follows:[1] 1,074,635 tons, assaying 3.95 per cent of copper; 92,000 tons, assaying 2.38 per cent of copper; and 100,000 tons, assaying 1.90 per cent of copper.

On account of the break in the price of copper during the early months of the European war, the mine and smelter were forced to shut down in the middle of October, 1914. They remained idle during 1915 and 1916 but reopened in 1917.

The mine is developed principally by crosscut tunnels, the upper one of which cuts the ore zone at a depth of 90 feet. The main tunnel, known as No. 4, is at an altitude of 5,096 feet; it cuts the ore at 1,200 feet from the portal and attains a depth of 410 feet below the outcrop. The ore is hauled out of the mine by electric traction and delivered to an aerial tramway, 6,250 feet long, which connects the mine with the railroad at Mason. A minor level, 70 feet below No. 4 tunnel level, has also been opened. The ore zone has further been explored by diamond drilling. The shrinkage stope system is the method of mining employed; the ground stands well, and little timber is required.

GEOLOGIC FEATURES.

The ore bodies of the Mason Valley mine consist of irregular lenses of pyrite and chalcopyrite in a gangue of pyroxene and garnet. These lenses occur in a garnetized zone which lies between a footwall of felsite tuff-breccia and andesite, and a hanging wall of limestone. The ore-bearing zone is about 1,200 feet long and from 150 to 375 feet wide. It is terminated on the north by faults, which have dropped a wedge of granodiorite between the ore zone and the Tertiary rhyolites on the north.

The geology in the vicinity of the mine is complex, as may be seen from inspection of figure 7, in which the distribution of the rocks is shown in considerable detail; its complexity is due to the profound metamorphism that has taken place here and to the severe faulting that has occurred during several epochs of disturbance. The most impressive evidences of metamorphism are the large areas of limestone and felsite that have been converted completely into garnet and epidote rocks.

[1] Mason Valley Mines Co. First Ann. Rept., for the year ended Dec. 31, 1910, 1911.

The most important rocks in the vicinity of the Mason Valley mine are crystalline limestones, ranging from fine to coarse grained. They are the rocks that have been altered into ore in the ore-bearing zone. They strike about north and dip 70° or more to the west. Below them lie felsites and lime-silicate rocks, principally garnetites; and below the garnetites is thin-bedded black limestone, which strikes N. 25° E. and dips 70° W. The garnetites are dense, heavy brown rocks of fine grain; under the microscope they are found to consist wholly of garnet, whose refractive index (1.81) indicates it to be a variety halfway intermediate between grossularite and andradite.

Igneous rocks are abundant near the mine and comprise a considerable number of types. The oldest are the felsites of Triassic age. A belt of felsite tuff-breccias, 100 feet wide, forms the footwall along the greater part of the ore zone. Part of the breccia is composed of sharply angular fragments of felsite, averaging a quarter of an inch in diameter and containing small sporadic phenocrysts of quartz. The breccias range in color from white to black, and where the fragmental structure is not apparent it is impossible to establish the identity of the rocks without the aid of the microscope. A notable feature of the breccia belt is the profound metamorphism it has undergone from place to place. Large amounts of it have been converted to fine-grained yellowish-green rocks composed solidly of epidote. In places it is obvious that this transformation has spread out from fractures. Toward the south end of the belt the action was particularly intense, and the felsite breccia was converted into a garnet-epidote rock over an area of several thousand square feet.

Other felsites occur below the footwall breccia. Thin beds of breccia and tuff are intercalated in the garnetite and other lime-silicate rocks. A belt of felsite is well exposed on the road between the office and the powder magazine; it is a snow-white dense variety, which resembles a dense fine-grained quartzite, but its analysis, given on page 15, proves its igneous origin.

An irregular mass of porphyry, here provisionally termed andesite, occurs also in the footwall of the ore zone. Its irregular shape suggests that it may be intrusive, but careful search failed to reveal any evidence tending to prove or disprove this possibility. The andesite carries numerous phenocrysts of plagioclase in an aphanitic groundmass; it is pyritized and at the surface is considerably oxidized. Underground this rock is exposed in the footwall crosscut of No. 4 level, where it is found to be a moderately dark porphyry showing abundant crystals of andesine; it is heavily pyritized, with the development of epidote, chlorite, and biotite. The andesite clearly came into its present position before the mineralization took place, and the most probable conjecture is that it represents a phase of the Triassic volcanic activity.

A belt of granodiorite occurs at the north end of the ore zone, where it is faulted between the pre-Tertiary rocks on the south and the Tertiary rhyolites on the north. Segments of the quartz monzonite porphyry dikes that followed the granodiorite intrusion are prominent at the mines and in the surrounding area and afford registers of some of the faulting that has taken place. The quartz monzonite porphyry dike that crops out strongly in the gully east of the incline tramway is cut by four small basic dikes, and similar dikes are rather commonly observed underground, especially in the north end of the ore zone. They range in thickness

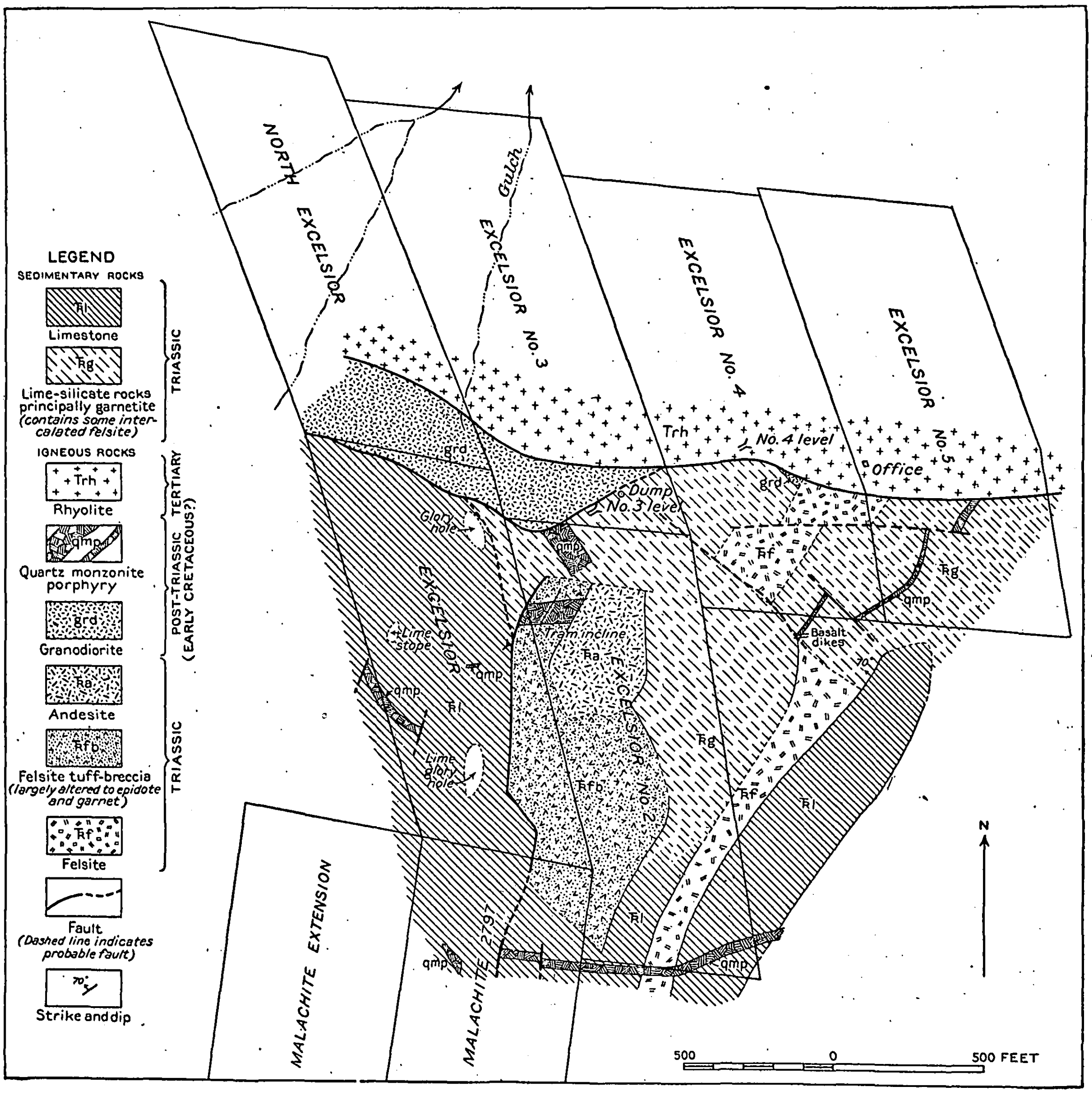


FIGURE 7.—Geologic map of the area surrounding the Mason Valley mine.

from 6 inches to 6 feet. They are later than the ore, which they cut, and show a notable tendency to split into branches. They appear to be of no especial significance and constitute so much waste rock in the ore. They are probably underground equivalents of the basalt flows of the district and are consequently of late Tertiary age.

The most prominent igneous rocks are the rhyolites, which because of their brilliant coloring and sharply eroded forms make a conspicuous element of the surface features at the mine. They are faulted against the rocks of the ore-bearing zone; they are of Tertiary age and hence of much later origin than the ore deposits. They are therefore of no economic importance in the exploration of the ore bodies.

The ore consists of chalcopyrite and pyrite in a gangue of pyroxene, garnet, and calcite. The pyroxene is by far the dominant gangue mineral, making up more than 75 per cent of the ore; it is a grayish-green variety halfway intermediate in composition between diopside and hedenbergite, as shown by its analysis on page 32. It is lamellar in habit and commonly forms radial groups 2 or 3 inches in diameter, though groups 10 inches across are observable here and there. The garnet, which proves to be andradite, appears to occur principally on the edges of the ore lenses. It is notably true that the great masses of barren lime-silicate rock associated with the ore bodies are highly garnetiferous; in fact, they are essentially garnetites. Thicknesses of over 100 feet of such barren garnetite are shown in the footwall crosscuts on No. 3 level.

Other minerals occurring in the sulphide ore are actinolite, calcite, chlorite, quartz, and magnetite. The actinolite forms the dense dark-green gangue rather characteristic of the Mason Valley ore; the calcite is invariably present as a minor interstitial component; the chlorite and quartz are recognizable only under the microscope; and the magnetite is an infinitesimal constituent.

The oxidized ore consists of cuprite, native copper, azurite, malachite, and chalcanthite, together with gypsum and limonite and partly decomposed pyroxene and garnet. Oxidation has locally extended as deep as No. 3 level, but the principal bodies of oxidized ore occur nearer the surface. Sulphides, in fact, occur in the outcrop. Some small amount of enrichment by secondary sulphides has taken place, chiefly by the development of covellite. Oxidation and sulphide enrichment have been restricted to zones of postmineral fissuring; they have been retarded by the presence of calcite and the imperviousness of the pyroxene gangue. Offsetting the presence of the calcite, however, is the prevalence of pyrite, which has yielded sufficient sulphuric acid to sulphatize the calcium carbonate. This reaction accounts for the high gypsum content of the oxidized ore; and the abundance of this comparatively soluble mineral proves the sluggish and ineffective lixiviation of the oxidized zone. The presence of chalcanthite in minable quantities is of course a testimony of the extreme aridity of the recent (post-Lahontan) climate.

The ore-bearing zone trends north and dips steeply to the west; it is 1,200 feet long and from 250 to 375 feet wide. On the north it is faulted against granodiorite, which lies as a narrow wedge between it and the Tertiary rhyolites. The footwall of the ore zone is the felsite tuff-breccia; its dip from the surface down to No. 4 level averages 70° W., but below this level it either flattens considerably or is displaced by a flat-lying fault. The hanging wall is marked by a zone of fissuring and crushing, dipping 75° W.; in places the shattered and broken limestone attains a width of 50 feet. The general structural relations at the mine are shown in figure 5 (p. 37), which is a section through tunnel No. 4, making an angle of 60° with the trend of the ore-bearing zone. The quartz monzonite porphyry dike is cut at right angles to the line of the section, so it is shown with its normal dip; the two basic dikes, however, make large angles with the line of the section, and their dips are consequently shown flattened to half their real amount. A belt of felsites, 80 feet wide as exposed in tunnel No. 4, lies immediately under the footwall but is not shown separately in the figure.

The general northerly strike of the footwall of the ore-bearing zone is broken near its south end by a fault striking N. 40° W., whereby the southern extension of the ore zone was displaced about 125 feet southwestward, as determined by the mapping of the surface geology. (See fig. 7.) This faulting occurred before the primary mineralization took place, and this fact has a bearing on the exploration for new ore bodies, as is pointed out on pages 35–37.

Postmineral disturbance has occurred along the footwall fissure of the ore zone and has produced considerable crushing, which is well shown on No. 1 level and the 170-foot sublevel below it. This crushing has facilitated the oxidation to greater depth and thoroughness than is common in the mine and accounts for the occurrence of high-grade oxidized ore found in the so-called east ore body.

The ore zone is made up of the ore bodies, pyroxene and garnet masses, and limestone. The ore bodies on the hole are situated nearer the hanging-wall fissure; below them—that is, toward the footwall—are great masses of barren garnet rock, attaining thicknesses as great as 200 feet. These relations are well shown in figure 5; the positions of ore and garnet rock are shown only for the different levels, as lack of data did not admit of their representation for the intervening space.

The ore bodies are irregular masses and lenses of irregular copper content. They grade into lean pyroxene rock, or into barren garnet rock, or into limestone. The transition from ore to pure limestone is as a rule extremely abrupt. The limestone adjoining the ore shows no coarsening of its grain; in this respect it contrasts with most ore deposits of similar type, in which proximity to ore is indicated by the increasing granularity of the inclosing limestone. Many of the ore lenses are of great size; and as the ground stands well after extraction of the ore large chambers have resulted, some being 100 feet long, 30 to 50 feet wide, and 50 to 60 feet high. The largest ore bodies occur on No. 3 and No. 4 levels; on No. 3 level the ore is practically continuous for a length of 800 feet. The copper content is erratic, however, and it is obvious that, as in most other contact-metamorphic ore deposits, it would be difficult to estimate the copper content with much accuracy in advance of exploitation and extraction. The ore so far developed on the 470-foot level is mainly lean garnet-pyroxene rock.

The main outcrops of the Mason Valley ore bodies are near the north end of the ore-bearing zone. Toward the south end outcrops of ore or other indications of ore are insignificant, yet as shown by the underground development large ore bodies occur below what on the surface is nothing but pure limestone.

In recent years an ore body was discovered in crosscutting east from the lime stope above No. 1 tunnel level, which is called the east ore body. Being somewhat closer to the felsite footwall than the ore bodies occurring in other parts of the mine, it lies somewhat to the east of them. A footwall crosscut was driven east from plug 373 for a distance exceeding 200 feet on No. 3 level, all in garnetiferous rock, in the endeavor to prove the downward extension of the east ore body. In this part of the mine the footwall of the ore zone is displaced about 125 feet to the southwest by a premineral fault; therefore, inasmuch as in the rest of the mine the ore tends to occur between the limestone and the garnetiferous zone that lies on the footwall, the ore zone in this part of the mine ought here to bend rather abruptly southwestward. Accordingly, crosscuts driven westward from this footwall crosscut will explore a considerable block of ground in which masses of ore are likely to occur.

MALACHITE MINE.

The Malachite mine adjoins the Mason Valley mine on the south, and its workings connect with those of the 300-foot level of the Mason Valley mine. The geology of the vicinity of the portal of the main tunnel is shown in figure 7. The fault cutting off the quartz monzonite porphyry dike at the main tunnel is well exposed at the surface and shows that the porphyry has been altered largely to epidote for a distance of 20 feet from the fault. The principal ore shoot has mineralogic features like those of the ore in the Mason Valley mine, consisting of pyrite and chalcopyrite in a gangue of grayish-green lamellar pyroxene, with subordinate brown garnet.

In addition to the ore found in the southern extension of the Mason Valley ore zone, some bodies of cupriferous lime-silicate ore have been explored that occur on the low ridge on the east side of the road to the McConnell mine. They are situated along the contact of felsite and gray limestone.

McCONNELL MINE.

The McConnell mine, owned by the McConnell Mines Co., is on the east flank of the range, about a mile southwest of the Mason Valley mine. The main workings consist of a large open cut or glory hole, the ore being taken out through two tunnels, the lower of which attains a depth of about 100 feet below the croppings. A vertical shaft 400 feet deep has been sunk and levels turned at depths of 200 and 400 feet.

Production began in March, 1912, at the rate of 50 tons daily and continued until November, 1913. The output aggregated 24,100 tons of ore, averaging slightly more than 3 per cent of copper. The ore carries no gold nor silver.

The mine is situated in the thick belt of limestone extending southward from the Mason

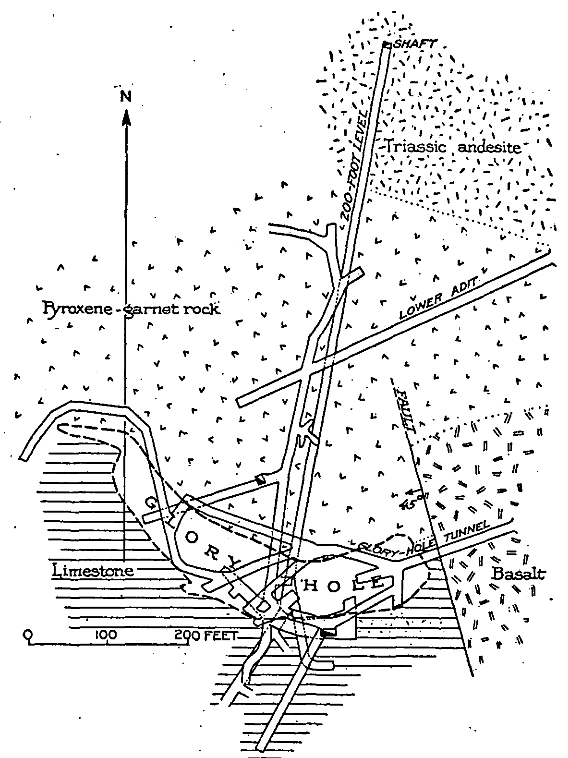


FIGURE 8.—Plan of the McConnell mine, showing the geologic relations. The heavy dashed line represents the outcrop of the body.

Valley mine and is a few hundred feet east of the quartz monzonite. The hill west of the mine, covering the area lying between the mine and the quartz monzonite, has been converted solidly into garnet. In this massive garnetite was found the *Halobia*-like fossil whose presence indicates a Triassic age for the rocks.

The rocks in the immediate vicinity of the mine are limestone, Triassic andesite, and Tertiary basalt. (See fig. 8.) Intense faulting of premineral as well as postmineral origin has complicated the mutual relations of these rocks. The andesites are separated from the garnet mass, in which the ore body is inclosed, by a fault trending east and dipping 65° S. They are fine-grained black rocks of obscurely porphyritic character and have been considerably recrystallized as a result of thermal metamorphism. Under the microscope they are found to consist largely of plagioclase and hornblende. As seen in the mine workings they show in addition the effects of intense crushing and shearing, and in consequence of the fissile structure they have assumed they are locally known as shales.

A portion of the basalt capping that overlies the mesa east of the McConnell mine has been faulted against the limestone in proximity to the ore body. The faults are well exposed in the upper and lower tunnels. The fault seen in the upper tunnel is a sharply defined plane trending N. 15° W. and dipping 54° W. The basalt (the footwall country rock) is considerably shattered near the contact, and the overlying limestone is brecciated for more than 20 feet from the contact. The fault shows on the 200-foot level also, but here it has passed through the basalt, and the andesites adjoin the limestone. These relations are shown in figure 4 (p. 29). The fault is a reverse fault, whose dip slip is at least 150 feet. The appearance of the andesites on the 200-foot level means either that the dip slip greatly exceeds 150 feet, or that the movement along the fault plane had a large horizontal component. On the surface the shifting of the contact of andesite and limestone by this fault amounts to 500 or 600 feet. The side of a separate mass of basalt is partly exposed in the south wall of the glory hole. It is better shown on the level of the lower tunnel, where it is found to be a brecciated mass at least 180 feet long and 30 feet thick. It is bounded on the north by a steep fault and on the south by a fault dipping 70° S. Later than this faulting is a vertical fault trending N. 60° E., whose slickensided surfaces are conspicuous features of the McConnell glory hole. The displacement along this fault is small, however.

The ore body is elliptical in plan. At the outcrop the major axis measured 400 feet and the minor axis 80 feet; on the level of the upper tunnel, which attains an average depth of about 40 feet below the outcrop, the dimensions were respectively 250 feet and 50 feet. Relatively little ore has so far been found on the lower levels.

The primary ore consists of chalcopyrite and pyrite in a gangue composed mainly of amber and pale-brown garnet. A light-green amphibole, pyroxene, and calcite occur as subordinate components. The croppings were highly oxidized, and the copper was present chiefly in the form of chrysocolla and malachite. Partly altered nuclei of chalcopyrite are present, however, in otherwise strongly oxidized ore. As a rule the oxidized ore is thoroughly permeated with gypsum, and this feature is especially marked in the vicinity of residual chalcopyrite, where there are not uncommonly plates of gypsum, as much as an inch in diameter and one-quarter of an inch thick, which have grown in the body of the ore. The area of garnet rock is considerably larger than the outcrop of the ore body, which is situated between the limestone and the barren part of the garnet mass.

The origin of the McConnell ore body appears to be connected with the fault that separates the andesites from the limestone belt. In places the limestone shows that the garnet and amphibole developed along fractures; and it is probable that the metalliferous solutions ascended along the fault and replaced the brecciated limestone adjoining it. Generally the replacement has been so complete that little evidence of its mode of operation remains.

The Red mine, which belongs to the McConnell Mines Co., is a few hundred yards southeast of the McConnell mine. Here was worked a body of oxidized ore, which was inclosed in limestone at the quartz monzonite contact. Intense crushing produced by postmineral dynamic disturbance has affected the deposit. The end of the lower tunnel follows a well-defined fault striking north and dipping 70° E. This is the fault that separates the quartz monzonite from the limestone, but a dike of andesite characterized by lustrous hornblende prisms has been intruded for some distance along the fault. Under the microscope the andesite shows phenocrysts of hornblende in a fluidal groundmass of slender plagioclase prisms; and these features leave little doubt as to the identity of this rock with the hornblende andesite that is common as a surface flow rock in the northern part of the district. Subsequent movement along the fault surface has profoundly sheared the dike, and much of the shiny gouge, characteristic of the mine, is sheared dike rock that has been stained deep red by the infiltration of iron oxide.

WESTERN NEVADA MINE.

The Western Nevada mine is at the head of a narrow canyon in the east flank of the Singatse Range, near the south end of the mineral belt. The mine has never shipped any ore, although a considerable quantity has been extracted and thrown on the dump. In March, 1915, the property was merged with that of the Nevada-Douglas Copper Co., forming the Nevada-Douglas Consolidated Copper Co., and active development and exploitation were contemplated.

In addition to a number of short adits near the outcrops, the mine is opened by two principal adits, of which the lower, or main adit, 140 feet below the upper, attains a vertical depth of 235 feet below the top of the hill in which the ore bodies lie. This adit is 1,000 feet long and strikes N. 50° W.; from it an extensive system of drifts extends northward, exploring an area of pyroxenic and garnetiferous rocks in which the principal ore shoot is inclosed. From this level a winze, 300 feet deep, was sunk, and the ore shoot was crosscut on the "300-foot" and "400-foot" levels.

The ore bodies and their associated silicate rocks occur in a thick belt of limestone, faulted on the west against quartz monzonite. A block of the Triassic andesites has been faulted against the limestone at the mine. The main adit, commencing in these andesites, cuts through 300 feet of them, then through lime-silicate rocks, and again through andesites, finally penetrating the quartz monzonite. The last few hundred feet of the adit is in very thoroughly crushed andesite (locally called "shale"). The cause of this crushed condition becomes plain from a consideration of the surface geology, from which it appears that the course of the adit trends at a narrow angle with the fault contact of the limestone and the andesites. The adit is now caved at 830 feet from the portal. Ransome, who examined the mine when the face of the adit was accessible, states that the quartz monzonite contact is due to faulting, the fault plane dipping 54° E. According to the same authority the hanging wall is much broken, but no mineralization has taken place along the fault. About 100 feet east of the fault there is a fissure trending nearly north which is partly filled by a quartz vein carrying pyrite but no constituents of value. This vein dips 35° E. It is probably younger than the cupriferous ore bodies in the limestone, but its age was not certainly determined.

Numerous scattered bodies of ore, generally from 10 to 20 feet long and trending parallel to the stratification of the inclosing limestone, are shown in the surface cuts and winzes at the summit of the hill. These ore masses are most abundant near the saddle overlain by the horizontal sheet of Tertiary basalt. The copper ore is associated with radial lamellar pyroxene, with garnet, or with both minerals; it is as a rule highly oxidized, consisting of gossany material netted with veinlets of chrysocolla and more or less gypsiferous. One outcrop shows garnet and other silicates extending continuously for a length of 100 feet and expanding at one place to a width of 20 feet.

The ore shoot explored on the level of the main adit is about 200 feet long and trends N. 15° E. It ranges from 2 to 6 feet in width and averages from 2 to 3 per cent of copper. Some enrichment by supergene sulphides has taken place, and chalcanthite is even now in process of formation by the feeble percolation of descending solutions. Toward the north this shoot is cut off by a fault along which an unusually fine example of a limestone attrition conglomerate has been produced.

The ore consists of chalcopyrite and pyrite embedded in an intergrowth of pyroxene and garnet with interstitial calcite. The pyroxene is dark grayish green, occurs in radial lamellar groups or in dense fine-grained aggregates, and is probably the predominant gangue mineral. The garnet, which is of the andradite variety, ranges from brown to amber and commonly shows crystal faces of dodecahedral and trapezohedral habit. Locally these minerals have altered to chlorite, amphibole, and serpentine, but this action has not been extensive or of economic significance.

GREENWOOD PROSPECT.

The Greenwood prospect is 1 mile northeast of Ludwig, at an altitude of 6,000 feet. The principal developments consist of an inclined shaft, which is cut by a tunnel 150 feet below. The general country rock is garnetite, which is traversed by a thick dike of quartz monzonite porphyry. The dike makes a rather abrupt bend in its course through the property, as shown in Plate I; and near this bend bunches of chrysocolla and copper pitch ore with subordinate malachite are found on both sides of the dike. The primary sulphide is chalcopyrite, but this has mostly been oxidized to the minerals mentioned; the gangue is mainly andradite garnet, with minor quartz and epidote.

LUDWIG MINE.

GENERAL FEATURES.

The Ludwig mine, around which the small settlement of Ludwig has grown, is on the west slope of the Singatse Range at the edge of Smiths Valley. The mine was opened in 1865 on oxidized copper ore lying in the footwall of the primary deposit, and a shallow tunnel was driven for 500 feet on the strike. Considerable bluestone was produced for the reduction works on the Comstock lode. In 1907 the mine was acquired by the Nevada-Douglas Copper Co., which commenced energetic operations in both the primary and the derived ores. The production from December, 1911, to August 1, 1914, was 125,689 tons of ore averaging 6 per cent of copper.

During the later part of 1914 experimentation was actively in progress to devise methods to treat the ores of the Nevada-Douglas Copper Co.'s mines—the Ludwig, Douglas Hill, and Casting Copper—by a leaching process. The plan under trial was designed to utilize the heavy pyritic ore of the primary ore body of the Ludwig mine to furnish the sulphuric acid required to leach the oxidized ores of this and the other mines. As a result of this experimentation a mill having a daily capacity of 250 tons was built at Ludwig during 1915.

The mine is worked principally through an inclined shaft situated near the north end of the lode. This attains a vertical depth of 678 feet. Eight levels extend from it along the strike of the lode, and the lowest level is known as the "800." An old vertical shaft 400 feet deep serves as an auxiliary entrance and in 1914 was used in exploiting the secondary ores occurring in the limestone footwall of the primary deposit.

The Ludwig deposit is essentially a replacement lode developed along the faulted contact of a massive limestone and an overlying series of garnetites and felsites. The fissuring along which the ore-forming solutions rose coincided approximately with the bedding plane between the footwall limestone and the dense garnetite that forms the hanging wall of the deposit. The salient features of the lode are well shown at the vertical shaft—the dense garnetite hanging wall, the bold quartzose iron-stained croppings, the footwall of white limestone in which occur more or less discrete pyritic lenses, and the irregular bodies of copper pitch ore in this footwall limestone.

accessory minerals practically proves that the quartzose gossan is the oxidized equivalent of the silicified and pyritized porphyry. It is believed that the porphyry, which by its alteration gave rise to the quartzose gossan, is mainly fault material dragged into the zone of fissuring.

The quartz outcrop formerly contained much cubical pyrite, as is shown by the many casts of this mineral and the prevalence of iron oxides.

The footwall of the lode is a coarse crystalline white limestone, which is approximately

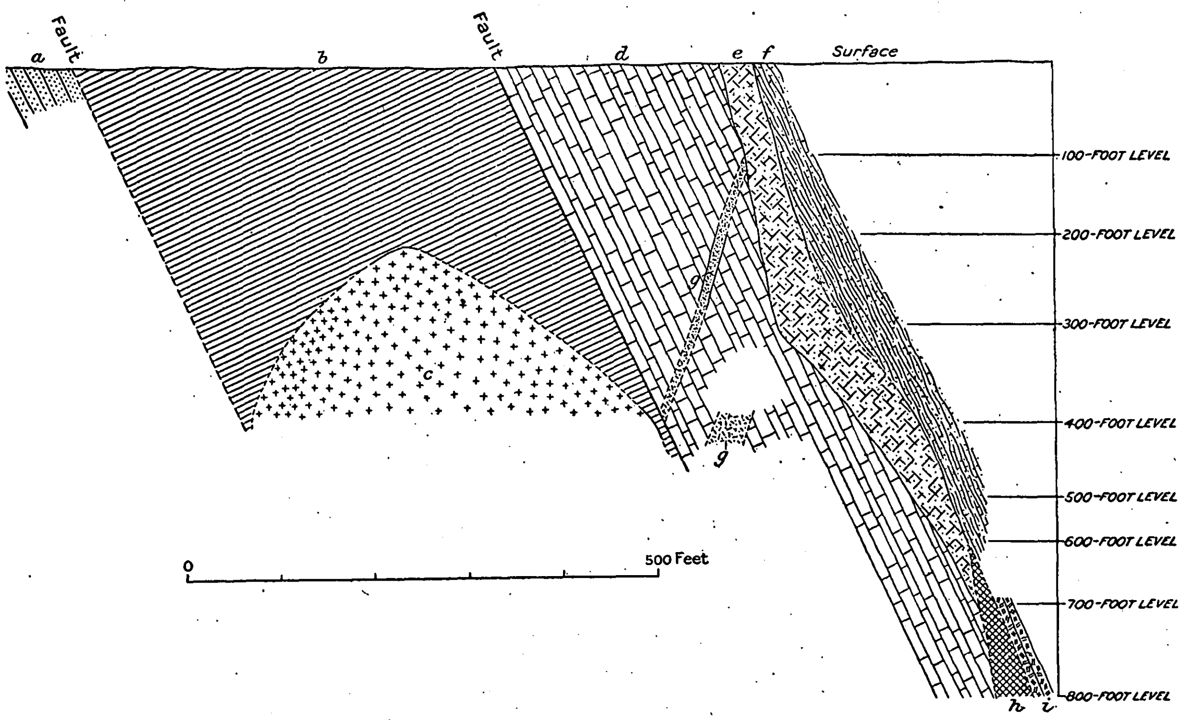


FIGURE 9.—Geologic section across the Ludwig lode at the vertical shaft, slightly generalized. *a*, Quartzite; *b*, gypsum; *c*, anhydrite; *d*, limestone; *e*, quartzose gossan; *f*, garnetite and other lime-silicate rocks; *g*, porphyry; *h*, heavy sulphide ore; *i*, felsite.

DETAILS OF THE GEOLOGY.

The prominent iron-stained quartz outcrop of the lode extends 600 feet south of the vertical shaft, ranging in width from 20 to 60 feet. The quartz mass is fine grained, wholly unlike the quartz of veins that fill fissures, and its general appearance strongly suggests the silicified porphyry that is found on the lower levels of the mine. Under the microscope the siliceous material of the outcrop is found to consist mainly of quartz, together with a little chalcedony and opal and the accessory minerals garnet, apatite, and zircon. As will be seen from the description of the altered porphyries found underground the presence of these three

170 feet thick. It is underlain by a gypsum bed, from which, as seen underground, it is separated by a fault breccia containing a considerable proportion of quartzite fragments. This breccia is locally known as the "conglomerate," probably because of the partly rounded condition of the limestone fragments it contains. So severe has the dynamic disturbance been that blocks of limestone have been split in two, and gouge filled with small angular fragments of quartzite has been squeezed into the fissure. The footwall limestone, although on casual inspection apparently a single massive bed, contains some thin strata of dark-gray limestone, and these serve as

registers of the remarkable internal disturbance to which the main stratum has been subjected. Reverse faults, with displacements ranging between 5 and 6 feet, are shown, and sharply angular fragments of the dark-gray limestone are embedded in the white limestone at considerable distances from their place of derivation.

The hanging wall of the lode, as seen at the surface and on the upper levels, consists of fine-grained lime-silicate rocks resulting from the metamorphism of a series of thin-bedded limestones. Their mineral makeup is not readily recognizable by the unaided eye, but under the microscope they are found to be composed principally of garnet. A specimen from the 100 level is a dense aphanitic garnetite composed almost wholly of a garnet intermediate between grossularite and andradite. In the 700 and 800 levels the hanging-wall rock as seen near the shaft is a banded felsite, more or less altered by pyritization and the development of garnet, epidote, and pyroxene.

The fault along which the lode occurs trends parallel to the formation and dips on the average 70° E. The average dip is apparently a little steeper than that of the stratification, which ranges from 60° to 65° E., and this supposition is strengthened by the fact that the lithologic character of the hanging wall changes in depth. The fault is well shown underground along barren stretches of the lode, along which the limestone lies directly against the garnetite hanging wall. It is excellently exposed on the 100 level, north of the vertical shaft, where it can be seen that the movement on the fault surface was mainly horizontal. The limestone in proximity to the fault at many places in the mine is tremendously shattered and brecciated, forming breccias as much as 80 to 100 feet thick.

Some postmineral faulting has affected the lode. At the vertical shaft a fault cutting the lode at right angles and dipping 70°–80° N. has displaced the lode about 50 feet horizontally southeast.

Porphyry dikes are common at the mine. One of these, which is over 100 feet thick, forms the hanging wall of the fissure north of the shaft; its course is shown on the geologic map (Pl. I), which shows also the interesting faulting to which it has been subjected. This porphyry contains phenocrysts of pearl-gray orthoclase, of plagioclase, and of hornblende. In the mine workings are found dikes of this character, and also porphyries especially characterized by the prevalence of rounded phenocrysts of quartz. The dikes of both kinds are much shattered. A short distance south of the south end of the quartz outcrop of the lode a large fragment of shattered porphyry, evidently fault drag, is inclosed in the fault zone along which the lode originated.

THE ORES.

The iron-stained cellular siliceous matter of the outcrop extends down to the 500 and 600 levels with little change of character. Along dip and strike, however, the dimensions of the gossan are markedly irregular, as shown in two cross sections of the lode, 320 feet apart (figs. 9 and 10).

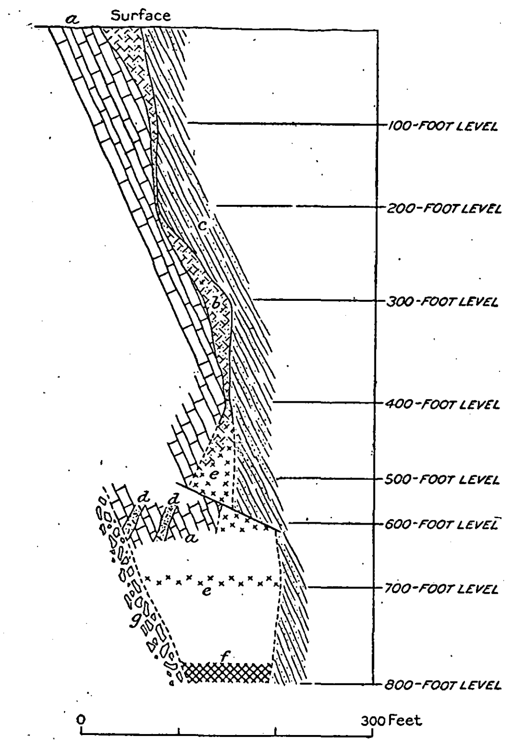


FIGURE 10.—Geologic section across the Ludwig lode 320 feet southwest of the vertical shaft. *a*, Limestone; *b*, quartzose gossan; *c*, garnetite; *d*, porphyry; *e*, heavy sulphide ore; *f*, pyritized and silicified quartz porphyry; *g*, limestone fault breccia.

The oxidized ores occur principally in the footwall limestone in extremely irregular bodies ranging from circular pipes to fairly persistent tabular masses. The ore consists largely of a reddish-brown aphanitic substance, copper pitch ore. It averages about 15 per cent of copper. Chrysocolla and cuprite occur in minor amounts and are the only definite copper minerals recognizable in the ore now seen. Formerly carbonates were abundant. The ore shows a rather well-defined layering parallel to the inclosing walls, and much of it plainly fills solution cavities in the limestone. The main occurrence of ore of this kind is in the footwall limestone in the vicinity of the vertical shaft—that is, near the postmineral cross fault already mentioned.

The copper of this secondary ore was evidently derived mainly from the siliceous gossan during its oxidation. The solutions that originated during this process tended to migrate into the footwall of the lode, and this tendency was augmented by the cross faulting and the shattering that accompanied this faulting. Once in this calcitic environment the copper was eventually precipitated as carbonates and chrysocolla.

Chalcocitized ore first appeared on the 500 level, the depth at which the water level was reached. Stopes on ore of this kind were worked on the 600 level, but below this the ore is mainly of primary origin. The secondary sulphide has formed chiefly at the expense of the chalcopyrite in the primary ore. Gypsum is common in the enriched ore. A notable example of this is the "selenite stope" on the 600 level, where the gypsum is crystallized in fine long prisms, which attain exceptionally a length of 8 inches.

Although primary ore predominates below the 600 level, some bodies of rich oxidized ore have been found even in the bottom level, consisting of coarsely crystalline cuprite partly mixed with native copper. They appear to have been localized along exceptionally favorable channels for downward-moving waters.

The primary ore, as seen on the 700 and 800 levels, consists largely of pyrite in a gangue of quartz, calcite, and andradite garnet. Chalcopyrite is a subordinate constituent, but in general no copper-bearing mineral is recognizable by the unaided eye. The ore is reported to average 2 per cent copper, and a body of this grade ranging from 50 to 100 feet wide is exposed on the 800 level. In this body the garnetiferous quartz-pyrite ore, carrying coarse calcite as a minor constituent, grades toward the footwall into a heavy pyrite ore with calcitic matrix. The pyrite has obviously replaced the cement of the limestone breccia that resulted from the faulting which took place along the contact of the limestone and the overlying rocks. The character of the primary ore differs somewhat from place to place. On the 700 level the ore consists of pyrite in large cubes, some as much as an inch in diameter, inclosed in coarse white quartz with which is mingled some sparry calcite. In addition to these varieties of ore there occur large pyritic masses derived from the mineralization of quartz porphyry dikes. These dikes are netted with quartz veinlets and have been so intensely silicified that only the quartz phenocrysts have remained intact. In places they have also been metamorphosed by the development of garnet and epidote, an alteration that has spread out from veinlets of quartz, calcite, garnet, pyroxene, and pyrite. These features are well shown in the long hanging-wall crosscut on the 700 level, and on the 600 and 500 levels. The most nearly unaltered porphyry was found on the 500 level near plug 518, and this proves to be quartz monzonite porphyry containing sporadic large orthoclase crystals, smaller and more abundant plagioclase crystals, and numerous corroded quartz crystals, which are the most conspicuous phenocrysts. The conditions shown in the drifts near plug 611 probably give a clearer idea of the relation of the porphyry dikes to the mineralization than can be obtained anywhere else in the mine. A number of narrow dikes cut the limestone here; the margins of the dikes have been severely brecciated, and the breccia is cemented by garnetiferous calcite-pyrite veinlets. The porphyry fragments have been altered beyond easy recognition, and it is manifest that where brecciation has been more extensive and the mineralization more profound, as on the 700 level, it would be impossible to discriminate between mineralized limestone and mineralized porphyry. The recognition of silicified, pyritized porphyry derived from porphyry that contained no quartz phenocrysts, like that of the thick dike occurring in the hanging wall of the lode, would be especially difficult. Silicified and pyritized porphyry of the kind so well shown on the 500, 600, and 700 levels is probably the material from which the siliceous outcrop of the Ludwig lode was mainly derived, as well as the great bodies of leached siliceous gossany material that extend down to the 600 level. The pyritic bodies derived from the metamorphism of the porphyry dikes are too low in copper to be ore.

In places the hanging wall of the lode is cut by quartz-garnet-sulphide veinlets. At the outcrop veinlets composed of quartz prisms and garnet dodecahedrons and carrying a little chrysocolla traverse the brecciated garnetite adjoining the quartz outcrop. Underground the penetration of the hanging-wall rocks by veinlets composed of quartz, calcite, garnet, and pyrite is well shown in a number of crosscuts. Near the shaft on the 700 and 800 levels the felsite hanging wall is cut by coarse veinlets of quartz, epidote, garnet, and pyrite. Microscopic examination shows that the felsite has been partly replaced by garnet, pyrite, calcite, epidote, and pyroxene.

GYPSUM DEPOSIT.

The large deposit of gypsum occurring on the property of the Nevada-Douglas Copper Co. has been extensively quarried just north of the Ludwig shaft. The gypsum, as first proved by A. F. Rogers,[1] has resulted from the hydration of anhydrite. This is excellently shown on the 400 level of the Ludwig mine, where a crosscut has been run into the deposit for a distance of 100 feet. The gypsum bed, as previously described, is separated from the thick limestone belt forming the footwall of the Ludwig lode by a fault breccia containing innumerable quartzite fragments; underlying this breccia is 10 feet of fine-grained gypsum which grades rather abruptly into hard, massive, coarsely granular anhydrite. The geologic relations are shown in figure 9 (p. 59).

The quarry was operated from November, 1911, to the middle of September, 1912, and during that time about 75 tons a day was shipped to the Western Gypsum Co. at Reno, Nev. Since then it has lain idle. The gypsum is reported to have averaged 96 per cent pure.

DOUGLAS HILL MINE.

The Douglas Hill mine, owned by the Nevada-Douglas Consolidated Copper Co., is on the summit of the ridge known as Douglas Hill, east of Ludwig. The workings consist principally of thirteen large pits from which the ore was taken out through tunnels, the lowest of which—the main haulageway of the mine—attains a depth of 120 feet below the crest of the hill. The production since December, 1911, has been 68,905 tons of ore carrying 5 per cent copper. In 1914, however, the mine was idle. At the time it was shut down, pending the construction of the leaching plant at Ludwig, the mine was furnishing 50 tons of 5 per cent ore—5 per cent being the minimum percentage at which it was profitable to ship ore to the smelter.

The ore forms irregular lenses in an immense mass of andradite garnet, which caps the summit of Douglas Hill. This great body of garnet resulted from the replacement of the massive limestone lying above a stratified series of fine-grained garnetites. The footwall of the ore zone is a belt of breccia, probably 20 feet thick. This breccia is composed of fragments of a dense aphanitic garnetite which are cemented by coarse euhedral yellow garnet. The garnet of the fine-grained rock, as shown by its refractive index (1.75), is a nearly pure grossularite; the garnet of the cement, as shown by its index (1.87), is a nearly pure andradite. The breccia structure—that is, the inclosure of sharp angular fragments of garnetite in coarsely euhedral garnet—is as a rule excellently shown; in places, however, the cement, the secondary garnet, appears to form an unusually large proportion of the rock mass, but this is undoubtedly due to the replacement of limestone that was originally present in the breccia. Chalcopyrite occurs sporadically in the cement.

The andradite of the ore-bearing zone is characteristically coarsely faceted and has a notably fatty or adamantine luster; and in these respects it contrasts strongly with the fine-grained garnetites, which obviously originated at an earlier epoch of metamorphism. Although the ore-bearing zone consists largely of andradite with locally some epidote and pyroxene, yet the surface exposures as well as the mine workings disclose sporadic residual masses of pure limestone, though even some of these are penetrated by stringers of garnet. In figure 11 the areal geology of the Douglas Hill mine is shown, and this map brings out clearly the erratic distribution of the ore lenses in the andradite rock, as indicated by the many pits.

The ore is predominantly oxidized; chrysocolla and copper pitch are the principal min-

[1] Econ. Geology, vol. 7, pp. 185-189, 1912.

erals. Brochantite in small emerald-green glassy prisms and malachite occur subordinately. Chalcopyrite is the main primary sulphide, pyrite occurring in traces only.

In places considerable postmineral movement has crushed and brecciated the garnet of

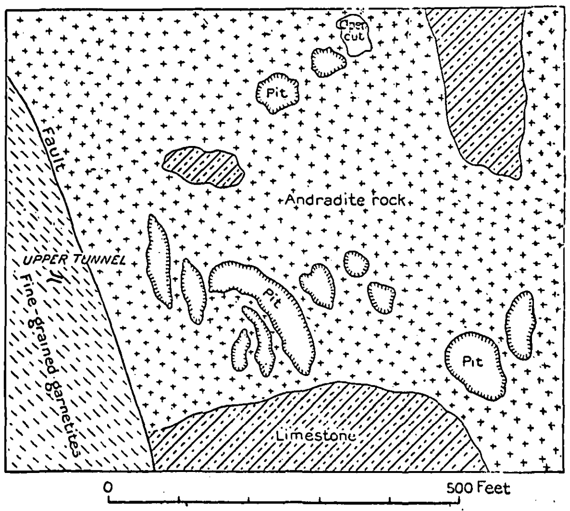


FIGURE 11.—Areal geology at the Douglas Hill mine.

the ore-bearing zone. Locally some downward sulphide enrichment has taken place, controlled possibly by the postmineral crushing just referred to; the ore known at the mine as "spot ore" was an example of an unusually high-grade chalcocitized ore, carrying as much as 15 per cent of copper. The deeper workings, however, show little evidence of enrichment.

CASTING COPPER MINE.

The Casting Copper mine, which is owned by the Nevada-Douglas Consolidated Copper Co., is just south of the town of Ludwig. It is developed principally by a shaft 350 feet deep. The production up to August 1, 1914, was 29,241 tons, averaging 5 per cent of copper. All ore has come from above the 200-foot level, and the greater part of it has come from the large glory hole, which is the prominent feature of the surface workings of the mine.

The ore-bearing zone lies along a fault that has caused a series of stratified black garnetites to abut against massive limestone, as shown in figure 12. The garnetites are dense, fine-grained rocks which are distinctly bedded in relatively thin strata; the limestone is coarsely crystalline and obscurely bedded. The rocks here referred to for convenience as garnetites probably include clinozoisite-vesuvianite rocks and allied varieties, as shown in the detailed section of the rocks at Ludwig, but except for one specimen, which proved to consist wholly of garnet crowded with carbonaceous matter, they were not examined microscopically.

The limestone is the productive rock; it has been replaced by coarsely crystalline garnet for a length exceeding 400 feet along the strike of the fault and for a width in places of 150 feet. The garnet rock of the ore-bearing zone is of highly distinctive appearance, consisting of notably lustrous resin-yellow andradite garnets, as a rule distinctly crystallized according to the common dodecahedral habit and surrounded by paler andradite, which is generally less distinctly faceted than the resinous garnet. A little calcite, 1 or 2 per cent, occurs interstitially between the garnet crystals. Along the fault contact the black garnetites have been slightly shattered, and the angular fragments are outlined by the thin veinlets of well-crystallized yellow garnets that surround them: the evidence of two distinct periods of garnetization is well shown in this mine. The contact between the ore-bearing garnet masses and the massive limestone is highly irregular, and veins and bunches of solid garnet are most erratically distributed through the limestone adjoining the main garnet masses.

The main ore body consists of a large lens which is reported to have been 120 feet long and 40 feet wide on the upper levels and to

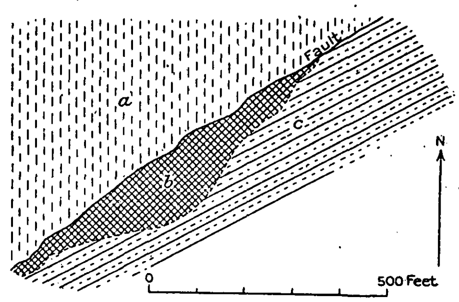


FIGURE 12.—Diagrammatic map of the surface geology at the Casting Copper mine: *a*, Garnetite; *b*, andradite of the ore-bearing zone; *c*, massive limestone.

have averaged 6 per cent of copper. At the time of visit the stopes on this lens had been carried down within 35 feet of the 200-foot level. The ore body is narrow here, averaging a few feet in width. The ore consists of partly enriched chalcopyrite inclosed in a gangue of altered garnet and pyroxene and permeated with a considerable amount of gypsum. The ore body is wholly inclosed in massive limestone, and blocks of limestone occur in it. The lateral drifts show, as is observable on the 200-foot level, that irregular veins and bunches of euhedral garnet occur in the limestone adjoining the ore body. Although the ore body is thus in a limestone environment and is more or less oxidized, copper carbonates are nevertheless scarce, and chrysocolla is the predominant recognizable oxidized copper compound, forming veinlets on the edge of the oxidized ore against the limestone.

Sporadic masses of ore lying in proximity to the main ore lens have been found on the 200-foot level. It is a noteworthy feature of the ore bodies in this mine, as it is of those at the Mason Valley mine, that, although the workings disclose immense bodies of practically solid garnet, the gangue of the ore-bearing parts of these great garnet masses is characterized by the presence of a considerable proportion of lamellar pyroxene.

All ore shows some sulphide enrichment, generally as a soft, sooty black mineral. Where recognizable, the secondary sulphide is commonly seen to be covellite, which tends to occur as plates lying parallel to the pyramidal cleavage of the chalcopyrite. The enriched ore contains prevailingly a notable amount of gypsum. Secondary sulphides in gypsiferous gangue extend as deep as the 200-foot level. Although secondary sulphides have formed throughout the ore bodies much of the sooty black mineral associated with the chalcopyrite proves to be black copper oxide.

A well-defined fault surface trending N. 50° E. and dipping 70° NW. determines the northwest face of the glory-hole pit; it is excellently shown on the 100-foot level. It limits the ore on the northwest and is a postmineral fault apparently coinciding closely with the premineral fault that cuts off the black garnetites against the massive limestone.

The recognition of the fact that the ore-forming solutions arose along a fault contact suggests that the ore-bearing zone can be explored most thoroughly by means of numerous crosscuts or drill holes extending at right angles to levels driven along the faulted edge of the black garnetites.

MINES AND PROSPECTS ON DEPOSITS IN IGNEOUS ROCKS.

MONTANA-YERINGTON MINE.

The Montana-Yerington mine is 2½ miles west of Yerington station. Before 1912 not much development work had been done, but since then an incline 300 feet long, sloping 45° S., has been sunk, and drifts extended from it at different levels. In 1914 the main work was being done on the 300-foot level. The mine is reported to have produced 2,500 tons of ore, averaging 6 per cent of copper and carrying a little silver and gold.

The country rock is granodiorite cut by dikes of quartz monzonite porphyry. The conglomerate at the base of the Tertiary section and the overlying glass flow, succeeded by quartz latites and rhyolites, occur near the mine. They have been faulted against the granodiorite, and the faulting has greatly shattered the belt of rocks in which the mine is situated. The vein, as seen on the 300-foot level, has a fairly well-defined footwall, striking N. 80° E. and dipping 55° S. The country rock has been crushed and roughly foliated, and along this zone the ore occurs in short stringers or small lenses of solid sulphide. Chalcopyrite predominates; pyrite occurs principally as isolated euhedral crystals; and the foliated rock inclosing the sulphides carries much finely disseminated flakes of specular hematite. The chalcopyrite has been slightly enriched by the development of sooty bluish and blackish sulphides. West of the incline the vein is cut off by a fault striking N. 20° E. and dipping 50° E. Some attempt to recover the vein has been made without success by drifting southward; if, however, the dislocation is a normal fault—that is, if the hanging wall has slipped down relatively to the footwall—the faulted segment of the vein will be found most expeditiously by cutting through the fault and drifting northward.

EMPIRE-NEVADA MINE.

The Empire-Nevada mine is half a mile west of Yerington station, on the Nevada Copper Belt Railroad. In 1914 the property was being worked by three separate parties of lessees of two men each. Considerable shallow surface work has been done in past years, and it is probable that several thousand tons of oxidized ore has been extracted. Five Keystone drill holes were put down in the spring of 1914, the deepest 700 feet deep, but the results have not been disclosed.

Some small bodies of quartz monzonite porphyry project through the alluvium in the vicinity of the mine. The porphyry, owing to the prevalence of phenocrysts of plagioclase ($Ab_{70}An_{30}$), orthoclase, biotite, and sporadic quartz, closely resembles a granitic rock, but under the microscope it is found to have a finely granular groundmass of orthoclase and quartz. Part of the biotite is derived from hornblende and has been largely chloritized. The porphyry has been irregularly fractured and silicified, and the silicification was apparently accompanied in places by the development of secondary biotite. Bunches of ore occur in the fractured porphyry and consist largely of cuprite, which is in places altered to malachite and other oxidized compounds. Pyrite or other sulphides have not yet been found.

JIM BEATTY PROSPECT.

The Jim Beatty prospect is at the southwest corner of the area shown on Plate I. The workings consist of two tunnels, which enter from opposite sides of a small hill and intersect, and open cuts extending for several hundred feet along the vein between the tunnels. Several shipments of ore have been made, amounting to a few tons. A lot shipped in 1914 is said to have carried $65 a ton in gold. The ore body, inclosed in quartz monzonite, consists of an 8-inch vein containing pyrite, chalcopyrite, minor galena, and their oxidation products in a gangue of coarse quartz and calcite.

TERRY & McFARLAND PROSPECT.

The Terry & McFarland prospect is near the southwest corner of the area mapped. The principal development work is a tunnel 380 feet long. This tunnel follows a shear zone in quartz monzonite which contains along most of its course an iron-stained quartz vein ranging from a few inches to 1 foot in thickness. The vein trends N. 15° W. and dips 70° W. Ore on the dump is coated with druses of malachite. The average value of the ore is said to be $8 a ton in gold.

BLUE JAY MINE.

The Blue Jay mine is 3 miles east of the town of Yerington, on the west flank of the low range of hills that projects above the level floor of Mason Valley. The mine is developed by a shaft 450 feet deep, from which drifts have been cut on the 200 and 400 foot levels. In 1914 a tunnel was being driven to cut the shaft 100 feet below the collar; this level will give a depth of 150 or 175 feet under the outcrop.

The prevailing country rock is a medium-grained granodiorite close to quartz diorite in composition. It is composed of oligoclase, biotite, augite, hornblende, quartz, and orthoclase and is a somewhat more basic variety of granodiorite than that on the west side of Mason Valley. The ore deposit occurs in a crushed zone in the granodiorite, which at the mine is 300 to 400 feet wide. The crushed condition of the granodiorite has favored its taking on a deeper coat of desert varnish than the massive granodiorite, and the zone is in consequence clearly visible from Yerington as a dark band trending nearly at right angles across the range of hills. A dike of granodiorite porphyry, 10 feet wide, strikes across the shattered zone; at the south margin of the zone it has been displaced 20 feet by the fissure that separates the massive from the shattered granodiorite.

The porphyry dike forms the footwall of the ore body. Above it is a roughly crescentic outcrop of quartz grading out into replaced granodiorite. A little chalcopyrite occurs in tight quartz, but as a rule the sulphides have been leached out.

Ore from the 200-foot level is a gray rock carrying chalcopyrite. Under the microscope it is found to be composed largely of orthoclase and quartz, with chlorite as a minor constituent. Chalcopyrite and chalcocite are present, and the chalcocite is clearly of secondary origin. All stages of replacement, from solid grains of chalcocite representing completely replaced grains of chalcopyrite to large particles of chalcopyrite peripherally coated with chalcocite, can be observed. Some brochantite accompanies the chalcocite. This gray ore appears to represent the extreme phase of alteration of the granodiorite by the primary mineralization, plus a slight alteration accompanying the enrichment by chalcocite. Less metamorphosed granodiorite is darker, owing to the prevalence of chlorite; epidote also is noteworthy in this phase; and pyrite occurs with the chalcopyrite.

Recently a small rich shoot of "cuprite" ore was found near the collar of the shaft. About half of the "cuprite" proves to be chalcocite. The ore consists of stringers and masses of chalcocite and cuprite traversing a grayish or greenish rock which the microscope shows to be composed of quartz whose structure indicates its origin by replacement, undoubtedly of granodiorite. The chalcocite incloses sporadic grains of native copper, with which is associated some brochantite.

The oxidized ore seen by Ransome contained chrysocolla, malachite, cuprite, and the rare copper phosphate libethenite, previously identified from this deposit by Smith. The chalcocite ore was the objective of the operations in 1914, and some high-grade ore, consisting of chalcopyrite almost wholly replaced by chalcocite, had been found at the time of visit.

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