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THE GEOLOGY AND ORE DEPOSITS OF ELY, NEVADA

BY

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PREFACE.

By F. L. Ransome.

The present report by Mr. Spencer is noteworthy not only as a monographic study of the most productive copper district in Nevada but as the first report to be issued by the United States Geological Survey to describe adequately some of the great deposits of disseminated ore which during the last few years have contributed so largely to the copper output of the country.

The general geologic features of the district are clearly and briefly set forth. The reader's attention may be directed especially to the interpretation of the erosional record in terms of the stages of Lake Bonneville. Mr. Spencer concludes that the alluvial cones of the Ely region accumulated during a dry period that preceded the formation of the great Quaternary lakes of Nevada and that their dissection was effected synchronously with the stages of lacustrine expansion as worked out by Gilbert and Russell. He regards all the coarse-grained intrusive rocks of the Ely district as produced during a single period of igneous activity, in this respect differing from Prof. Andrew C. Lawson, who in 1906 published a report on the district.

The chemistry of ore deposition and enrichment is discussed more thoroughly and closely in this report than it commonly is in a geologic monograph, and because of the author's wide field experience and of the many suggestions that he makes for future experimental investigations this part of the report should be of special value. Among the contributions that tend to give greater definiteness to our views on downward enrichment is the discussion wherein Mr. Spencer reaches the conclusion that rain water alone could not carry down enough oxygen to effect the observed results, and that consequently much of the enrichment must have taken place above the permanent water level, where the air could penetrate to the seat of chemical activity.

OUTLINE OF REPORT.

The Ely district, officially known as the Robinson mining district, is in White Pine County, Nev., about 140 miles south of the Southern Pacific Railroad and 50 miles west of the Utah-Nevada boundary line. The district occupies a central position within the undrained region known as the Great Basin, a region characterized by meridional mountain ranges from 5 to 20 miles in width, separated by valleys of like breadth.

The Egan Range, in which the Ely district is situated, presents a generally bold scarp toward Steptoe Valley on the east, whereas toward the west it is less sharply individualized. When viewed from within the part of the range with which we are here concerned it appears as a rather disorderly aggregation of mountains that have no obvious dependence upon features of geologic structure. The extreme range of elevation is from 6,400 to 8,000 feet above the sea.

In neighboring districts where considerable areas lie above 8,000 feet in elevation there are heavy growths of aspen, spruce, fir, and pine, but here the mountain slopes support only such trees as piñon or nut pine, juniper or red cedar, and mountain mahogany.

Preliminary to the discussion of the geology of the district the general features of northeastern Nevada are outlined.

The rocks which enter into the architecture of the Basin Ranges in western Utah and central-eastern Nevada are mainly sedimentary formations that range in age from Cambrian to Carboniferous, but lavas including rhyolite, andesite, and basalt occur extensively, and igneous rocks of several types break through the stratified formations. In general the metalliferous deposits of the region are found in those districts where intrusive igneous rocks occur.

The eastern part of the Great Basin occupies geographically an intermediate position between an eastern region where all the intrusive rocks younger than the Archean are of post-Cretaceous age and a western region where intrusive rocks of similar types are believed to have been injected during a physical revolution that closed Jurassic time. Though it is not possible to reach a decision in regard to the age of the intrusive rocks at Ely the writer is inclined to the belief that they belong to the older rather than to the younger epoch of igneous activity.

The larger topographic features of Nevada and of the neighboring parts of Utah are to a marked degree expressive of the type of structure which is commonly designated "Basin Range structure," the north-south ranges being commonly limited on one or on both sides by great fault breaks. The so-called desert valleys between the ranges are deeply filled with débris that has been derived from the neighboring mountains. Where side valleys open into the broad northerly depression there are alluvial cones, and where such piles of débris are at present traversed by perennial streams, grades have been established from 100 to 200 feet below the general surface of the cones. The topographic features of an alluvial cone occurring on the east side of Steptoe Valley southeast of Ely are described. In a discussion of the origin of these local features an attempt is made to trace the climatic history of the region during Quaternary time, and this history is brought into accord with that of the ancient Bonneville and Lahontan lakes as worked out by Gilbert and by Russell.

The great bulk of the rocks of the Ely quadrangle are limestones, quartzites, and shales, which range in age from Ordovician to Carboniferous and which have an aggregate thickness of more than 9,000 feet. The sedimentary rocks have been classed under eight formations. They have been greatly disturbed by folding and especially by faulting, so that their areal distribution is very irregular. The six uppermost of the eight formations are found in one place or another to have been invaded by masses of monzonite porphyry.

The igneous rocks of the district include an older set of monzonite porphyry intrusions and a younger set of tuffs, obsidians, and rhyolites. The monzonitic rocks are of particular interest because the genesis of the metallic ores of the district is closely connected with their geologic history. The conclusion is presented that all the coarse-grained intrusive rocks of the district are to be referred to a single epoch of igneous activity, and it is shown that present differences in composition are due in the main to the more or less intense metamorphism which in many places the rocks have suffered.

Interpretation of valley fillings, of outwash gravels, and of terraces leads to the recognition, from entirely local features, of climatic episodes which are correlated with those indicated by a study of the alluvial cone at the mouth of Steptoe Creek, and thus indirectly with the history of the Great Basin lakes.

On the basis of analogy with other ranges in the general region the Egan Range is regarded as a block elevated above Steptoe Valley on the east. Within the range in the Ely district there are important faults of later date than the extrusive rhyolites, but the formations had been greatly warped and faulted, and they had been intruded by masses of monzonite porphyry before the time of volcanic activity, and therefore previous to the development of the northerly faults which are supposed to define the Steptoe depression between the Egan Range on the west and the Schell Creek Range on the east. As opposed to the orderly arrangement of the master faults of the general region the structures within the ranges are very unsystematic. Within the Ely quadrangle the distribution of the sedimentary formations is very irregular, but if the area is considered as a whole it is possible to make out a synclinal structure trending north and south and two rude arches flanking this downfold. Both arches are complicated by faults.

The easterly course of the principal zone of intrusion is out of harmony with the axial trends of the broad structures of the district, and these earlier structures seem to have been modified but slightly by dislocations connected in origin with the injections of the igneous material. Though some of the faults are very much younger than the porphyry masses others certainly existed previous to the igneous intrusions and some of the major dislocations may have been contemporaneous with them. Throughout the central part of the district intense metamorphic effects are everywhere associated with the occurrence of porphyry masses, but very little alteration is present adjacent to certain large porphyry bodies which occur north of what is called the principal zone of intrusion. The observed differences in the degree of metamorphism are what would be expected if the porphyry bodies along the central zone were essentially cross-breaking bodies and if, on the other hand, the outlying masses were sills. In the main the facts conform with this suggestion.

Two kinds of metamorphism of the rocks of the district are distinguished. Under igneous metamorphism are included all those alterations which attended or followed the invasion of the sedimentary formations by the magmatic material that eventually crystallized as monzonite porphyry. These alterations have affected the invaded limestones and shales and also the igneous rocks themselves. To this metamorphism is to be attributed the formation of the primary metalliferous deposits of the district. The second kind, atmospheric metamorphism, includes weathering, or decomposition and leaching by oxidizing surface waters, and cementation, or changes involving the deposition of material taken into solution during the process of weathering. The enriched copper ores of the district have been formed as a result of atmospheric metamorphism.

The principal zone of porphyry intrusion has a length of about 7 miles and a width of half a mile to nearly a mile. Within this zone and for irregular distances along the flanks of the numerous separate intrusions the invaded limestones and shales have been variously changed from their normal condition. Within this zone also the masses of igneous rock themselves have been greatly altered. The action of heated solutions is regarded as the cause of this metamorphism, and the source of these solutions is sought not in the porphyry masses themselves but in the general magmatic reservoir from which the intrusive masses had been derived, and it is shown that the principal metamorphic changes were effected after the bodies of porphyry that are now altered had become crystalline.

The chemical character of the metamorphosing solutions may be approximately determined from a consideration of the substances deposited by them, which, though chiefly silica, sulphur, iron, and potassium, comprise several other elements, including copper, lead, zinc, silver, and gold. Carbon dioxide is believed to have been present in large amounts.

A theoretical discussion of the chemical reactions involved in the alterations of the rocks and in the deposition of metallic sulphides in them is presented. No firmly grounded deduction can be drawn in regard to the alkaline or acidic nature of the primitive solutions, but the conclusion is reached that if the solutions were originally acidic the metallic minerals were probably deposited only after an alkaline or neutral condition had been attained.

When primary metallization had ceased, and before erosion had removed great amounts of material, the whole mass of metamorphosed and mineralized rocks must have exhibited an arrangement of concentric shells, characterized in part by progressively changing proportions of iron, copper, lead, and zinc. These shells would have formed an arch whose general crest was conformable with the axis of the central line of intrusive bodies. Deep erosion has planed away the medial portion of the upper or outer shells, so that what is now seen of them are merely lateral remnants. A consideration of the features of the central core and of the lateral remnants is sufficient to indicate that the metals were differentially deposited from solutions which originally contained them all. Iron and copper must have been present in the highest degree of concentration because they are widely distributed, whereas lead and zinc hardly occur except in localities removed from the core of the metamorphosed district. In general, the richer silver and gold ores of the district occur in outlying situations, and these metals are found principally in deposits that carry lead.

The products of igneous metamorphism are described in detail and losses and gains of substance in the porphyry are calculated from chemical analyses of normal and altered facies of the rock. Next the effects of weathering on the several sorts of altered rocks are considered, and as a special phase of cementation chalcocite enrichment is discussed. The reactions that ensue beneath the weathered capping involve a succession of oxidations of the primary sulphides, whereas the changes in the descending solution are those of reduction. These changes are indicated by means of chemical equations, which, however, are to be regarded rather as diagrammatic representations than as established reactions. Practically all the secondary or added copper now present in the disseminated ore bodies of the district is thought to have been brought together before the beginning of Quaternary time, but undoubtedly redistribution of this metal has since been going on, so that the tops of the chalcocite-bearing ore bodies have been gradually brought to lower and lower levels.

The metalliferous deposits of the district are regarded as epigenetic. They are classified as those that contain copper and also, as a rule, very small amounts of silver and gold, and those valuable chiefly for their content of the precious metals, and for descriptive purposes the deposits of these broad classes are subdivided with reference to form, degree of compactness, and mineralogy. In the copper deposits lead and zinc are practically absent, whereas in the silver-gold deposits lead is generally more abundant than copper, and minor amounts of zinc may be present.

Mining activity began with the discovery of gold and silver-lead ores in 1868 and 1869, and prior to 1902 it is thought that the mines of the district may have produced metals having a total value between $500,000 and $600,000. The present industrial importance of the district is the outgrowth of the discovery and development of bodies of chalcocite-bearing porphyry between the years 1901 and 1904. Up to the close of 1913 perhaps 80,000,000 tons of these concentrating ores, carrying from 1 to 3 per cent copper and minor amounts of gold and silver, had been developed, and during the years 1908 to 1913, inclusive, approximately 12,000,000 tons had been mined and treated.

Though extensive prospecting has been carried on in the expectation of finding large deposits of richer copper ores the results of this work have been thus far disappointing. Such bodies of oxidized or partly oxidized copper ore as have been discovered in metamorphosed limestones occur at depths of 500 to 1,200 feet below the surface.

THE GEOLOGY AND ORE DEPOSITS OF ELY, NEVADA.

By Arthur C. Spencer.

INTRODUCTION.

The geologic field work on which this report is based was done during the summers of 1909 and 1910 under the general direction of S. F. Emmons and Waldemar Lindgren. The topographic map which was available for plotting the areal geology of the district had been made in 1906 by Fred McLoughlin. This map was revised in 1910 by W. O. Tufts.

Geologic work had been done in the district by Lawson[1] in 1904, and the results of his investigation, which were published in 1906, have been freely used in connection with the writer's own observations. It is of interest to note that the general features of the mineralized zone were concisely outlined by Raymond[2] in 1873.

It is a pleasure to acknowledge the many facilities afforded by the officers of the Nevada Consolidated Copper Co. and of the Giroux Consolidated Copper Co. and the hearty cooperation of the active mining men of the district.

Credit for the determination of fossils is due to E. O. Ulrich and G. H. Girty, and for chemical analyses to Chase Palmer, George Steiger, and R. C. Wells. The photographs reproduced in Plates III, IV, and V were taken by C. D. Gallagher, of Ely.

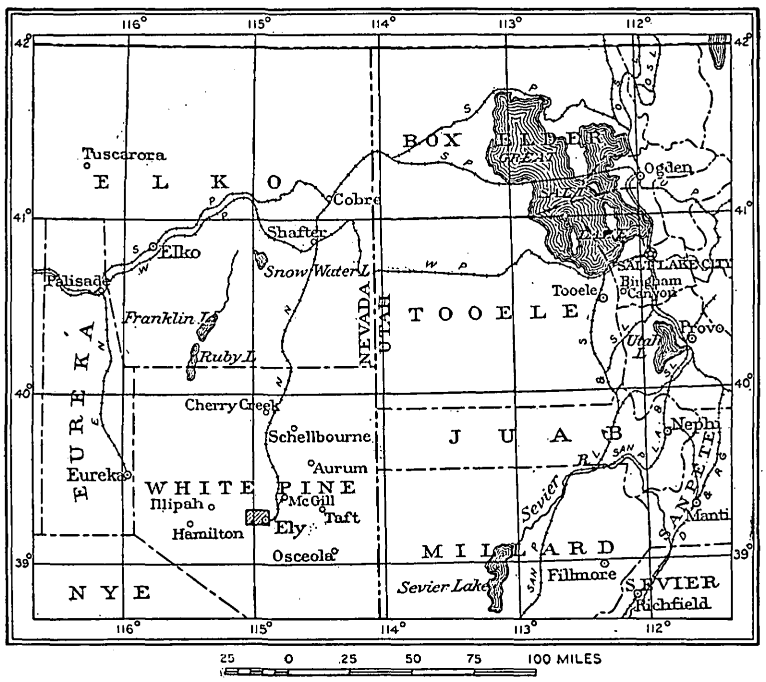


Figure 1.—Index map of northeastern Nevada and northwestern Utah, showing location of the Ely district.

GEOGRAPHY.

SITUATION OF THE DISTRICT.

The Robinson mining district includes all the ore-bearing country contiguous to Ely, White Pine County, Nev. Though thus officially designated by the office of the surveyor general, it is commonly referred to as the Ely district, and this usage will be followed in this report. To avoid confusion it should be noted here that Ely mining district is the official designation of an area that lies in Lincoln County about 150 miles south of the Robinson mining district. Its principal town is Pioche.

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 287-357, 1906.
[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, pp. 169-171, 1873.

The district described in this report is situated near but somewhat south of the center of White Pine County, and about 50 miles west of the Utah-Nevada line. (See fig. 1.) The towns of Ely and East Ely are located on the west side of Steptoe Valley, about 140 miles south of Cobre station on the Southern Pacific Railroad, from which point they are reached by the Nevada Northern Railway.

The mines of the district, which lie within the Egan Mountains west of Steptoe Valley, are served by an extension of the Nevada Northern Railway over which the ores produced by the Nevada Consolidated Copper Co. are hauled to the smelter at McGill, on the east side of Steptoe Valley about 16 miles northeast of Ely.

The map of the Ely quadrangle (Pl. I, in pocket) shows an area of about 45 square miles, which is bounded by meridians 114° 53′ and 115° 2′ 30″ W. and parallels 39° 14′ and 39° 18′ N.

PHYSICAL FEATURES OF THE REGION.

White Pine County, Nev., occupies a central position within the undrained region known, since the explorations of Frémont, as the Great Basin. This region is characterized by northward-trending mountains. It is bounded on the east by the Colorado Plateaus, which lie west of the Park Mountains (the Wyoming and Colorado portions of the Rocky Mountain system), and on the west by the Sierra Nevada of the Pacific mountain system.

The terms Basin Range system and Basin Ranges were applied by Gilbert[1] and Powell[2] to a much more extensive region extending southward far beyond the limit of the Great Basin.

The Great Basin has been described as a plateau-like region whose valley floors have a general elevation of 4,000 to 6,000 feet above the sea. Many nearly meridional ranges from 5 to 20 miles across traverse the plateau and are separated by valleys of approximately the same breadth. The mountains rise from 1,000 to 6,000 feet above the valley floors and present rather even crests, though a few culminating peaks reach elevations between 11,000 and 12,000 feet above the sea.

Separate ranges, many of them 30 to 100 miles and a few 150 miles in length, are disposed in overlapping or echelon arrangement. Where individual ranges disappear the contiguous valleys merge to form broad plains or basins, locally called deserts. One of the most noteworthy of these arid plains, because of its extent, is the Great Salt Lake Desert, which is crossed by the Southern Pacific and Western Pacific railroads.

These topographic features are, to a marked degree, expressive of certain structures which characterize the region lying between the Sierra Nevada on the west and the Wasatch Mountains and Colorado Plateaus on the east, described by Gilbert as Basin Range structure. These structures are determined by great faults of considerable individual continuity, disposed in subparallel, nearly meridional relations, and commonly overlapping in echelon. The rocky subsurface is riven into long and rather narrow blocks, some of which are rather simply upraised, others are relatively depressed, and still others are strongly tilted and warped. Perhaps the tilted blocks are more numerous than the others.

The mountains are deeply dissected by transverse valleys, and as a rule their rather abrupt slopes and numerous rocky ledges contrast in a very marked way with the smoothness of the intervening depressions. The wider valleys are indeed deeply filled by débris contributed by the mountain streams, principally in former times, when precipitation may have been somewhat greater than at present.

As the climate is notably dry, there are marked local differences in rainfall, and it is only within the higher ranges, where snow accumulates, that perennial streams arise. Exceptions to this rule are noted in a few piedmont springs that are fed from high mountains through subterranean channels. Few of the main valleys are occupied by flowing streams for more than short distances, for much of the water contributed by lateral creeks sinks beneath the surface. Where valley streams persist, they eventually find their way into lakes or into so-called

[1] Gilbert, G. K., Geology: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 22, 1875.
[2] Physiographic regions of the United States: Nat. Geog. Soc. Mon., vol. 1, No. 3, pp. 65-100 and map, 1895.

sinks. Very little of Nevada has free drainage, and the few rivers which drain to Snake and Colorado rivers are confined to the northern edge and the southeastern corner of the State.

Gosiute and Steptoe valleys, through which the Nevada Northern Railway from Cobre to Ely runs southward for 140 miles, lie between the Gosiute and Schell Creek ranges on the east and the Pequop and Egan ranges on the west. These depressions are representative of the desert valleys of the Great Basin. Except near the low divide between the two valleys, where rhyolite may be seen from the car window, the valleys are floored by débris which has been accumulating throughout Quaternary time.

When viewed longitudinally the valleys appear almost level, though they are really broken by low divides into a series of basins without free drainage. In cross sections the valleys exhibit noticeable though low grades from the middle toward the sides and the low slopes become somewhat steeper near the mountains.

Where living streams debouch from the mountains enormous alluvial cones extend out into the valleys. A very striking example is the great pile of material opposite the mouth of Duck Creek, which rises in the Schell Creek Mountains and comes out into Steptoe Valley north of McGill. Here, where the valley is at least 10 miles wide, the lowest depression lies well toward its west side. Each of the few perennial streams that flows into Steptoe Valley threads its way across a pile of alluvial débris, and similar deposits are present opposite the canyons of intermittent streams. Such alluvial deposits in the aggregate make up the deep valley filling, which may be 1,000 and perhaps 2,000 feet in maximum thickness.

There is probably a very considerable flow of water beneath the surface of Steptoe and certain other desert valleys, and in places it may prove feasible to utilize these supplies of water by means of bored wells.

The Egan Range, in which the Ely district lies, is sharply and regularly bounded on the east by Steptoe Valley; on the west there are projecting spurs in the more northerly section, and a high connection across toward the Long Valley Range opposite the central sections, northwest of Ely. Its long, straight, eastward-facing front is scarcely broken by embayments, the only notable broad opening being about 15 miles north of Ely. Across Steptoe Valley the Egan Mountains are opposed by the equally abrupt and even higher Schell Creek Range, the two ranges being essentially parallel in meridional trend. West of Ely the Egan Range is bounded by White River valley. The width of the range is from 6 to 12 miles.

When viewed from Steptoe Valley the bold front of the Egan Mountains gives promise of considerable roughness of detail. In fact, however, although sharp declivities are present adjacent to the lower course of canyons that open to the main valleys, the topography within the range is marked by broad and not deeply dissected valleys. Such interior basins in the region of the Ely district are underlain by friable volcanic tuff, as in the upper valley of Robinson Canyon, or by readily decomposed monzonite, as in Weary Flat. The areas of low relief are surrounded by mountains of resistant limestone, the irregular disposition of which bears no obvious relation to any large features of geologic structure. Massive flows of rhyolite, later in origin than the volcanic tuffs, are also prominent mountain makers in several localities. When viewed from within this part of the range is seen to be a somewhat disorderly aggregation of mountains, the topography being such as would result from the rather mature dissection of an uplifted region underlain by rocks of unequal resistance to erosion.

Elevations within the area represented by the Ely map range from 6,400 feet near Ely to somewhat more than 8,000 feet on Rib Hill.

CLIMATE AND VEGETATION.

In a region like eastern Nevada, which is characterized by a yearly precipitation so moderate that vast areas contribute no water to the sea, the characteristics of the assemblages of plants at different elevations are strongly marked. In the higher mountains the flora closely simulates that of the Uinta, Wasatch, and Rocky mountains, whereas the lower slopes are rather sparsely clothed, and the valleys are at least locally almost bare. South of Ely the upper slopes and coves of Ward Mountain carry aspen, spruce, balsam fir, and several varieties of pine. So also in the Snake and Schell Creek ranges to the east well-forested areas are found above 8,000 or 9,000 feet elevation and grasses form a luxuriant growth. Lower slopes support mountain mahogany in patches, and juniper and nut pine or piñon grow almost everywhere. Round about Ely the three species last named are the only trees. The mountain mahogany is by no means abundant, but juniper and nut pine grow on every ridge and slope. Sagebrush and rabbit brush are luxuriant wherever alluvial fillings exist, and a low growth of sagebrush covers the broad interior valleys. Grasses grow at all elevations in the hills and with numerous flowering plants afford good range for sheep or cattle. Though such country always seems inadequate for the support of domestic animals, stock ranging has long been and is still a profitable industry in this part of the State. In May and early June the gillia, lupine, cornflower, forget-me-not, the charming Mariposa lily, stonecrop, and many other plants are in blossom. Somewhat later great white poppies relieve the sagebrush gray, which during August and the autumn months produces a flat, monotone effect.

Agriculture flourishes wherever water for irrigation is available. Oats ripen in the open valleys, hay crops do well, and potatoes are always prolific.

The population attendant on productive activities in the mines and smelters of the district has created a demand for farm products from irrigable valleys within a radius of 50 to 75 miles.

GEOLOGY OF EASTERN NEVADA.

GENERAL CHARACTER AND AGE OF THE ROCKS.

The rocks which enter into the architecture of the Basin Ranges in western Utah and central-eastern Nevada are mainly limestones, shales, and sandstones and range in age from Cambrian to late Carboniferous. Locally there are areas of Archean schists and granites. Lavas of Tertiary age are abundant in the mountainous belts and cover considerable areas in some of the lower country. Mesozoic rocks, which occupy extensive areas east of the Great Basin, and which are likewise prominently developed in central and western Nevada, are not present in western Utah or eastern Nevada. This part of the Great Basin seems therefore to have constituted a land area throughout Mesozoic time and consequently may have been subject to erosion during a long period.

Igneous rocks of several types have broken through the Paleozoic sedimentary formations in a few places. Where these rocks are present there are usually at least indications of metalliferous deposits, and several of the productive mining districts are characterized by the occurrence of intrusive rocks.

Tertiary formations of sedimentary origin are principally confined to the intermontane areas, and commonly they appear at the surface only along the foothills, since they are extensively covered by the detrital deposits of Quaternary and probably Pliocene age, which floor the wide valleys.

Lavas, including andesite, rhyolite, and basalt, occur extensively throughout the eastern part of the Great Basin.

ARCHEAN ROCKS.

Rocks which have been regarded as older than Cambrian and called Archean occur in perhaps a dozen localities in western Utah and eastern Nevada. In Promontory Range and on Fremonts Island in Great Salt Lake, and at Spruce Mountain in the Peoquop Range, different kinds of schist are referred to the Archean by King.[1] Elsewhere in the eastern part of the Great Basin the rocks mapped as Archean by the geologists of the Fortieth Parallel Survey are granites or related rocks. Some of these occurrences may be correctly placed in point of age, but others intrude the Paleozoic formations.

In discussing the relations of granites and Cambrian rocks in the Snake Range of eastern Nevada Spurr[2] inclines to the belief that the granites are really older than the Cambrian rocks,

[1] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 54, 58, 1878.

[2] Spurr, J. E., Descriptive geology of Nevada south of the 40th parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 27, 1903.

despite the fact that minor intrusive phenomena are encountered. He suggests that both the Archean granite and the overlying Cambrian quartzite have been locally cut by younger dikes of granite.

Rocks described as granites occur in the Wachoe Mountains, which are situated between the Schell Creek and Egan ranges, about 70 miles north of Ely. These rocks were regarded by Emmons[1] as questionably Archean, but with the alternative suggestion that they represent an intrusion of Jurassic age comparable with the intrusions in western Nevada.

On the east side of the Egan Range, at Egan Canyon, Cambrian quartzites are underlain by mica granite.[2]

In the central and western parts of Nevada Archean exposures are much more extensive than in the eastern part of the State. In the East Humboldt Range they are particularly accessible, for here the former cover of Paleozoic formations has been eroded from very wide areas.

PALEOZOIC ROCKS.

The eastern half of the Great Basin is shown by King[3] to have been an area of sedimentation during the whole of Paleozoic time. Continued deposition resulted in the accumulation of a great sequence of limestones, shales, and quartzites, the aggregate thickness of which was estimated at 40,000 feet. In the Wasatch Mountains[4] the section measures 32,000 feet, and at Eureka[5] 30,000 feet of strata are exposed.

All the rocks, from the Cambrian to the late Carboniferous, are greatly disturbed. They are accessible for observation only within the mountains, and because of intervening mantles of Tertiary bedded formations, volcanic flows, and Quaternary valley fillings it is commonly difficult to correlate formations from place to place. This is particularly true of massive limestones or quartzites in the absence of fossils.

The ranges of northeastern Nevada as far south as the line between Elko and White Pine counties are characterized by Carboniferous limestones and quartzites. The most northerly ranges comprise the rocks which the geologists of the Fortieth Parallel Survey called the Permo-Carboniferous limestone group and the Weber quartzite, which lies below it, but some distance south of the Southern Pacific Railroad the last of these higher formations is seen, and the southern ends of the Pequop and Gosiute ranges are composed essentially of Carboniferous limestones which belong stratigraphically below the Weber quartzite. The same beds form the northern portion of the Egan Range and are conspicuous in the Deep Creek Range 50 miles to the east.

Southward along the Egan Range lower and lower formations outcrop until the base of the Cambrian appears at Egan Canyon. In this vicinity Cambrian fossils have been reported from the summit of the range. In the Ely district no part of the Cambrian is exposed, the lowest strata being of Ordovician age. The highest formations here present are stratigraphically lower than the Weber quartzite. South of Ely Carboniferous limestones occupy the east side of the range at least as far as Ward, and distant views of Ward Mountain lead to the impression that Devonian beds occur on the west flank of the Egan Range. Farther south Devonian rocks are extensively developed, and Silurian rocks are reported by Spurr.[6]

East of Steptoe Valley the northern part of the Schell Creek Range is composed of volcanic flows, but south of Schellbourne Cambrian rocks appear. Still farther south, and east of Ely, all the Paleozoic formations below the horizon of the Weber quartzite are present. The structure of this range is very complex. East of the Schell Creek Mountains lies the Snake Range, in the constitution of which the Cambrian formations play a large part. Here Silurian and Carboniferous rocks are also present.

[1] Hague, Arnold, and Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 476-478, 1877.
[2] Idem, p. 488.
[3] King, Clarence, op. cit., p. 228.
[4] Idem, p. 155.
[5] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 13, 1892.
[6] Spurr, J. E., op. cit., p. 49.

MESOZOIC ROCKS.

Sedimentary formations of Triassic, Jurassic, and Cretaceous age are not known in the central part of the Great Basin. This fact and the great dissimilarity in the nature of the Mesozoic sediments of western Nevada and those of the plateaus and mountains east of the Salt Lake depression indicate that throughout the Mesozoic era northeastern Nevada and the adjacent part of Utah constituted a land area lying between two basins, in both of which sedimentation was in progress. In western Nevada, where the ranges are composed of Triassic and Jurassic formations, both groups of strata have been greatly folded. So also the Paleozoic rocks of the more easterly ranges are everywhere disturbed, and it is commonly held that the folding of the whole region was brought about by mountain-making activities in post-Jurassic time.[1] However, as the eastern part of the Great Basin was a land area prior to the post-Jurassic deformation, the uplift which followed the close of Carboniferous deposition may have been accompanied by extensive folding throughout the region wherein several thousand feet of Paleozoic sediments have been laid down. Difficulties in the way of discriminating two periods of deformation are, however, very great, and it is hardly probable that post-Carboniferous and post-Jurassic folding can ever be separated.

According to this view as qualified, the primary structural features of the Basin Ranges were determined by the folding which followed the completion of Jurassic deposition, but these features were greatly modified by folding, and especially by faulting, which took place on a grand scale at different times within the Tertiary era.

During the physical revolution in which the Paleozoic and Mesozoic formations were upheaved and corrugated there were extensive invasions of igneous rocks in the Sierra Nevada and in the Great Basin.[2] The later disturbances were likewise accompanied by igneous activity, and great volumes of lavas were poured out on the surface of the land. The relations of certain ore deposits to igneous rocks intruded during the post-Jurassic revolution are mentioned in a later section.

TERTIARY DEPOSITS.

Sedimentary deposits of Tertiary age, which cover extensive areas to the east of the Wasatch Mountains and also in western Nevada, are much less prominently developed in eastern Nevada. Eocene strata are reported by the Fortieth Parallel Survey[3] on the east side of the Ombe Mountains near the Utah-Nevada line and in the vicinity of Peoquop Pass, a few miles west of Cobre. These beds were correlated, though somewhat tentatively, with the middle Eocene deposits of the Green River basin in eastern Utah.

Formations referable to the later Eocene or to the Miocene have not been found in the eastern half of the Great Basin. King[4] thought that this part of the region must have existed as a land area during Miocene time.

Deposits within the Great Salt Lake basin and westward on the divide between that basin and the valley of Humboldt River were regarded as of Pliocene age by King.[5]

Quotations from the report of the Fortieth Parallel Survey will serve to indicate the nature of these deposits:

> The broad Quaternary valley of Deep Creek[6] is flanked upon the west by low, softly sloping hills, which rise about 1,000 feet above the valley. The exposure for a distance of 25 miles north and south by 6 or 7 miles transversely is entirely of fine white sands and marls, with a few rather fine gravelly conglomerates unquestionably referable to the Pliocene age. One particular bed is conspicuous for its very rough texture; it is a rearranged volcanic ash, similar to those found in the region of Toano.[6]

[1] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 73, 1878. Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, pp. 8-10, 1892. Louderback, G. D., Basin-range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, p. 340, 1904.

[2] King, Clarence, in Hague, J. D., Mining industry: U. S. Geol. Expl. 40th Par. Rept., vol. 3, p. 2, 1870.

[3] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 391, 1875. Hague, Arnold, and Emmons, S. F., Descriptive geology: Idem, vol. 2, pp. 498, 501, 1877.

[4] Op. cit., p. 412.

[5] Op. cit., pp. 434-443.

[6] Deep Creek is near the Utah-Nevada line, about 70 miles southeast of Cobre. The site of Toano is near the present Cobre.

Between Thousand Spring and Gosiute valleys, and throughout the entire western slope of Toano Pass, similar horizontal beds of rearranged sand and volcanic material occupy the rolling country. They overlie the upturned Eocene of Peoquop Pass with clear nonconformity.[1]

At the pass [Toano] the depression is occupied by the latter deposits [largely comminuted volcanic material], mainly lavender-colored pumice-like beds, exceedingly friable but distinctly bedded, and composed largely of rhyolitic, siliceous, and feldspathic material, in which are some sandy, earthy seams, rearranged and deposited under water.[2]

Though the formations to the west, along Humboldt River, with which the beds of Toano and Deep Creek were correlated by King, are now known to be Quaternary,[3] the beds of Toano and Deep Creek may still be regarded as Pliocene. These beds are composed of rhyolitic material, and as such materials are not contained in the Quaternary formations deposited in the near-by Lake Bonneville basin the Tertiary age of the deposits seems to be assured.

QUATERNARY DEPOSITS.

East-central Nevada occupies a position between the Lahontan Basin on the west and the Bonneville Basin on the east. Though the Quaternary history of these basins has been worked out in detail by Gilbert[4] and Russell,[5] no similar study of the intervening region has been made.

The history of the Bonneville Basin may be briefly summarized as follows: (1) Pre-Lake Bonneville epoch, characterized by arid climate and marked by accumulation of alluvial deposits which flank the mountain masses; (2) first flooding of the basin as a result of increased humidity; (3) desiccation, pointing to aridity of climate; (4) second flooding, indicating humidity; (5) present epoch of aridity.

The desert valleys of eastern Nevada, like those of the Great Basin region in general, are to a great extent deeply filled with débris. The central parts of the broad depressions appear to the eye to be level floored, but along the valley sides the infilled materials present steeper and steeper slopes until they rest against the rocky walls of the limiting mountains. The sculpturing of the mountains and the abrupt manner in which their precipitous sides plunge to meet the alluvium in the valleys suggest that the bases of the mountains are buried to considerable depths, and borings in certain of the desert valleys are reported to show the existence of loose materials to a depth of about 2,000 feet.

These valley fillings are of more complex origin than would be indicated by the bald statement that the materials which they contain have been derived from the neighboring mountains. The lateral portions of the fillings are made up of merging talus piles and alluvial cones, the talus occurring between the mouths of valleys which extend back into the ranges and the cones piled up opposite the valley openings. The talus-derived portions are doubtless still receiving additions through the shedding of the mountain slopes and surface creep and through the effects of recurring rains and occasional cloudbursts. On the other hand, the alluvial heaps are not being built up. Perennial streams in some places have cut channels from 100 to 200 feet below the cone surfaces, so that these masses of débris have been wasting rather than growing for a considerable period of time. It is natural to correlate the lateral alluvial cones of the desert valleys with the similar features within the Bonneville Basin. Gilbert[6] shows that these great alluvial deposits existed before the first epoch of flooding, and shows that they accumulated during an epoch of relative aridity. The cones in valleys like Steptoe Valley constitute the earliest record of Quaternary events in eastern Nevada, and they were probably built under the dry climate which marked the pre-Lake Bonneville epoch as defined by Gilbert.[7] At the time of greatest expansion the shores of Lake Bonneville washed the east base of the Snake Range, not over 30 miles distant from Steptoe Valley.

[1] U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 437, 438, 1878.
[2] Idem, vol. 2, p. 502, 1877.
[3] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, p. 145, 1885.
[4] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.
[5] Russell, I. C., op. cit.
[6] Gilbert, G. K., op. cit., pp. 189, 220.
[7] Idem, pp. 214-222.

Undoubtedly the several epochs of Lake Bonneville time are recorded by physiographic features from place to place within the desert valleys, but present lack of knowledge of these features precludes any comprehensive discussion of the problems involved. The observations of the writer have been limited to localities near Ely, including the merging cones opposite the mouths of Murry and Robinson canyons on the west side of Steptoe Valley, the Steptoe Creek cone, situated diagonally across that valley toward the southeast, and that portion of the headwater region of White River situated within the Ely quadrangle.

The deposits of the Murry, Robinson, and Steptoe valleys are of enormous size, and they have been deeply dissected by Steptoe and Murry creeks. (See Pl. III.) Corresponding though less bulky deposits within the upper basin of White River are spread over evenly sloping ridges, which rise from 50 to 100 feet above the bottom of the adjacent drains.

The Steptoe cone, which will be discussed in the section on Quaternary deposits (p. 30), may be interpreted in accordance with the Lake Bonneville history and, when thus correlated, leads to a more acceptable explanation of the late physiographic history within the Ely quadrangle than could be reached from a study of that area alone.

VOLCANIC ROCKS.

The general region of the North American Cordilleras, within which the Great Basin occupies a central position, was the scene of noteworthy volcanic activity during Tertiary time.

In western Nevada volcanic outbursts appear to have begun in Eocene time and to have continued through the Miocene and Pliocene.[1] Here the oldest flows were rhyolite and subsequent flows comprise a variety of andesites, rhyolites, and basalts.

In the West Humboldt Range and in adjacent ranges Louderback [2] finds the succession of lavas to be rhyolite tuff, rhyolite, rhyolite tuff, and basalt. These volcanic rocks rest on a surface of low relief, ascribed to erosion during Cretaceous, Eocene, and part of later Tertiary time. The lavas of this region thus appear to be of Pliocene [3] age, though Louderback is somewhat indefinite on this point.

Throughout eastern Nevada and in western Utah rhyolites and rhyolite tuffs are developed on a grand scale, and here they are regarded as Pliocene by King [4] and Hague.[5]

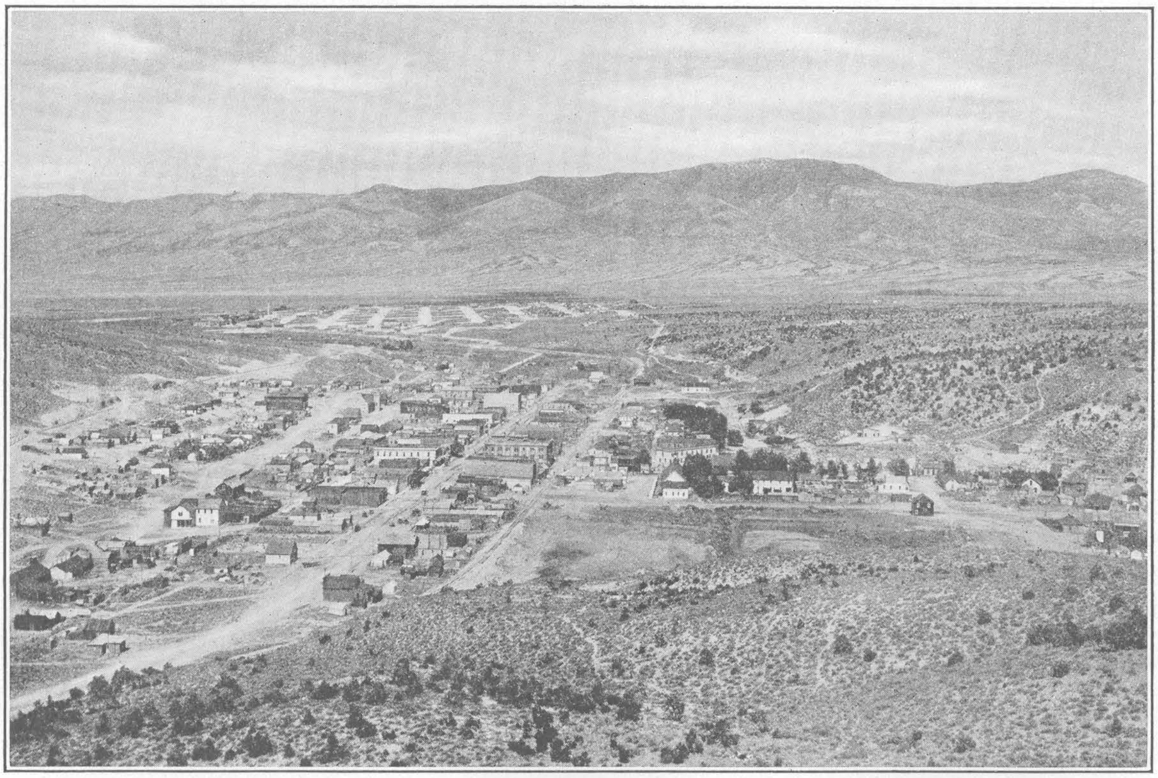
Rhyolite occurs in the northern part of Egan Range, on the broad divide at the north end of Steptoe Valley, farther west in the Wachoe Mountains, and in the northern part of the Schell Creek Range. These areas, except that in Steptoe Valley, are separated from one another by areas of valley débris, and it is more than likely that the rhyolite is actually continuous beneath these mantles from the foot of Egan Range for a distance of 30 miles to the east.

Within the Ely district rhyolite tuffs and flows have a considerable development, and large areas of these rocks occur west of the Egan Range between the upper basin of Robinson Canyon and Butte Valley and also in the upper part of White River valley. East of the range, beginning a few miles south of Ely, outcrops of rhyolite appear in the foothills and continue southward at intervals for a distance reported to be not less than 25 miles. These rocks are well exposed in the vicinity of Ward, where the impression is gained that they may extend toward the east, beneath the floor of Steptoe Valley.

Near Ely several large faults displace the volcanic rocks, and elsewhere in Nevada, Utah, and Colorado, as well as in the States both north and south, prominent fault structures have been developed since the period of the greatest volcanic activity.

Locally throughout the Great Basin and very generally in Colorado metalliferous deposits are connected with the volcanic activity that was manifested in Tertiary time. The deposits at Eureka,[6] and in several districts of southwestern Nevada, and also in certain districts in

[1] Spurr, J. E., Succession and relation of lavas in the Great Basin region: Jour. Geology, vol. 8, pp. 621-646, 1900.
[2] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 289-346, 1904.
[3] Idem, p. 337.
[4] King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 694, 1878.
[5] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 232, 1892.
[6] Idem, p. 294.



A. STEPTOE VALLEY AND THE SCHELL CREEK MOUNTAINS FROM THE VICINITY OF ELY.

B. EAST FLANK OF THE EGAN RANGE.

Ward Mountain in the distance. Shows heavy alluvial deposits east of upper valley of Murry Creek.

western and central Utah, notably Tintic [1] and Iron Springs,[2] are of this type. At Ely all the primary metalliferous deposits were formed before the outburst of the volcanic rhyolites.

INTRUSIVE ROCKS.

In the western portion of North America two great periods of igneous or volcanic activity have been recognized exclusive of pre-Cambrian time, and these times of igneous invasion are in the main readily correlated with periods during which extensive deformation of the rocks occurred. The first of these periods of intrusion followed Jurassic deposition; the second was subsequent to the Cretaceous and extended through Tertiary time. The post-Jurassic revolution produced folding on the grandest scale in the Sierra Nevada, and here plication of the stratified rocks was accompanied or followed by the invasion of great volumes of igneous material. Eastward from the Sierra Nevada the effects of this revolution extended for nearly 500 miles, involving all of the Great Basin, and in parts of this region the upheaval and folding of the bedded formations was likewise accompanied by a certain amount of igneous activity. However, except in the west third of the Great Basin adjacent to the Sierra Nevada, the development of igneous rocks referable to post-Jurassic intrusion is not extensive, and in eastern Nevada and western Utah some doubt may be entertained regarding the age of the invading masses that are known to exist. The reasons for this uncertainty lie in the absence of Jurassic and Cretaceous formations throughout the general region and in the presence of comparable intrusives of Tertiary age in central Utah at Tintic,[3] and in southwestern Utah at Iron Springs.[4]

Although these two instances of Tertiary intrusion suggest the possibility that the invading masses of rock occurring at Bingham, Utah, and in some of the mining districts in western Utah and eastern Nevada may be of Tertiary age the present writer is inclined to assign them to the post-Jurassic. Butler,[5] however, suggests that the intrusive rocks are of early Tertiary age.

GENERAL GEOLOGY OF THE DISTRICT.

GENERAL CHARACTER AND AGE OF THE ROCKS.

The great bulk of the rocks of the Ely quadrangle are limestones, quartzites, and shales, whose aggregate thickness is more than 9,000 feet. These formations range in age from Ordovician to Pennsylvanian. They have been greatly disturbed by faulting, and to a less extent by folding, so that their areal distribution is very irregular. Several of the formations are invaded by masses of monzonite porphyry. Certain of the intrusive masses north of Lane, which show the form of sills, have produced very little alteration of the limestone in contact with them, but along an eastward-trending series of cross-breaking stocks, which extends through the central part of the district, the inclosing limestones and shales have been very notably metamorphosed, and the intrusive rock itself is greatly altered. The ore deposits of the district are associated with these stocks of monzonite porphyry.

The intrusion of the monzonite was followed by a long period of erosion during which the region was reduced to a condition of moderate relief. This period of erosion was closed by the beginning of volcanic activity, probably in late Tertiary time. Extensive beds of pyroclastic material were deposited, and later there were outbursts of rhyolitic lava. Volcanism was perhaps accompanied by and was certainly followed by faulting. Throughout the volcanic period erosion may have been actively in progress, as since its close lava beds have been entirely removed from extensive areas, and the existing topography has been produced.

Materials furnished by erosion of the mountains during early Quaternary time accumulated in Steptoe Valley at the mouth of Robinson Canyon, and locally within the mountainous area. When these deposits were formed the climate of the region was fully as dry as that of the present, but two epochs of humidity which have intervened are recorded in the district.

[1] Tower, G. W., jr., and Smith, G. O., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 715, 1899.
[2] Leith, C. K., and Harder, E. C., U. S. Geol. Survey Bull. 338, 1908.
[3] Tower, G. W., jr., and Smith, G. O., op. cit., p. 655.
[4] Leith, C. K., and Harder, E. C., op. cit., p. 47.
[5] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, pp. 64-70, 1913.

SEDIMENTARY FORMATIONS.

AGE AND THICKNESS.

The sedimentary formations of the Ely quadrangle, eight in number, are all of Paleozoic age. At the bottom of the exposed section is the Pogonip limestone, the base of which is buried by a heavy talus deposit. This formation carries Ordovician fossils in some of its higher members. The unfossiliferous Eureka quartzite overlies the Pogonip and is followed by the Nevada limestone of Devonian age. Succeeding the Nevada limestone are three formations of Mississippian age which have been named the Pilot shale, the Joana limestone, and the Chainman shale. The Pilot and Joana formations have not yielded organic remains for age determinations, but the Chainman shale carries fossils regarded as Mississippian (lower Carboniferous). The remaining formations are of Pennsylvanian (upper Carboniferous) age and are designated as the Ely and Arcturus limestones.

Formations present in the Ely quadrangle.

	Feet.
Carboniferous:	
Pennsylvanian:	
Arcturus limestone, exposed	400
Ely limestone	2,500
Mississippian:	
Chainman shale	250
Joana limestone	100–400
Pilot shale	200
Devonian:	
Nevada limestone	4,000
Ordovician:	
Eureka quartzite	150
Pogonip limestone, exposed	1,400
	9,200

ORDOVICIAN SYSTEM.

Pogonip limestone.—The name Pogonip, from Pogonip Mountain, in the White Pine Range, was applied to a group of limestones lying above Cambrian quartzites, which the geologists of the Fortieth Parallel Survey [1] found to be generally distributed throughout the section of eastern Nevada visited by them.

In the Ely quadrangle the Pogonip limestone occupies a small area north of Ely on the east slope of the mountains facing Steptoe Valley. Above the thick talus deposit which flanks the valley the lowest exposures are of greenish shale and gray flaggy limestone. Next above these beds lie alternating thick-bedded and thin-bedded gray limestones, aggregating about 1,100 feet. Then comes a bed of dark shale in which thin layers of fossiliferous limestone are locally developed. This shale, which is, perhaps, 200 feet in thickness, is succeeded by about 100 feet of massive dark-hued limestone, above which comes the Eureka quartzite. The strike of the formation is essentially north, and the dip is 5°–10° W. The following fossils from the upper part of the formation were determined by E. O. Ulrich:

Orthis n. sp. (near O. tricenaria).
Orthis, two undescribed species.
Several undescribed species of Ostracoda.

This fauna is known in different parts of the West. In northern Utah it is found in the Swan Peak quartzite. In Oklahoma it is present in the lower portion of the Simpson formation. Compared with the New York section the horizon represented by this fauna should lie intermediate between the Beekmantown and Chazy.

Eureka quartzite.—The quartzite which makes prominent cliffs along the east face of the steep mountain north of Ely is correlated with the Eureka quartzite of the Eureka district on general stratigraphic grounds. Similar quartzite occurs above the Pogonip limestones near Cherry Creek in the Egan Range, about 50 miles north of Ely.[2]

[1] U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 284, 1878; vol. 2, p. 542, 1877.
[2] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 48, 1903.

The formation is a massive bed of fine-grained and very dense quartzite about 150 feet in thickness. It is sharply defined from the Pogonip below and from the Nevada limestone above. Most of the rock is white, though locally some pink and yellow material is present. When examined in thin sections under the microscope the white rock is found to be composed of interlocking angular grains of quartz without any interstitial cement. Many of the quartz grains contain minute inclusions, some of which are probably rutile. Material that is not white shows many rounded grains of quartz surrounded by apparently ferruginous material of an undetermined character.

In addition to the main outcrop of Eureka quartzite two small exposures occur in the northeast corner of the quadrangle. In this locality the quartzite rests directly on the shale member of the Pogonip, without any intervening bed of limestone.

DEVONIAN SYSTEM.

Nevada limestone.—At Eureka a limestone formation about 6,000 feet thick, of well-established Devonian age, was named the Nevada limestone by Hague.[1] The formation is a constant element in the Paleozoic section of Nevada, and it seems desirable to retain the name for the body of Devonian limestones which occur in the Ely district, although there is a possibility that the limestones mapped as Nevada limestone in the Ely district may at the base include a representative of the Ordovician Lone Mountain limestone of the Eureka district.

Within the Ely quadrangle the limestone mapped as Nevada limestone occupies areas aggregating nearly 6 square miles, of which 4 square miles are situated north and immediately northwest of Ely. The entire formation is exposed in the mountains near Ely, but the structure of these mountains is so complicated and the general aspect of the limestones is so massive that no actual determination of thickness has been possible. It is estimated, however, that the aggregate measure of the beds is not less than 3,500 feet and not more than 5,000 feet.

Along Robinson Canyon and for some distance to the north the originally dark strata have been considerably metamorphosed and bleached. In the western part of the quadrangle north of Weary Flat the Nevada limestone is extensively exposed. Here again the rocks have been rather generally bleached and are locally crystalline.

The Nevada formation is made up of massive beds of limestone, usually separated by rather ill-defined partings. Its colors vary from dark gray to dark blue and nearly black, dark hues and dull aspects being predominant. The texture is almost uniformly compact, but certain beds may be described as gnarly. Others, occurring in the upper half of the formation, though massive as a whole, are composed of alternate black and gray layers less than half an inch in thickness. When free from metamorphic changes these limestones as a whole are readily distinguished from those of the other formations of the district, but locally they have been crystallized and have lost their color, so that they have become essentially marble.

The formation is not very fossiliferous, though ill-preserved shells and crinoid stems occur at several horizons. The following Devonian forms, determined by E. M. Kindle, were collected from beds belonging in the medial portion of the formation:

Atrypa reticularis.
Spirifer utahensis.
Spirifer argentarius.
Euomphalus sp.

CARBONIFEROUS SYSTEM.

AGE AND CORRELATION OF THE ROCKS.

The three formations which lie between the Nevada limestone and the Ely limestone were grouped together by Lawson[2] and correlated with the White Pine shale which occurs at Eureka and in the White Pine Mountains. Walcott[3] regarded the White Pine shale as of Devonian age, but more recent studies by Girty[4] indicate that it is Mississippian (early Carboniferous).

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[1] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 63, 1892.
[2] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 296, 1906.
[3] Walcott, C. D., Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, p. 5, 1884.
[4] Girty, G. H., The relations of some Carboniferous faunas: Washington Acad. Sci. Proc., vol. 7, p. 12, 1905.

These three formations consist of an upper and a lower shale separated by a limestone. In the Ely quadrangle no fossils have been found in the lower formations, which are here named the Pilot shale and Joana limestone, but collections from the overlying Chainman shale comprise characteristic upper Mississippian forms, and it is thought that the lower part of the section may be of lower Mississippian age. The formations above the Chainman shale are of Pennsylvanian age.

As described below, the Ely limestone is given a considerably greater thickness than that assigned to it by Lawson.[1] This result arises from the discovery that the "Ruth" limestone, as mapped by him,[2] lies much lower in the section than he supposed, and in fact is the same as the Ely limestone. The discovery of fossils in abundance in the overlying Arcturus limestone has made it possible to outline the distribution of that formation, and here again the geologic map is different from that of Lawson.

MISSISSIPPIAN SERIES.

Pilot shale.—The Pilot shale, which rests on the Nevada limestone, is named from Pilot Knob in the western part of the Ely quadrangle. This formation appears a short distance west of Ely, in the middle slopes on the south side of Robinson Canyon. It is exposed again in the open country just north of Copper Flat and in several places in the northwestern portion of the quadrangle.

The Pilot shale ranges in thickness from 100 feet in the areas north of Lyon Springs to about 400 feet in the area adjacent to Pilot Knob. The formation breaks down at the surface, and there are very few exposures of rock in place. From a few pits and tunnels it appears to be made up entirely of soft, highly carbonaceous shales, varying in color from drab to nearly black.

No fossils have been found in the Pilot shale, so that it is not possible to fix its age exactly.

Joana limestone.—The Joana limestone is named from the Joana mine, situated on the south side of Robinson Canyon, 2 miles above Ely. It forms a series of rugged knobs and prominent cliffs on the mountain slopes south of the lower part of Robinson Canyon. From a position on the east more than 1,000 feet above the valley the formation is dropped toward the west by several faults and disappears beneath the valley floor in the vicinity of Lane. The limestone is exposed also in the railroad cut just west of Copper Flat station, in the ridge that trends northwest from Pilot Knob, in several belts in the vicinity of Lyon Springs, and in Robinson Valley, on the north edge of the quadrangle.

Along the Pilot Knob ridge, where the formation is highly inclined, its thickness is approximately 400 feet. In the eastern part of the quadrangle it is about 250 feet thick, and in the most northerly exposures it can scarcely exceed 100 feet. The Joana limestone is made up of massive uniformly bluish-gray beds which in a few places contain nodules of chert.

No fossils have been found other than fragments of crinoid stems and a single coral, which is probably a species of *Zaphrentis*.

Chainman shale.—The Chainman shale is named from the Chainman mine near Lane. This formation occupies several separate areas in the eastern and western parts of the Ely quadrangle, but in the central part it is covered by younger formations.

West of Ely and south of the lower reach of Robinson Canyon these shales have been so eroded as to form a well-defined bench which is supported by the Joana limestone, and this bench continues westward for some distance beyond the Chainman and Saxton mines. A few good exposures on the Golden Fleece claim indicate a sharp passage from the Joana limestone to the Chainman shale, but alternations of limestone and shale show a transition between the Chainman shale and the overlying Ely limestone. In mapping the formation the intention has been to draw the upper boundary just above the uppermost shale bed of the transition zone. In the eastern part of the quadrangle the formation has a thickness of about 200 feet.

West of Copper Flat the Chainman shale is charged with pyrite, and east of Butte-Ely gulch along the southern part of the area, as represented on the geologic map, it is much silici-

[1] Lawson, A. C., op. cit., p. 295.

[2] MS. map loaned by the general manager of the Nevada Consolidated Copper Co.

fied. Consequently, both at these places and westward as far as the Kimberly store the boundary between the shale and the Ely limestone is indistinct and on the map is somewhat arbitrarily drawn.

The Chainman shale occupies the upper part of Weary Flat and extends past Kimberly and a mile beyond Veteran village. Near Veteran the formation has an apparent thickness of nearly 1,000 feet, but this is attributed to duplication by folding and crumpling.

Between the northeast corner of the quadrangle and Lyon Springs there are several separate strips of the Chainman shale. In this region the formation seems to differ greatly in thickness from place to place.

The Chainman formation is essentially composed of soft, fissile clay shales grading locally into fine-grained sandy shale. The shales, which contain much carbonaceous matter, are almost uniformly of a very dark hue. In a few places they contain cobble-like segregations of iron carbonate, which become rusty on exposure.

In the northwest corner of the quadrangle a heavy bed of quartzite about 30 feet thick lies in the middle of the formation, but elsewhere no sandy beds have been observed. Locally the upper part of the Chainman formation carries intercalations of gray limestone.

The only fossils noted occur in the upper third of the section. The forms listed below have been identified by G. H. Girty:

Fenestella sp.
Menophyllum sp.
Lingulidiscina sp.
Productus semireticulatus.
Productus inflatus?
Productus pileiformis?
Liorhynchus carboniferum.
Nucula sp.
Edmondia? sp.
Schizodus? sp.
Bucanopsis aff. B. textilis.
Pleurotomaria sp.
Schizostoma aff. S. catilloides.

Mr. Girty makes the following statement:

I am tentatively assigning this horizon to the upper Mississippian and correlating it with the Quadrant formation of northwestern Wyoming and south-central Montana. A suggestion of Pennsylvanian affinity is seen in the occurrence of the species of Schizostoma which is closely similar to the Pennsylvanian form *S. catilloides*.

PENNSYLVANIAN SERIES.

Ely limestone.—The name Ely limestone was proposed by Lawson [1] and was used by him in describing the lowest formation of Pennsylvanian age in the Ely district. (See p. 26.)

The Ely limestone covers a greater area in the Ely quadrangle than any other formation. Its distribution and stratigraphic relations bring out the existence of a shallow syncline trending north and south through the central portion of the district. Mountains carved from the Ely limestone usually show castellated summits and slopes that are marked by numerous terraces and cliffs.

The formation is fully 2,000 feet and perhaps 2,500 feet thick. It is made up of gray or bluish dense limestone in well-defined massive beds from a few feet to nearly 50 feet in thickness. The massive beds are separated by partings of shaly limestone or by mere seams. Nodules of chert are a prominent feature of certain of the limestone beds. Locally, as seen in the foothills south of Lane, there is a 30-foot bed of gray clay shale about 200 feet above the base of the formation.

Though the Ely limestone is fossiliferous at several horizons, organic remains appear to be more abundant in its upper part. The following forms, which have been recognized by G. H. Girty, are stated by him to fix the age of the Ely limestone as Pennsylvanian:

Derbya sp.
Spirifer rockymontanus.
Composita subtilita.
Productus cora.
Productus aff. P. porrectus Kutzorga.
Lonsdaleia? sp.
Campophyllum? sp.
Stenopora sp.
Fusulina cylindrica.
Lithostrotion mamillare?

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 295, 1906.

In the collections made by Lawson from the "Ruth" limestone (which is now known to be the same as the Ely limestone) Mr. Girty reported the following fossil forms:[1]

Fusulina cylindrica.
Fusulina elongata?
Productus aff. P. porrectus Kutzorga.
Lonsdaleia n. sp.
Lonsdaleia n. sp. var.
Seminula subtilita.
Diphyphyllum n. sp.
Zaphrentis sp.
Stenopora sp.
Lithostrotion mamillare?

Arcturus limestone.—The name of the Arcturus limestone was taken from the Arcturus mining claim on which the formation occurs. It is about 400 feet thick and lies in the broad central syncline of the Ely district and in the southwest corner of the quadrangle. In both places it is partly covered by rhyolite flows or by volcanic tuff. Many of the component beds are deeply weathered, and such beds seem to have contained a large proportion of earthy impurities. Leaching of such impure limestones has left a light-weight, marly material which resembles tripoli.

In the country north of the rhyolite area between Copper Flat and Star Pointer, also in the Robinson Valley above Keystone, and locally in the southwestern area, the weathered products of the formation are characterized by brilliant hues of yellow, orange, and red. Beds which have not yielded to weathering are dense light-gray limestone. Both massive and shaly beds occur, and some of the shaly beds are highly fossiliferous.

The deep weathering exhibited by the Arcturus limestone is not confined to that formation but is noted in places in beds belonging to the Ely limestone. It is probable that this weathering took place prior to the volcanic period and that the weathered beds have been exposed by the rather recent stripping off of the rhyolite and tuffs.

The following fossil forms are reported by Mr. Girty from collections made in different parts of the Ely quadrangle:

Spirorbis sp.
Leda obesa.
Nucula levatiformis.
Pinna aff. P. peracuta.
Schizodus aff. S. wheeleri.
Pleurophorus sp.
Pleurophorus? sp.
Dentalium mexicanum?
Plagiophorus sp.
Bellerophon aff. B. crassus.
Euphemus subpapillosus.
Murchisonia aff. M. terebra.
Schizostoma n. sp. aff. S. catilloides.
Naticopsis? sp.
Holopea? sp.
Cytherella benniei?
Nucula levatiformis.
Pteria sp.
Soleniscus planus?

Mr. Girty remarks of this fauna:

> A number of its species are closely similar to or identical with forms occurring in the Kaibab limestone of the Aubrey group of Arizona and in the Manzano group of New Mexico, but many Aubrey and Manzano forms are not present in the Arcturus collections, notably the Brachiopoda, which are entirely unrepresented.

QUATERNARY SYSTEM.

CHARACTER OF THE DEPOSITS.

The Quaternary deposits of the Ely district are accumulations of rock detritus derived from the erosional wasting of the local mountains. Materials shed from the higher slopes have lodged on the lower declivities and in the valleys, forming deposits which are locally of very considerable depth and commonly hide the bedrock formations more or less completely. The distribution of these deposits has been only in part indicated on the geologic map, the areas represented being those within which the bedrock geology could not be made out or plausibly inferred. All other areas are omitted in the interest of simplicity. For convenience in description the Quaternary deposits may be divided into valley fillings, outwash gravels, and recent wash.

[1] Lawson, A. C., op. cit., p. 293, 1906.

VALLEY FILLINGS.

The great Steptoe Valley, on the western side of which the town of Ely is situated, is deeply filled with débris that was washed into this wide depression through gorges which traverse the adjacent mountains. Opposite the mouths of these gorges there are tremendous alluvial cones, characteristic examples being the great merging cones of Robinson and Murry canyons, which engulf the base of the Egan Range; and the cone of Steptoe Creek, on the opposite side of the valley, where the stream emerges from the Schell Creek Range. It is sufficiently obvious that these deposits are made up of material eroded from the areas tributary to the several canyons. In the Robinson cone may be found specimens of nearly all the rock varieties which outcrop in the Ely district. Railroad cuttings and occasional excavations reveal a jumbled aggregate of sand, gravel, and angular rock fragments of all sizes, the largest fragments having a diameter of more than 2 feet. A rough stratification is seen in many places, and locally at least the material is cemented by carbonate of lime. The deposit has an exposed thickness of about 160 feet, which may be seen as a result of modern erosion by Murry Creek, but its full depth may be here more than twice as great.

OUTWASH GRAVELS.

While no sharp distinction can be made between valley fillings and outwash gravels, it is convenient to use the term "outwash gravels" for the mantles of rock débris that are present on many of the gentler slopes within the Egan Range. These mantles are accumulations of materials shed from the steeper mountain declivities. They are prominently developed in the northeast and northwest corners of the Ely quadrangle. In both localities they begin well up in the foothills and merge downward with the valley fillings in the broad depression that drains the region immediately north of the Ely Mountains.

In many places in the upper basin of Robinson Canyon, and in the region west of the Giroux mines, outwash gravels cap broad ridges which lie between the numerous drains. A good example of such detrital mantles is seen on the first ridge beyond the county road about half a mile west by southwest from the Giroux shaft. Here the detrital capping may be 10 or 15 feet deep. Though it is composed principally of limestone fragments, it contains also fragments of jasperoid and pieces of garnet rock.

There are other ridges capped by outwash gravels in the open country of gentle slopes which lies immediately north of Copper Flat and Ruth village; for example, the first ridge west of the railroad, which heads against a broad swale that extends back into the area of rhyolite, is mantled by detritus principally from the hills which lie south of Copper Flat.

In the region between Lyon Springs and Keystone there are two well-marked terraces above the present drainage floor. The upper terrace, which rises nearly 150 feet, is locally capped by heavy gravel beds, while the lower, rising about 30 feet above the swales, is covered by only a thin mantle of outwashed detritus. It seems most probable that the higher gravels correspond with those which cap the ridges on the south side of the same drainage basin.

Between Ruth Gulch and the Chainman mine a series of ridges rises sharply from Lane Valley and extends with gradually increasing slopes back to the steeper declivities of the mountains on the south. These ridges rise 50 feet or more above the intervening drains. Their side slopes and their end slopes next to Lane Valley are essentially free from accumulations of rock detritus, but their crests are mantled by outwash gravels which are commonly a yard or more in depth. Similar deposits are present in a few places on the north side of the main valley, as, for instance, on the summits of the ridges just north of the Chainman mine, also on an isolated hill which lies just west of the Golden Gate shaft of the McDonald-Ely Co.

It is noteworthy that the outwash gravels on both sides of Lane Valley are distinct from the deposit of loose material which fills the valley itself. The lateral mantles are perched upon the ridges, and they must have originated at a time when the valley was somewhat less deep than at present.

RECENT WASH.

Accumulations of rock detritus at cliff bases, at the mouths of steep ravines, and along the bottoms of swales and graded valleys are here included under the designation "recent wash." Throughout the region large portions of the mountain slopes are mantled by loose material, and though rocks may outcrop in the steeper parts of ravines, along the more gentle reaches the solid formations are usually hidden by rock débris. Where steep gulches join valleys of lower gradient the deposits form alluvial cones, such as may be seen at places along the sides of Robinson Canyon.

The main valley from Keystone to Ely is floored by loose deposits, which are known from several shafts to be 30 to 80 feet in depth. From Keystone to the mouth of Ruth Gulch, and from the lower end of Lane Valley to Ely, the valley is closely confined between precipitous slopes and the gravel floor is narrow, but through the middle section the valley walls fall back on either side and the flood plain is correspondingly wide. (See Pl. IV.)

INTERPRETATION OF QUATERNARY DEPOSITS.

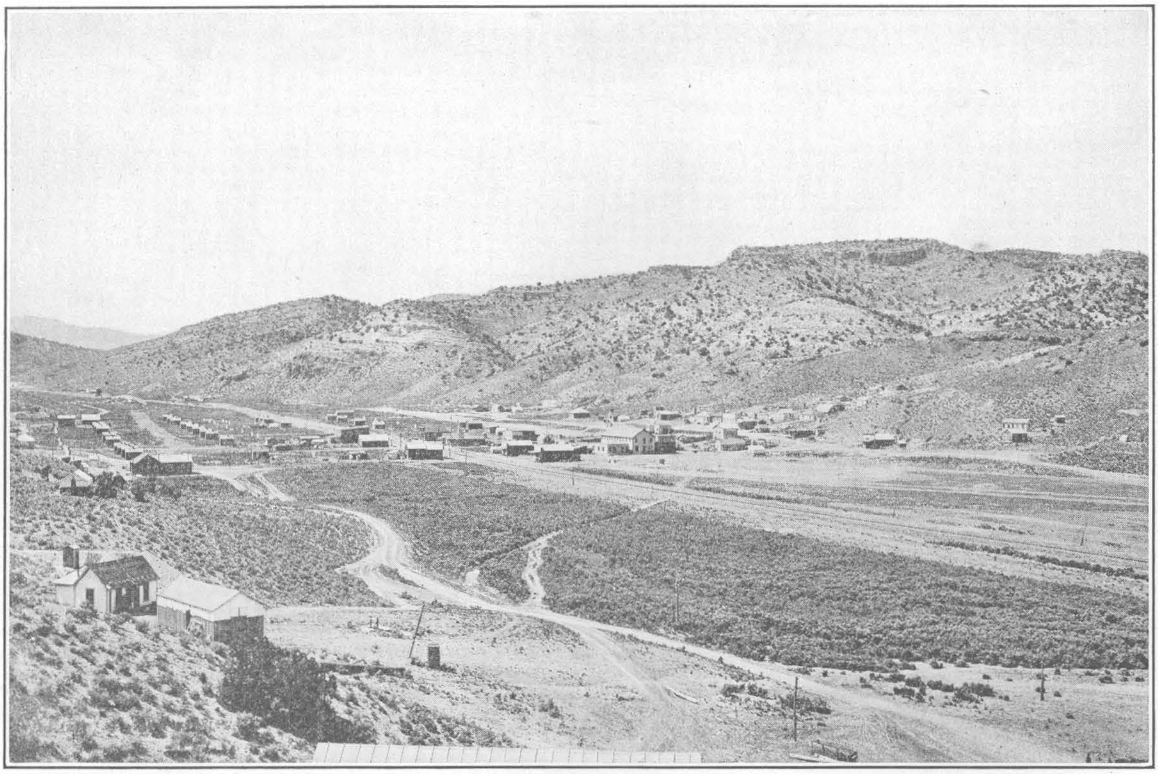
The interpretation of the Quaternary deposits of the Ely district is involved in the climatic history of the Great Basin region, an outline of which has been given elsewhere in the present volume. The features of the Steptoe Creek alluvial cone will now be discussed in an endeavor to show that the local history conforms to that of the general region.

The Steptoe cone is traversed from head to foot by Steptoe Creek, a perennial stream flowing in a valley from one-fourth to one-half mile wide from rim to rim and more than 200 feet deep. The sides of this valley are marked by two well-defined terraces, the higher perhaps 150 feet and the lower about 40 feet above the flood plain, which constitutes the valley floor. From a consideration of the known processes of the formation of alluvial cones the conclusion is obvious that just after the building of the great mass of débris had been completed it could not have been trenched by any valley at all comparable with the one now existing. In order that the deposit should have accumulated, it is indeed necessary to assume that the waters of the creek did not form a constant stream flowing well out into the broad intermontane valley as at present, but instead that the stream was intermittent, and that throughout the epoch of alluvial growth its waters were ordinarily not sufficiently voluminous to reach the edge of the cone itself. Accordingly, it is believed that the climate of the epoch was essentially dryer than that of the present day, and it seems probable that it was on the average dryer than that of any succeeding epoch. This epoch corresponds with the pre-Lake Bonneville epoch. (See p. 21.)

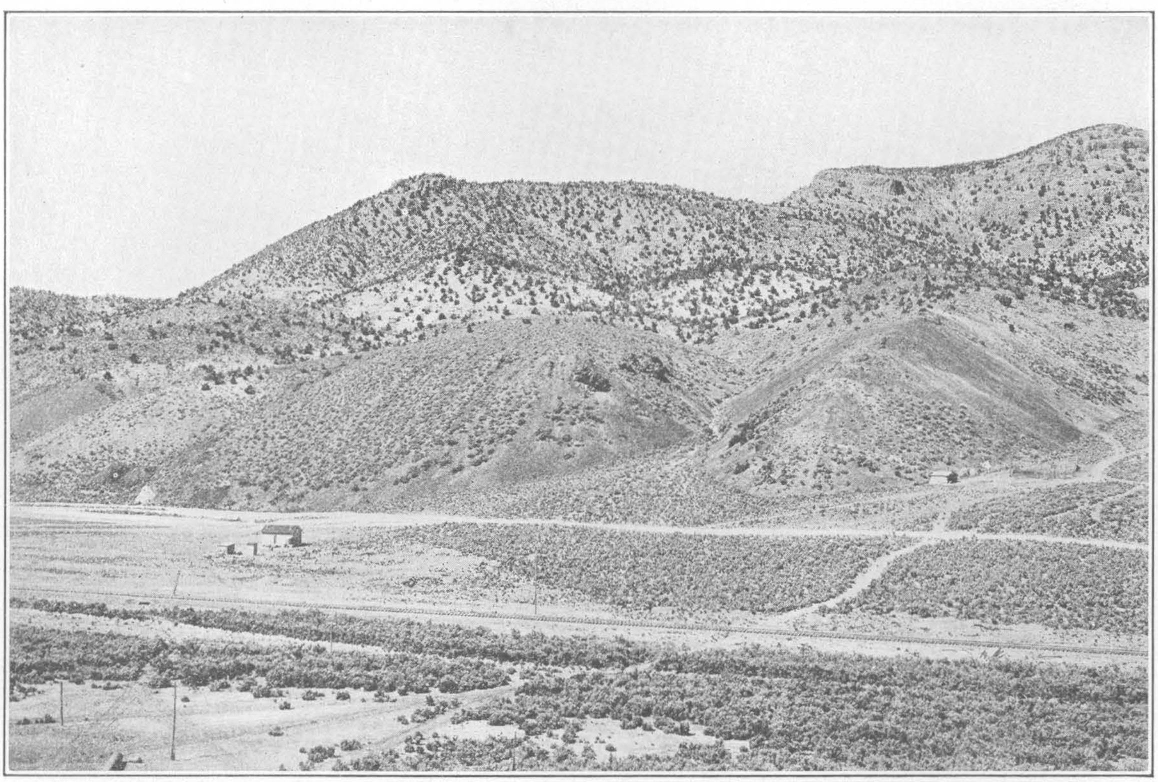
In view of the fact that the cone has been deeply trenched, it is evident that its median portion has been cut away by the same stream that built it up. In general, when loose material is delivered to drainage channels, intermittent streams will establish steeper grades than constant streams. Transportation by intermittent streams is accomplished solely by pulses of short duration, but in constant streams there is added to the paroxysmal effects of freshets the steadily operating activity of the normal current. This every-day work is effective in keeping materials derived at flood stage on the move, and the result is a distributed gradient according to the volume of the stream, though dependent as well on the amount and nature of the loose materials which the stream receives and with which it is forced to deal.

After the completion of the Steptoe cone increasing humidity probably rendered the flow of Steptoe Creek more and more constant, and its steady or normal discharge increasingly voluminous. The waters of the creek thus reached farther and farther down the valley. The old steep slope of aggradation could not persist in the presence of a perennial stream, and erosion of the deposit necessarily ensued. The materials picked up by the stream were carried out into the lower valley, where they were distributed and dropped, the combined effect of erosion above and deposition below being a stream-bed profile of essentially even grade.

On the whole, demolition of the cone seems to have been going on since it was first attacked, but the progress of dissection has not been without material halts, as is witnessed by the two



A. LANE VALLEY FROM CHAINMAN MINE.
Fits at left of view shown below.



B. LOWER PART OF LANE VALLEY FROM CHAINMAN MINE.
Mountains of Ely limestone, foothills of metamorphosed shale, modern alluvial cones.

existing strongly marked terraces. If the first downcutting is attributed to increased humidity, it appears that the upper terrace represents a flood plain produced by lateral erosion after the revived stream had established such a grade as was demanded for the efficient transportation of the loose materials which it currently received. This epoch of increased stream flow is reasonably correlated with the first flooding of Lake Bonneville.

Physical features leading to a recognition of a succeeding dry epoch have not been discriminated. A marked diminution in stream volume would presumably have resulted in the formation of a new alluvial cone resting on the flood plain previously formed. If such a cone was formed within this section of the valley it has since been destroyed. It is a warrantable suggestion that the inter-Lake Bonneville epoch of aridity was less dry than the pre-Lake Bonneville epoch and that the alluvial cone then built was situated within the valley well below the more ancient cone. It must have been comparatively small, broad rather than high, and its features would have been largely masked by subsequent erosion and deposition.

The lower terrace and the inner floor of the valley, in accordance with this reasoning, are to be explained as effects of increased constancy and volume of the stream, these in turn being results of greater humidity of climate.

These suggestions demand three epochs of successively greater humidity since the building of the great Steptoe cone. As already indicated, the first of these wet epochs is to be correlated with the first flood epoch of the Great Basin lakes, which was followed first by essentially complete desiccation and then by a second accumulation of waters, after which the present desiccation was inaugurated.

For ancient Lake Lahontan Russell[1] shows that the second rise of the waters was interrupted by two noteworthy halts, during each of which the waters remained at constant stage long enough for the development of well-marked shore terraces. Thus the increase in humidity is found to have been progressive in steps, a finding with which the foregoing suggestions are in accord. It seems, therefore, that the grading of the former surface, represented by the lower terrace, is to be assigned to an earlier portion and the grading of the present valley floor to a later portion of that comprehensive epoch which was principally characterized by the second flooding of the Lahontan and Bonneville basins.

Though the growth of the Steptoe cone points to an early dry epoch, and the way in which it has been dissected indicates subsequent epochs of successively greater humidity, no local features have been observed which can be interpreted as evidence of a second dry epoch to correspond with the inter-Lake Bonneville epoch, which was characterized by the complete desiccation of Lake Bonneville. To this extent then the historical outline recorded in this old alluvial volume is incomplete, and the lost chapter must be supplied from the contemporaneous Bonneville and Lahontan books. It is believed that the several direct correlations which can be confidently made fully warrant the conclusion that all eastern Nevada experienced the same dry climate which from the history of the Great Basin lakes is known to have obtained between the two established epochs of high water.

On a map showing the lakes of the "Glacial period" King[2] represents somewhat extensive bodies of water, including the areas occupied by the present Ruby, Franklin, and Eagle lakes. On a similar map Russell[3] shows a lake that includes the northern end of Steptoe Valley. It is judged that this valley could not have been flooded as far south as the alluvial cone opposite the mouth of Duck Creek. The upper valley shows no physiographic features which can be interpreted as effects resulting from the presence of a former lake. Directly opposite East Ely and southward to the Steptoe Range the foot of the alluvial cone presents a westward-facing embankment. The steeper slope serves to connect the original surface of the cone with the flood plain of Steptoe Creek, and it is all but obvious that this stream has both attacked the cone and filled in against it. Neither the upper nor the lower edge of the embankment is even approximately level.

[1] Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, pp. 236, 261, 1885.

[2] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, map pl. 6, 1878.

[3] Russell, I. C., op. cit., pl. 1.

Although the alluvial accumulations in front of the Egan Range at Ely reveal the events of Quaternary time in less detail than does the Steptoe cone just described, yet by considering all of the detrital deposits of the district and by taking into account certain associated features of topography, it is possible to outline the local history and to show that its episodes correspond to those of the general region.

The great alluvial cones were built up during an early epoch when the prevailing climate was at least as dry as and probably somewhat drier than that of the present. This conclusion can be reached by a consistent line of reasoning based upon the known behavior of streams in respect to the transport and deposition of materials which they receive. Gilbert [1] reaches the same conclusion in regard to similar accumulations of débris within the Bonneville Basin, where the ancient alluvial piles were formed when the basin contained no lake, and therefore during a time characterized by aridity of climate. (See p. 21.)

Since their formation the Murry and Robinson cones have been greatly dissected. It is sufficiently obvious that when their building had been newly completed they must have presented unbroken slopes from their bases, situated well out in the great valley, to the point where their surfaces met the mountain wall on either side of the canyons, and that the canyons themselves must have contained similar débris to heights which would bring their old floors above the heads of the cones at the canyon mouths. From this reasoning the conclusion follows that in the lower part of Robinson Canyon there was formerly a gravel-covered floor not less than 200 feet above the present stream bed, and that the old high-level floor must have extended well up the valley. This last inference finds corroboration in the perched gravels on the ridges adjacent to Lane Valley. Here the ridge crests are capped by outwash material, but the valleyward slopes and the flanks of the ridges are not similarly covered. It is evident that these gravels could not have been thrown out onto ridges which existed as such when the detrital material was being distributed. Together the covered crests and bare slopes offer strong evidence that the floor of Lane Valley is now fully 60 feet lower than when the gravels were deposited.

Throughout the less rugged portions of the district the outwash gravels are present on the crests of ridges which usually rise about 50 feet above the intervening broad drains. Here again the detritus must have been distributed before the drains were excavated, and the old surface now represented by the ridges thus corresponds with the former high floor of Robinson Canyon and with the surface of its alluvial cone at the time when the cone reached its maximum development.

The completion of the cone at the mouth of the canyon marked the close of the first dry epoch of Quaternary time. The succeeding epoch was characterized by a distinctly moist climate. During the dry epoch, as at present, Robinson Canyon was probably a dry valley throughout the greater part of each year, and whatever movement of débris took place through the valley must have resulted from intermittent flow of storm waters and of waters derived from the rapid melting of accumulated snows. On the other hand, it would seem that the observed lowering of the drainage channels throughout the greater part of the basin could not have been accomplished except through the action of perennial streams sufficiently voluminous to transport all loose material washed into their channels and with reserve energy for corrasion.

The Quaternary history of the general region shows that there have been two humid epochs and two dry epochs (including the present) since the formation of the great alluvial cones. The cones were built during a dry epoch preceding the expansion of the Quaternary lakes.

Records of the first change from dry to wet are sufficiently obvious in the Ely district, but the succeeding dry epoch has left no conspicuous record. A halt in the dissection of the old drainage surface is, however, indicated by a low but definite terrace which is developed in the area of volcanic tuffs between Keystone and Lyon Springs. This terrace doubtless corresponds with the upper terrace of Steptoe Creek (see p. 30), and the excavation of the friable tuffs down to the former valley floor, of which the terrace is a remnant, may be assigned

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 92, 1890.

to erosion during the first humid epoch. From our knowledge of the regional history the second episode of dry climate may be interpolated at this place in the local record, and the broad swales that have been excavated below the terrace in the volcanic tuffs are then assignable to erosion during the succeeding humid epoch. The later downcutting is thus correlated with the second flooding of the Lahontan and Bonneville basins, just as the earlier excavation corresponds with the first flooding.

The present dry climate is reflected by the clogged condition of the Robinson Valley below Keystone, where loose débris fills the channel to depths of 30 to 80 feet, and in the conical piles of alluvium at the mouths of steep side gulches.

IGNEOUS ROCKS.

GENERAL CHARACTER.

The principal igneous rocks of the Ely district include an older set of monzonite porphyry intrusions, and a younger series of tuffs, obsidians, and rhyolites, which, though essentially extrusive, occur also in part as dikes and small stock intrusions. The older intrusive rocks are of particular interest because the genesis of the metallic ores of the district is intimately related to them. Though the age relations of these rocks are not closely determinable, it is probable that they were intruded at the close of Jurassic time.

The writer has reached the conclusion that all the coarse-grained intrusive rocks of the district, however varied in appearance and composition, are to be referred to a single epoch of igneous activity. This conclusion, however, is contrary to the view of Lawson,[1] who regards the darker and fresher monzonites and monzonite porphyries as distinct from and geologically older than the pyritized porphyry of the district, certain masses of which have been extensively developed in the mines. Perplexing features arise from the fact that the ore porphyry as it occurs in outcrop and in the mine workings is a greatly altered rock, so that in general its primal characters can only be ascertained by indirect means. The consideration of material brought to light through mine developments since the district was examined by Lawson in 1905 eaves no room for doubt that the disseminated ores of the Ely district have been formed by the mineralization of rock originally like that of Weary Flat and having the chemical composition of monzonite.

Material collected by Lawson in the workings of the Ruth mine has been described by him as minette. The writer did not recognize this material while on the ground, so that no original descriptions can be given.

MONZONITE AND MONZONITE PORPHYRY.

DEFINITIONS AND NOMENCLATURE.

Strictly defined, monzonite is a plutonic rock intermediate in chemical and mineral composition between syenite and diorite. It is characterized by nearly equal amounts of orthoclase (potash feldspar), and plagioclase (lime-soda feldspar), together with some dark mineral such as hornblende, augite, or mica. Quartz monzonite lies similarly between granite and granodiorite. The term porphyry (with the corresponding adjective porphyritic) is used to indicate, in an igneous rock, the presence of phenocrysts or well-individualized crystals of one or more constituents. When the phenocrysts are set in a perfectly crystallized granular matrix the rocks are properly called porphyritic monzonites, and rocks showing an imperfectly crystallized or dense groundmass are distinguished as monzonite porphyries.

In the Ely district most of the intrusive rocks, where fresh, have the mineral composition of quartz monzonite, but in certain of them there is very little quartz, so that the rock meets the strict definition of monzonite. With reference to texture they are porphyritic quartz monzonites or porphyritic monzonites, but examples of monzonite porphyry with a rather dense groundmass are of local occurrence. For convenience in the following pages the technical nomenclature outlined above will be disregarded, except where accurate distinction is required, and the name porphyry will be used generally for the monzonitic rocks.

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 287-337, 1906.

OCCURRENCE AND DISTRIBUTION.

In different parts of the Ely quadrangle masses of intrusive porphyry are found in contact with six of the eight Paleozoic formations which have been represented on the geologic map. The stratigraphic range of the intrusions thus amounts to at least 5,000 feet, the lowest beds observed in igneous contact with porphyry masses being well down in the Nevada limestone and the highest some distance above the base of the Arcturus limestone.

Fifty-two separate areas of porphyry have been noted within the Ely quadrangle (Pl. II, in pocket). Of these at least half are the outcrops of minor intrusions. The remainder represent exposures of at least several acres and one irregular area has an extent of considerably more than a square mile. The intrusions are disposed within an easterly zone 4 miles wide and about 8 miles long and most of them lie within a belt which measures scarcely a mile across. This belt will be referred to as the principal zone of intrusion. It trends nearly east and west as far as the Liberty pit, but from there it extends northwest through the Giroux property.

The extensive area of porphyry which lies north of the upper end of Lane Valley represents the partly exposed and somewhat eroded surface of an irregular and locally crosscutting sill, the roof of which is formed in different places by Ely limestone and Chainman shale. It is probable that this sill passes beneath the block of limestone just north of Watson Spring and connects with the exposed porphyry masses on the north side of the upper end of Lane Valley. On the south slope of Elijah Hill the top of the porphyry mass passes beneath a massive layer of limestone and rises with this layer toward the north.

In the principal zone of intrusion there are 17 considerable areas of porphyry besides several minor patches. Most of the intrusions are thought to be essentially crosscutting stocks, though there are indications that in a few places the contacts conform to the stratification of the inclosing rocks. In the eastern part of the zone, on the north side of the canyon, the porphyry is fairly fresh, though material cut in some shafts is irregularly impregnated with pyrite. Essentially unaltered rock occurs also in Weary Flat and north of Pilot Knob, but in all the other masses of the central intrusive zone the porphyry is greatly changed from its normal condition, having suffered great alterations, first, from the action of heated solutions, which percolated through the rock subsequent to but perhaps not long after its intrusion, and, second, to deep leaching of the mineralized rock by atmospheric waters.

The bodies of porphyry north of the canyon in the eastern part of the intrusive zone are stocks inclosed by Nevada limestone.

On the south side of Lane Valley an area of porphyry 800 feet wide extends westward from the Chainman mine for a distance of three-fourths of a mile. At the surface the porphyry of this area is greatly decomposed and bleached, and tunnels which have been driven into the mass show that it has been very thoroughly impregnated with pyrite. The rock in surface exposures resembles the cap rock in the central and western portions of the intrusive zone.

Northeast of Ada Hill a mass of porphyry lies between Chainman shale and Ely limestone. This rock is impregnated with pyrite, as is shown by material from a shaft on the Missing Link claim. Similar pyritized rock occurs in the small intrusion just west of Ada Hill.

Toward the west, between the upper part of Lane Valley and Star Pointer, there are several irregular areas of porphyry, each surrounded by Ely limestone.

Two areas of porphyry near the mouth of Ruth Gulch are probably parts of a single mass which is partly hidden by alluvial material and which can hardly fail to connect beneath the wash of Lane Valley with the sill of similar rock that lies to the north and rises to Elijah Hill.

The mass of porphyry which forms Kimbley Hill and extends southward across Ruth Gulch appears to have an inclined contact with the limestone along its southerly edge, as shown by drilling on the Turkoy claim. Here it seems, therefore, to have an attitude that would correspond to the upper edge of a thick sill, but the nature of the boundaries on the east, north, and west shows that the body as a whole distinctly crosscuts the inclosing limestone. This mass of rock has been prospected by drilling, and though it is everywhere charged with sulphides the amount of material found with a copper tenor above 1½ per cent was not regarded as worth consideration in the estimate of the ore reserves of the Nevada Consolidated Copper Co.

The next large mass of porphyry outcrops in an irregular area, covering the high ground north of the Ruth shaft and extending as far as the crest of Hayes Ridge. The greater part of this mass is charged with sulphides, and in the southern section most of the rock may be classed as copper ore. This body of disseminated ore has been fully developed by the Ruth workings and by systematic drilling.

The mass of porphyry opened by Copper Flat and Liberty pits has a width from north to south of about 1,300 feet and a length of about 3,200 feet. It is bounded on the south, and probably on the north also, by metamorphosed Ely limestone. On the east an easterly dipping fault brings rhyolite against the intrusive rock, and on the west the porphyry ends against a wedge of rhyolite which has been thrown down between two faults. Although this mass is represented on the geologic map (Pl. II, in pocket) as having a connection with an area of similar rock exposed on the ridge to the north of Liberty pit, this connection could not be actually established. This intrusive body is bordered by wide zones of metamorphism, and the surficial portions of altered sedimentary rocks have been fully oxidized by the action of weathering, so that structural relations are very obscure. However, at the south end of the Copper Flat pit the irregular surface between the porphyry and the mineralized and oxidized limestone declines toward the north at a rather steep angle. That the Chainman shale north of the porphyry mass is very generally charged with pyrite has been shown by churn-drill prospecting within the area of the shale, and it may be suggested that this area is underlain by a mass of porphyry that has a deep connection with the intrusions on Copper Flat and Weary Flat.

South of Reipetown heavily pyritized porphyry in Butte-Ely gulch exhibits a close similarity to the ore porphyry of the Copper Flat area. This mass of rock appears to be directly connected with that of the Weary Flat area lying immediately north. Drill holes along a line extending northward from the Butte-Ely ore bin have revealed the presence of sulphide-bearing porphyry as far north as a point about 300 feet south of the railway, but exposures along the track toward the west, and also between the track and the east-west wagon road, show coarse-grained rock which is not notably mineralized. The rock of Weary Flat, however, is locally charged with pyrite, as may be noted by the examination of material thrown out from several wells and shafts in the vicinity of Reipetown. On the east and west this intrusion is bounded by more or less metamorphosed shales, which are supposed to belong to the Chainman formation, but the structural relations in this part of the quadrangle are imperfectly known. The alternative is that the shales belong to the Pilot formation.

An area of coarse-grained quartz monzonite situated north of Pilot Knob is separated from the area on Weary Flat by a few hundred feet of sedimentary rock. It lies between Nevada limestone and Pilot shale.

There remain for consideration the porphyry masses of the west end of the intrusive zone and two intrusions within the property of the Giroux Consolidated Mines Co. One of these two has been developed by the Bunker Hill, Brooks, and Morris mines and by systematic drilling. The other, which outcrops on Old Glory Hill, has been explored only by means of churn drills. The mass of porphyry that outcrops on the east face of the ridge forming the White River divide appears to have the general form of a sill that dips steeply to the southwest. By comparing the position of the east edge of the outcrop with the corresponding edge, as located on the first mine level in the Brooks and Bunker workings, the dip of the bottom surface of the porphyry mass is found to be about 60°. The intrusion is continuous from the Bunker Hill shaft to the vicinity of the Old Glory shaft, a distance of 2,900 feet. In Old Glory Hill the wall of the porphyry mass stands at a much higher angle than at the Brooks shaft. Highly metamorphosed limestone is found both above and below the porphyry sill. In the mine workings the porphyry is broken by several irregular masses of rhyolite, the largest of which comes to the surface just east of the Bunker Hill shaft.

The porphyry mass of Old Glory Hill, which is very poorly exposed, covers an irregular area of about 20 acres. It is surrounded by highly silicified and otherwise metamorphosed limestone. This mass is probably an irregular stock.

The body of porphyry at the Veteran mine offers few outcrops, and as represented on the map its area is probably somewhat larger than it should be. The extent to which the surrounding rocks have been silicified and impregnated with silicate and sulphide minerals is very noteworthy in respect to the apparently small size of the intrusive mass, and the outcropping porphyry is perhaps merely the crest of a buried mass of considerable bulk. Inspection of the workings of the Veteran mine shows that the porphyry is a cylindrical or pluglike body that plunges toward the northwest.

PETROGRAPHIC AND CHEMICAL CHARACTER OF THE NORMAL PORPHYRY.

The term normal porphyry is here used to designate essentially unmetamorphosed intrusive monzonitic rock. The larger areas of the normal porphyry usually offer fairly fresh exposures, but the rock of small areas is commonly more or less weathered, and in certain places has completely disintegrated.

The characteristic aspect of the fresh monzonitic rocks is porphyritic. Orthoclase (potash feldspar) is invariably present in well-formed crystals or phenocrysts which are commonly two to several times larger than the other components. Textural variations are very great, both between different masses of the rock and within single intrusions. Certain of these rocks have very large phenocrysts and a groundmass of moderate coarseness. Others have phenocrysts of fair size only, with a medium-grained or fine-grained base. The groundmass itself has a characteristic porphyritic fabric, due to the development of small phenocrysts of plagioclase and in many facies of well-formed hornblende. What may be termed the interstitial or ultimate groundmass is invariably composed of orthoclase and quartz. This material ranges in grain from fine to coarse. Quartz crystals that have a diameter of 1 millimeter or more usually contain many minute specks which are probably cavities, and some larger grains contain cavities which under high powers of the microscope show a liquid and a bubble. To judge from the relative development of the constituent minerals, the different phases of the normal porphyry do not vary greatly in chemical composition. They appear to carry about the same amount of ferromagnesian minerals (mainly hornblende) throughout, and variations that may exist in the relative amounts of the feldspars can not be estimated by inspection of thin sections under the microscope. Four complete chemical analyses indicate a fairly constant composition, a fifth, however, being divergent. Very little of the rock is entirely free from alteration, evidences of which appear in the development of such minerals as calcite, sericite, kaolinite, and epidote, which may be seen under the microscope to have been formed at the expense of original minerals of the rock.

In the eastern part of the intrusive belt on the north side of the canyon there are four good-sized stock intrusions. Parts of the porphyry composing these masses are considerably metamorphosed, but other parts are relatively unaltered. In all four occurrences the rock has the same general appearance, the only differences observable from place to place (aside from differences in degree of alteration) being that one of the stocks contains much larger crystals of orthoclase than the others. This normal rock is composed essentially of orthoclase feldspar, plagioclase feldspar (composition about Ab_1An_1), hornblende, and a little quartz, with apatite, magnetite, and sphene as accessory minerals. Augite and brown mica are locally constituents. The rock is everywhere porphyritic through the development of good-sized crystals of flesh-colored orthoclase, in places very prominent because of their abundance and their dimensions, which reach 3 to 4 inches. As a whole it may be properly designated as porphyritic monzonite tending toward quartz monzonite. It closely resembles much of the rock from the Weary Flat area except for its larger phenocrysts of orthoclase.

In a road cutting near the Chainman mill Lawson[1] collected "a bright yellowish-gray rock showing numerous small porphyritic feldspars of a fresh glassy aspect." As the writer collected no specimen from this locality, Lawson's description of the rock, which he calls "augite andesite," is here given:

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 323, 324, 1906.

Under the microscope this is seen to consist of fine holocrystalline groundmass made up of allotriomorphic and interlocking feldspars, some of which show lamellar twinning. These are approximately equidimensional and generally free from decomposition products. In this groundmass are embedded numerous phenocrysts of plagioclase, colorless augite, and apatite. The feldspars * * * have extinctions corresponding to the composition Ab_2An_3.

The lamellar twinning shows that the mineral is plagioclase. A selected sample was analyzed by Herbert Ross with the following result, quoted from Lawson:

Analysis of porphyry from road cutting near Chainman mill, Ely, Nev.

[Herbert Ross, analyst.]

SiO_2	63.30	K_2O	......
Al_2O_3	17.90	P_2O_5	0.69
FeO	1.83	Ignition	1.18
MgO	2.53		
CaO	10.45		100.18
Na_2O	2.30		

No rock similar to this one has been recognized in any of the thin sections examined. It is much higher in lime than the ordinary rock of the district, and the analysis does not indicate that the excess of this oxide can be present in the form of the carbonate, calcite. As the intrusive rocks of the district are characteristically potassic the analysis would have a greater value had it included this oxide. This rock, which may be a dike, has been mapped as part of a porphyry intrusion, the rock of which is everywhere else greatly metamorphosed and weathered.

The normal phase of the rock in the vicinity of Elijah Hill is a monzonite porphyry that exhibits sharply defined phenocrysts of orthoclase, the largest half an inch in length, set in a rather dense matrix, of which the most prominent component is black hornblende. Under the microscope all specimens are found to contain abundant plagioclase of the same composition as that present in the eastern stocks, most of it in well-formed crystals. The plagioclase is accompanied by phenocrysts of hornblende and usually by sphene, and these minerals are set in a groundmass composed mainly of orthoclase with a little plagioclase and some quartz. The groundmass is commonly very dense. To the unaided eye, freshly broken surfaces show only the large orthoclase crystals and hornblende, but slight weathering brings out the white plagioclase against the general gray of the rock, or produces a pitted surface by the decomposition of that mineral.

The rock of the area that lies mainly in secs. 6, 1, and 38 differs greatly from place to place. In general its groundmass is somewhat more coarsely crystallized than the rock of the Elijah Hill area, but it is composed of the same minerals and these show the same relations as to relative importance and as to the order of their crystallization. In places brown mica is present in addition to hornblende.

A chemical analysis by Herbert Ross, which is presented by Lawson,[1] is here quoted. The analysis represents a typical specimen collected north of Lane.

Analysis of monzonite porphyry from Lane, Nev.

[Herbert Ross, analyst.]

SiO_2	59.79	K_2O	4.19
Al_2O_3	17.70	BaO	.21
Fe_2O_3	2.42	MnO	.09
FeO	2.76	P_2O_5	.37
MgO	1.92	H_2O (ignition)	2.00
CaO	5.22		
Na_2O	2.64		99.31

The close correspondence of this analysis with those of the monzonite of Weary Flat recorded below (p. 39) is worthy of note.

The porphyry east of Keystone Hill and near by in Robinson Canyon has not been studied in thin section. Though considerably weathered, as seen in outcrop, it closely resembles the porphyry north and east of the area of rhyolite on Garnet Fields, northeast of Robinson Canyon.

[1] Lawson, A. C., op. cit., p. 310.

The porphyry masses of Ruth Gulch and Hayes Ridge are greatly altered. Normal porphyry, however, has been recognized at a few localities. It occurs at the American shaft of the Ely Consolidated Co., by the roadside southwest of the Ruth shaft, and as a small dike about a fourth of a mile southeast of the Ruth shaft. The two occurrences last mentioned are not represented on the accompanying maps. A fourth occurrence of rather fresh appearing rock is seen on the Turkoy claim, east of Ruth Gulch. Detailed mapping suggests that this is an apophysis from the main intrusion. Unmetamorphosed porphyry is exposed also in a prospect pit on Willard Hill, just over the crest of the divide and nearly west of the Ruth shaft. As a result of exposure since this pit was dug, the rock is now very friable. Lawson [1] describes this rock as follows:

> The rock has a compact gray matrix in which are interbedded large orthoclase crystals up to 25 millimeters in length, with Carlsbad twinning and fresh lustrous cleavages, smaller, dull feldspar, and numerous black hornblendes up to 15 millimeters in length. Under the microscope the groundmass proves to be very murky. It is largely isotropic, but with doubly refracting areas in it. The smaller feldspars can not be advantageously studied owing to their decomposition. Apatite is a common accessory.

Other exposures of essentially normal though considerably decomposed porphyry may be noted on the northerly slope of Hayes Ridge, along the northern border of the porphyry area which lies athwart Ruth Gulch and Verzan Canyon, and in the western part of the neighboring intrusion near the mouth of Ruth Gulch. These rocks represent minor portions of the porphyry that escaped the general alteration which most of the intrusive material has undergone.

In the western part of the main zone of intrusion deeply weathered and disintegrated but otherwise unmetamorphosed porphyry occurs on the slope above the railroad just east of the rhyolite area near the Brooks shaft, north of the ore porphyry opposite Morris shaft No. 2, in the ground between Morris shaft No. 1 and Old Glory shaft, and in the dike near the western boundary of the quadrangle on the Matilda group of claims. The disintegration products include fragments of orthoclase crystals, and a knowledge of the field makes it certain that these products represent normal porphyritic monzonite.

The porphyry of the crescentic intrusion about half a mile northwest of Veteran village is a slightly altered monzonite porphyry which closely resembles the rock north of the upper end of Lane Valley. Rock of similar character though of fresher appearance is exposed on the edge of the quadrangle about a mile northwest. The rock on Great Bend Ridge is also very similar in type, though much disintegrated.

The rocks of the intrusive mass on Weary Flat and of the neighboring mass which lies near it on the northwest are essentially identical in character. They are more even grained than those of other intrusions, though they are for the most part of porphyritic texture. Their color in general is gray, though locally they are pink or reddish, as in the vicinity of Taylor shaft in the NW. $\frac{1}{4}$ sec. 8, and along the road southwest of Reipetown that runs east and west. These pink facies are all coarse grained. At only one place along the railroad west of Reipetown station was a similar coarse fabric noted in gray rock.

These coarsely crystallized monzonites carry orthoclase crystals an inch or more in length. Plagioclase is characteristically phenocrystic and is distinctly older than the dark-green hornblende and the locally present light-green or nearly colorless pyroxene. Sphene, magnetite, apatite, and zircon are the principal accessory minerals. The groundmass of the rock is composed of orthoclase and quartz, the orthoclase in notable excess and the quartz in general of later crystallization than the orthoclase. All the quartz is specked with inclusions or cavities too small to be resolved by the microscope, but here and there are seen "negative crystals" with the characteristic bipyramidal form of quartz, containing liquid and vapor. Two complete analyses of the rock from Weary Flat are available, one made for Lawson by Herbert Ross,[2] the other made in the chemical laboratory of the United States Geological Survey by R. C. Wells. These analyses are given in tabular form, together with an analysis of typical monzonite by Von Hauer quoted from Brögger.[3]

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[1] Op. cit., p. 309.

[2] Idem, p. 307.

[3] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, pt. 2, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, p. 50, 1895.

Chemical analyses of monzonite from Weary Flat, Nev., and monzonite from Hodritsch, Hungary.

	1	2	3		1	2	3
SiO_2	57.26	61.69	61.73	CO_2	0.04	....	....
Al_2O_3	17.79	17.26	17.45	P_2O_5	.21	0.34	....
Fe_2O_3	3.39	3.53	....	BaO	.07	.10	....
FeO	3.45	1.91	5.94	SrO	Trace.	....	....
MgO	2.02	1.45	2.29	MnO	.29	.09	....
CaO	6.58	5.49	4.52	F	.04	....	....
Na_2O	3.06	3.05	3.12	Cl	Trace.	.03	....
K_2O	4.15	3.88	3.88	Cu	Trace.	....	....
H_2O-	.53	....	....	FeS_2	.13	....	....
H_2O+	.55	[a] .73	[b] 1.16				
TiO_2	.71	....	....		100.27	99.55	100.09

[a] Ignition. [b] Stated as H_2O; probably represents ignition.

1. Monzonite from Weary Flat, Nev. Specimen 35. R. C. Wells, analyst.
2. Monzonite from Weary Flat, Nev. Herbert Ross, analyst. Lawson, A. C., op. cit., p. 307.
3. Monzonite from Hodritsch, Hungary. K. von Hauer, analyst.

Calculations of the mineral composition of the two monzonites from Weary Flat are as follows:

Mineral constitution of monzonite from Weary Flat, Nev.

	1	2		1	2
Quartz	10.00	13.00	Sphene	1.76	....
Orthoclase	24.50	23.00	Magnetite	4.00	....
Albite molecule	24.00	26.00	Calcite and fluorite	.15	....
Anorthite molecule	19.20	22.00	Pyrite	.13	....
Hornblende	15.00	15.00			
Apatite	.51	.65		99.25	99.65

1. Specimen analyzed by R. C. Wells.
2. Specimen analyzed by Herbert Ross.

The plagioclase appears from both calculations to be andesine of a composition represented by about $Ab_{55}An_{45}$, and this is accordant with the determinations by optical methods.

Determinations by the writer of the specific gravity of samples of rock from the Reipetown localities gave an average of 2.71.

As pointed out by Lawson, the rock of Weary Flat corresponds to typical monzonite in its chemical and mineral composition. The present writer selected material for analysis to represent, as nearly as possible, the average monzonitic rock of the several intrusions that occur in the Ely district. The analyses given probably illustrate the full range in the chemical composition of the normal porphyry.

AGE OF INTRUSION OF THE PORPHYRY.

Although the age of the porphyries of the Ely district can not be closely determined, it is probable that they should be assigned to Mesozoic rather than to Tertiary time. It can hardly be doubted that the post-Jurassic warping which affected all of the Great Basin region developed much of the local structure, and it is most likely that the intrusion of the monzonitic porphyries took place during this deformation. The porphyries are thus tentatively correlated with the rocks of similar composition occurring throughout the Sierra Nevada and in the western part of the Great Basin.

VOLCANIC ROCKS.

CHARACTER AND AGE.

Within Tertiary time the general region around Ely, including at least all of northeastern Nevada and adjacent portions of Utah, was the scene of volcanic activity on a truly grand scale. (See p. 22.) Though now less than 10 per cent of the region represented by the Ely map is covered by beds of volcanic tuff and flows of rhyolite lava, there are good reasons for the belief that these rocks were formerly more extensive, and originally they may have formed a nearly continuous mantle over the whole region. It is certain that the existing relief of the Great Basin region has been developed since the volcanic rocks were piled up, and the molding of the topography has undoubtedly involved the removal of these rocks from very considerable areas. Though the rhyolites are mainly developed as truly effusive rocks, they occur locally as intrusive masses, either as narrow dikes or as small stocks. These bodies probably occupy the channels through which the lavas came to the surface.

The rhyolitic rocks present a great variety of types, among which, by comparing the several areas in which they occur, a definite order or succession may be recognized, as follows: White agglomerate and tuff, commonly well bedded; black obsidian or pitchstone; purple or red massive rhyolite; and black to gray platy rhyolite. The age of these extrusive rocks is regarded as late Tertiary, probably Pliocene.

TUFF AND AGGLOMERATE.

The oldest or basal member of the volcanic series is composed of bedded white tuffs with coarse agglomerates in the lower part and finer grained materials above. The coarser beds contain fragments of rhyolite intermixed with volcanic sand composed of small grains of feldspar, quartz, and pyroxene, and the finer beds are composed essentially of fragments of minerals and shreds of pumiceous glass. The nature of these materials indicates clearly that they have originated in volcanic eruptions of an explosive nature. In places the fragmental deposits have a thickness of 30 to 40 feet, and locally there may be fully 150 feet of these accumulations.

The tuffs appear to be rather irregularly developed in the area north of Lane Valley. (See Pl. II, in pocket.) No exposures were noted along the northern or along the southern borders of this area, but uncompacted coarse agglomerate has been revealed by shallow excavations along the east and west sides. Though there are no natural exposures, because of the abundant talus of rhyolite, the tuffs here can hardly reach a maximum thickness of 20 feet. A greater development of the volcanic tuffs is seen in the broad, rolling country in secs. 3, 4, and 34, between the upper part of Robinson Canyon and Lyon Springs. Here the white to gray fragmental materials are distributed over a compact area of nearly 2 square miles within the quadrangle, and they extend for an unknown distance toward the north. They are overlain or perhaps intruded by flows of rhyolite only in the neighborhood of Keystone Hill. Elsewhere they are superficially hidden by products of their own disintegration or by gravelly débris.

About half a mile west of Keystone, where the mine railroad leaves the canyon, coarse stratified tuffs are well exposed in quarry openings, from which considerable rock has been taken out for building and for boiler settings. Here are found abundant fragments of rhyolite, but throughout the western and northern parts of the same general area the tuff is composed of a fine sand made up entirely of subangular grains of feldspar, quartz, and pyroxene, with sharply angular flakes of pumiceous glass.

White tuffs occur locally along the eastern border of the volcanic area which lies between Ruth village and Copper Flat. Here the beds of fragmental material pass beneath the massive rhyolite, which is locally the prominent member of the series. The tuff is composed largely of fragments of rhyolite and at the point of the northeast salient represented on the geologic maps (Pls. II, in pocket, and XI, p. 154), excavations for cellars show it to be a coarse rubble of rhyolite with here and there a few pieces of limestone.

The easterly and southeasterly slopes of the hills northwest of the wagon road which leads from Ruth village to bench mark 7169 are formed by massive rhyolite, but along the base of the ridge the white tuffs emerge and extend more than half a mile toward the southeast. Then comes a short gap, beyond which the volcanic material may be traced to the border of the quadrangle.

In the southwest corner of the quadrangle the white tuffs were not seen at the base of the volcanic series, though they constitute a prominent feature in the upper valley of White River only a short distance away. Specimens of fine-grained tuffs collected on the Monitor claim, which is situated about 2 miles west of the Veteran shaft, are composed of shreds of colorless glass and fragments of quartz, plagioclase feldspar, and light-green pyroxene. Though much of the tuff in this vicinity is entirely uncompacted it is locally cemented by carbonate of lime. Tuffs of this sort must be regarded as accumulations of material from volcanic eruptions of an explosive nature.

OBSIDIAN.

In two localities surface flows of black obsidian or pitchstone immediately overlie the basal tuffs of the volcanic series.

On the west side of the volcanic area north of Lane Valley local exposures extending along the hillside for a quarter of a mile or more indicate the presence of a sheet of the glassy rhyolite from 10 to perhaps 20 feet in thickness. Below this sheet of lava there can hardly be more than 20 feet of tuff, as is inferred from the character of the profile of the hillside, for there are no exposures for some distance below the obsidian sheet, the slope being covered with talus débris from the overlying masses of rhyolite.

The other flow of obsidian which has come under observation may be seen near the railroad spur some distance west of Star Pointer. Here the black, glossy rock lies between the tuffs on the east and the purple rhyolite on the west, and the thickness of the sheet appears to be between 30 and 40 feet. The outcrops are very few, so that the extent of the flow can not be ascertained.

Besides its occurrence in the form of surface flows obsidian is found also as small masses which show intrusive relations. One of these intrusions, situated near the northern boundary of the Copper Queen claim, about 500 yards due north of the Ruth shaft, is perhaps 30 feet in diameter, though it may be somewhat larger. It is surrounded on all sides by porphyry, though no walls are exposed. This glassy rock and the inclusions of shale which it carries have been described by Lawson: [1]

> Under the microscope the obsidian appears as a brownish glass with a well-marked flow structure containing occasional fragments of crystals of sanidine and quartz. Under high powers the glass appears whitish, and the brown color is seen to be due to numerous brownish, irregularly shaped, ragged, or flocculent inclusions.

The shale inclusions were doubtless derived from the black shale formation which lies beneath the Ely limestone, as indicated by Prof. Lawson. Chiastolite and flakes of brown mica are developed in them, both of which have been formed through the effects of thermal metamorphism.

Aside from the occurrences mentioned the only others noted are small dikes. Two of these were observed underground in the Alpha mine on the 1,000-foot level, one in the Old Glory workings on the 350-foot level, and a third is exposed in some shallow excavations on the south slope of Pilot Knob near the Giroux concentrator.

RHYOLITE.

The rhyolites of the Ely district constitute the most prominent feature of the volcanic series. For the most part they occur as surface flows, but in addition to the extruded lavas there are several examples of intrusive masses, most of which are of inconsiderable size. The intrusive rhyolites are supposed, though without definite evidence, to have been essentially contemporaneous with the flows of similar rock, and it appears likely that the flows must have found their way to the surface through fissures and pipes like those occupied by the observed

[1] Lawson A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 350, 1906.

dikes and small stocks. Some of the intrusions may actually have been feeders, though the probability of this supposition can not be strongly urged.

The intrusive occurrences, in so far as they have been discovered, are most numerous in the western part of the mineral belt. On the geologic map (Pl. II, in pocket) are shown the locations of several irregular masses on the westerly slope of the White River divide, and of a dike and a considerable stock which break through the porphyry. These last intrusions have been found in the Brooks and Bunker Hill workings.

About a mile northwest of Copper Flat weathered rhyolite is seen in a shallow pit. This intrusion can hardly have a diameter so great as 20 feet.

A prominent dike of rhyolite in the great pit at Copper Flat is indicated on the map. Its maximum width is about 20 feet. The remaining examples of rhyolite showing definite intrusive relations are very small bodies, one of them situated about a mile southwest of Ely and four others in the high country north of the town.

The extrusive rhyolites occur in five separate areas which are ranged along a northeasterly line extending from the southwest corner of the quadrangle. These rocks comprise two sets of lava—an older and a younger set. The older set is made up of purple or red rhyolite of a generally massive appearance. The ordinary phases of this rock show a dense reddish matrix carrying grains of black quartz and splendent phenocrysts of sanidine (a feldspar closely related to orthoclase). Under the microscope it is observed that many of the quartz grains are badly corroded, though some of them are perfect individuals and exhibit characteristic double terminations. Mica and plagioclase are subordinate constituents. The groundmass ranges from glassy to stony, but invariably presents a semiopaque appearance, evidently due to incipient crystallization.

This type of rock is characteristic of the area which occupies the southwest corner of the quadrangle and it forms the greater part of the series in the area west of Liberty Pit, though White Hill is formed by a younger flow. The massive rock of the same sort is found throughout the area between Copper Flat and the Star Pointer and in Keystone Hill. It also makes up the middle part of the volcanic series in the area north of Lane Valley.

The younger rhyolite is lighter colored than the older and instead of being massive is characteristically thin layered or platy and has a pronounced fluidal structure. Its texture is compact and stony because its degree of crystallization is very incomplete. Examples of the rock examined under the microscope show a glassy matrix colored with minute crystallites, which is interleaved with layers of small spherulites. In the area north of Lane Valley much of the rock carries abundant spherulites, the largest several inches in diameter, and certain layers are characterized by more or less globular vesicles that contain beautifully crystallized deep-red garnets. These garnets are commonly small, but a few of them are a quarter of an inch or more in diameter. Their crystal form is invariably that of the icositetrahedron, but all of them have broad bases of attachment, so that none of the crystals are more than half complete. Some of the vesicles have linings of crystalline quartz and in a few specimens a single brilliant garnet is set in a matrix of quartz, forming a natural gem of rare beauty.

A noteworthy development of spherulitic rhyolite occurs on the north side of Keystone Hill. Here some of the spherulites reach a diameter of 2 feet or more.

The maximum thickness of the volcanic rocks within the Ely district is probably attained in the area east of Copper Flat. Here the massive rhyolite has been dropped down along a fault break which forms the western border of the area and its depth was found to be 468 feet in the Eureka shaft of the Ely Central Copper Co. If the massive rhyolite in this locality was formerly capped over by flows of platy rhyolite, such as appears to the west on White Hill and to the northeast in the Garnet Fields area, the original thickness of the volcanic series may have been about 700 or 800 feet.

To judge from topography alone the total thickness of the volcanic rocks in the Garnet Fields area would seem to be about 400 feet, and in the southwest corner of the quadrangle probably somewhat less. For the rhyolite of the White Hill area Lawson has estimated a thickness of at least 300 feet.

STRUCTURE.

GENERAL FEATURES.

The dominant tectonic features of northeastern Nevada are the meridional ranges and valleys, which were produced by block faulting subsequent to the close of late Tertiary volcanism. Without detailed evidence, but on the basis of analogy with similar ranges throughout the Great Basin region, the Egan Range is regarded as a block elevated with respect to the Steptoe Valley block. Within the range in the Ely district there are important faults of later date than the volcanic rocks, but the formations had been greatly warped and faulted and masses of igneous rock had been intruded into them before the time of volcanic activity, and therefore long before the development of the northward-trending faults, which are predicated to explain the existence of the Steptoe Valley depression between the Egan Range on the west and the Schell Creek Range on the east. The existing structure is therefore the combined effect of at least two, and probably of several, crustal disturbances. As opposed to the orderly arrangement of the master faults which outline the Basin Ranges, the structures within the ranges appear to be very unsystematic and notably out of accord with the meridional structures. This is true both as regards the older structures and the younger faults.

The sedimentary rocks of the district constitute an essentially accordant succession of Paleozoic formations about 9,000 feet in thickness. As shown on the geologic map (Pl. II), the distribution of these formations is very irregular, as a result of numerous faults, but if the area is considered as a whole it is possible to make out a synclinal depression extending southward across the quadrangle from the upper Robinson basin and, flanking this downfold, two rude arches or anticlinals. The arch on the west has a trend of about N. 15° W., as determined from the strike of the formations along its flanks. The other arch, which is only partly included within the quadrangle, seems to have no well-defined trend, but to form an irregular dome. Both arches are greatly complicated by faults.

The sediments are broken by intrusions of porphyry which occur in the form of crosscutting stocks and as sills conformable to the stratification. The crosscutting stocks extend in a definite easterly zone, which is transverse to the general structural trends of the invaded formations, but the sills show a notable tendency to follow the surface of parting between the Ely limestone and the Chainman shale.

In one place or another the volcanic rocks of the district rest on all the Paleozoic formations except the Eureka quartzite and the Pogonip limestone. The topography of the ancient land surface on which these rocks were extruded appears to have been of somewhat lower relief than that of the present.

DETAILED SECTIONS.

In order to give a more concrete idea of the structure of the district the sections shown in Plate II (in pocket) are here described.

Section A–A′.—The general structure of the western arch is illustrated in section *A–A′*. On the left, at the edge of the quadrangle, the lowermost beds of the Arcturus limestone are exposed with southwesterly dips. Then comes a band of Ely limestone a mile wide, broken only by the porphyry stock of Old Glory Hill, and beyond this all the formations down to the Pilot shale. Next there is a stock of porphyry in the flat northeast of Pilot Knob, and beyond this the Nevada limestone, forming the core of the arch. Exposures are not adequate for understanding the details of structure, and the portion of the section in the vicinity of Pilot Knob is very much a puzzle. The backbone of the Pilot Knob ridge is formed by the Joana limestone, which stands vertically, but just south of the knob this massive formation gives place to metamorphosed shales, which are evidently brought into this situation by a cross fault of very considerable displacement. As represented on the geologic map the extension of this fault would intersect the line of section *A–A′*, but no evidence could be found that the boundary between the Ely limestone and the underlying shale formation is displaced by this break.

On the northeast side of the arch, the Joana limestone is downthrown against the Nevada limestone along a southeasterly fault, having a displacement of not less than 500 feet. The limestone is exposed for about a quarter of a mile where it passes beneath a cover of volcanic tuffs. Just within the volcanic area a fault has been represented, as required by the interpretation of the structure northwest of the section, but aside from this the relations of the sedimentary formations beneath the beds of tuff can not be inferred. The limestones which occupy the Robinson Valley above Keystone are very poorly exposed. The beds are greatly weathered and the products of their decomposition are red and yellow marls and clays, like those which are found elsewhere in the areas of the Arcturus limestone. These beds are assigned to the Arcturus formation on the basis of characteristic fossils discovered in loose slabs of limestone about half a mile north of Keystone. In the higher ground northeast of the valley the rocks are massive limestones belonging to the Ely formation.

Section B–B′.—The central syncline of the district and the southerly extension of the western arch are clearly exhibited by section *B–B′*, which gives a suggestion also of the broader arch or dome in the eastern part of the quadrangle. On the left are massive flows of rhyolite which lie on the Arcturus limestone, certain beds of which afford abundant fossils in the vicinity of the section. As the dip is marked toward the southwest, the Arcturus soon gives place to the underlying Ely limestone, the strata of which continue to dip steeply until they are broken by a great fault. In the block beyond this displacement the bedding is nearly horizontal as far as the ridge between White and Rib hills. On the northerly slopes of this ridge exposures are so poor that the structure can not be determined, and the relations along the south wall of the porphyry intrusion of Copper Flat are not actually known.

The line of the section runs near and almost parallel with a fault which crosses the Rib Hill ridge. Though the stratification is nearly horizontal in the block northwest of this break, in the Rib Hill block the beds stand almost on edge and strike at right angles to the line of fault.

On the east side of Copper Flat pit the porphyry is cut out by rhyolite, which has been faulted down against the intrusive rock. Beyond the area of rhyolite comes the Arcturus limestone, which lies in the central syncline, the axis of which is diagonal to the line of the section. Next follows the Ely limestone, which shows a minor syncline in the vicinity of Keystone. In the canyon there is an irregular dike of porphyry.

Northwest of the canyon the structure is largely conjectural, except that the rhyolite flows obviously rest on an old land surface of rather low relief. The porphyry sill has been represented as lying between the Ely and Chainman formations because it appears to occupy this horizon about half a mile southeast of the section in the northern part of sec. 6.

The gravels which occupy the surface in the northeast part of the quadrangle have not been represented in the section.

Section C–C′.—The general structure of the eastern arch of the district is illustrated by section *C–C′*. On the left it shows the beds of fine-grained volcanic tuff in the upper basin of Murry Creek. The western boundary of this volcanic area is in line with the Copper Flat fault, but exposures are too poor to indicate whether the break extends so far to the southeast. To the northeast the beds of the Ely limestone rise gently along the section until they are broken by a fault with an apparent downthrow on the northeast. For some distance beyond this break the strata show considerable folding, but no regularity of structure can be made out. The Chainman formation, which emerges south of Ada Hill, is rather generally metamorphosed and is charged with pyrite wherever excavations have revealed the unweathered rock, except in the southern part of the belt. Natural exposures are rare, and the ground is covered with small rusty fragments of indurated shale.

This strong metamorphism is doubtless related to the crosscutting intrusion of porphyry on the south side of Lane Valley. The porphyry which outcrops on the north side of the valley appears to pass beneath the Ely limestone, which occupies the hill slope above, and to be part of the extensive sill-like intrusion which comes to the surface in the large area north of Lane. The position of the feeder of this sill is not known. Presumably it connects in depth with the stock intrusion which outcrops to the south of the valley. It is noteworthy that to the north of Lane Valley the limestones have not suffered any general alteration as a result of this intrusion. The absence of metamorphism is favorable to the conclusion that the porphyry has the general form of a sill rather than that of a stock.

The right-hand portion of the section shows the uplifting of a great block of the Nevada limestone east of a northward-trending fault, whose displacement is in excess of 1,000 feet. The age of this break is not definitely determinable, but it seems likely that it existed before the porphyry was intruded or was developed at the time of intrusion. This suggestion comes from relations exhibited on the north side of Lane Valley, where the line of the fault conforms with the western boundary of the porphyry mass that lies between the Chainman and Nevada formations.

One of the most striking structural features of the whole district is the block of Ely limestone shown in the eastern part of section *C–C′*. This block has dropped between two blocks of Nevada limestone, the displacement being at least 1,200 feet and probably not less than 1,800 feet. On the east this block is bounded by a third fault, which has cut out all the formations between the Pogonip and the Ely and which consequently involves a displacement of fully 5,000 feet.

On the extreme right the line of the section runs diagonal to the general strike of the strata, which is essentially east. This block is made up of the lower portion of the Nevada formation, as may be seen from the fact that the Eureka quartzite and the shaly beds of the upper Pogonip appear in the northeast corner of the quadrangle.

Section D–D′.—The southwest part of section *D–D′* shows all the formations from the Ely down to the Nevada dipping toward the southwest and away from the great arch. North of the canyon there are two masses of porphyry which are inclosed by Nevada limestone. These bodies of porphyry belong to the principal zone of intrusion, which extends through the district from east to west. Near their contacts the limestone is charged with silicate minerals and with pyrite, and for fully half a mile toward the east the naturally dark limestones have lost their color and are now nearly white.

Structural details in the mountainous country north of the canyon are very obscure, and it seems likely that there is considerable faulting which has not been detected. Throughout the region it is usually impossible to locate exactly faults which are known to exist, by reason of the discordant distribution of the formations and the abnormal changes in strike and dip.

The northeast part of the section shows two faults. The first of these is conjectural, but its existence is probable from the great displacement between the Ely and Pogonip blocks in sec. 4 northwest of the line of the structure section. A short distance beyond this supposed fault the Eureka quartzite appears, dipping strongly toward the southwest. Below it lies a heavy bed of limestone, followed by the fossiliferous shales and massive layers of the Pogonip formation. The second fault is the extension of the one shown in section *C–C′*, on the northeast side of the Ely block. Here it brings the Nevada formation down against the Pogonip beds. In the gulch southeast of the line of the section the position of the break is marked by veins of aragonite.

FAULTS.

Although a large number of faults are delineated on the geologic map (Pl. II, in pocket), several which are not essential to an explanation of the distribution of the formations are omitted. Many breaks which are known to exist can not be traced for any great distance, especially in the areas occupied by the massive limestones of the Nevada and Ely formations. It is believed that there are many other dislocations in those areas which have not been recognized at all. Those faults which have been mapped within the Ely limestone are inferred from discontinuity in stratigraphic relations. In the Rib Hill block, for example, the limestone beds dip steeply to the northeast, whereas on the south the dips are toward the southwest, and in the block to the northwest the beds lie nearly flat.

Along the lines of faulting exposures are lacking as a rule, so that no general statements are possible in regard to brecciation of the walls or in regard to whether the breaks are simple or complex. Veins of aragonite are seen in a few situations which are on known lines of dislocation. Such veinstuff occurs south of White Hill, a hundred yards or so west of the White River divide, and on the east side of the quadrangle in sec. 4, T. 16 N., R. 63 E.

Considered broadly the faults of the district present no orderly arrangement, for they trend in all directions. Very little is known from direct observation in regard to their dips, but in that of the fault at Copper Flat it is toward the downthrown block, conformable to the definition of normal faulting. All the faults are probably of the normal type, and as a rule the fault surfaces appear to stand at steep angles.

In the northwest part of the quadrangle there is a series of six faults arranged somewhat in the shape of a fan opening toward the west and northwest. These breaks are recognized from the erratic distribution of the Ely, Chainman, Pilot, and Joana formations. From Pilot Knob to the first fault the Joana limestone stands on edge, whereas in the block beyond the break it dips about 60° W. The displacement increases toward the northeast and diminishes toward the southwest, the change being so abrupt that the boundary between the Chainman shale and the Ely limestone is not offset. Beyond the second fault the strata are again less strongly tilted, and also as before the break is a scissors fault whose displacement increases toward the center of the fan. The remaining faults of the series, Nos. 3 to 6, are essentially strike faults. The third fault shows a minor upthrow on the east, but the others are all thrown down on the east.

On the south side of the canyon west of Ely a set of faults displaces the Ely limestone and the three formations below it. These formations lie on the flank of the eastern arch of the district, which takes on a domelike character in this vicinity. West of Murry Creek, on the slopes of the mountain facing Steptoe Valley, the Ely limestone dips steeply toward the east, but in the block beyond the first break, it dips at slight angles toward the south, except in the knob on the 7,000-foot contour, where the dips are steep toward the southeast. The second fault diverges from the first at the mouth of the canyon, but finally turns and runs parallel with it. The throw of both faults is upward on the west, and both show a diminishing displacement as they are followed toward the south. The remaining faults of the set bring the formations down in three steps. Fault No. 3 may be recognized on the south wall of the canyon.

The fault which is mapped as extending with a northerly course through the Nevada limestone areas in secs. 9 and 4, T. 16 N., R. 63 E., is inferred from discordance of dips on the two sides of Calumet Gulch. Along its course there are two small dikes of rhyolite which are shown on the map, and a minor intrusion of porphyry which is not shown. Although this fault is probably one of rather large displacement, there is no evidence of its existence on the divide at the head of the gulch. Where it cuts the Eureka quartzite this formation is tilted on edge.

Faults are mapped in sections 4 and 33 in the eastern part of the quadrangle to account for the distribution of the formations. Fossils characteristic of the Ely limestone are found on the hill rising above the 7,350-foot contour, and the Chainman shale outcrops along the base of the mountains farther north and dips toward the west. This block of Ely limestone must have been dropped not less than 1,200 feet against the Nevada limestone blocks on either side, and on the east a displacement cuts out not less than 5,000 feet of strata.

On the north side of Lane Valley opposite the town there is complicated faulting which has not been fully deciphered. The geology of this area as shown on the map is considerably generalized. The disorderly attitudes of the strata are probably the result of the intrusion of the bodies of porphyry on both sides of the disturbed area. There remain for discussion the faults which have been mapped in the portion of the district adjacent to Copper Flat. The geology of this neighborhood, and especially that of the country north of the railroad, is very puzzling, because it is impossible to fully establish the identity of some of the formations and because the distribution of the different sorts of rocks is in part greatly obscured by a high degree of metamorphism and in part hidden by loose débris, which has been washed over the surface.

The fault which limits the ore body on the east is well exhibited in the Copper Flat pit, where it brings the rhyolite down against the intrusive mass of porphyry which constitutes the ore. The dislocation shows a definite break accompanied by minor spurs, and the main fissure is filled with a claylike gouge which contains fragments of rhyolite and in places considerable ground-up ore. The dip of the fault surface is very irregular, but from its position in the

Ely Central shaft, at a depth of 468 feet, its average inclination toward the east is known to be about 30°. The throw of this fault is judged to be not less than 500 feet. Aside from the manner in which the rhyolite and tuff are thrown down against the porphyry and against the Ely limestone a dislocation of considerable importance is indicated by contracting strikes and dips of the strata in the Rib Hill block and in the block which lies east of the Copper Flat fault.

The rhyolite in the White Hill area appears to indicate a downthrown block between two faults, which come together just north of the Liberty Pit. This block appears to be tilted toward its easterly apex. The more northerly fault appears to dip toward the south, but the other break stands nearly vertical, as is shown by a study of the cuttings from a series of drill holes along the north side of the Westphalia claim. The extension of this fault toward the southwest is indicated by an aragonite-bearing vein, situated south of the wagon road, a short distance beyond the White River divide. Its extension toward the northeast to meet the Copper Flat fault is entirely conjectural, and in the absence of exposures the supposed boundary of the porphyry intrusion has been represented without indicating any offset where it meets the line of the supposed fault. In the area beyond the Copper Flat fault it seems necessary to accept the existence of a very considerable dislocation in order to explain the contiguous outcrops of Arcturus limestone on the southeast and on the northwest of shales and associated limestones, which belong several thousand feet below the Arcturus formation. About 700 feet north of the railroad a division of this break is represented, one line of dislocation being shown as trending northeastward and the other northward. The fault running northeast is introduced to account for the occurrence of characteristic Arcturus beds with dips of 70° SE. on the ridge east of the railroad, and of nearly horizontal Ely limestone beds wherever there are exposures on the ridges west of the track. There is little reason for doubting that there is a fault between the Arcturus and the Ely limestones, but the position of the break is not actually known, and its representation on the map is therefore arbitrary. The north-trending fault is required to account for the otherwise anomalous distribution of the Chainman shale and the Nevada limestone in the vicinity of the wagon road that runs east and west half a mile north of Copper Flat.

In the structural block which lies west of the north-trending and the southwest-trending fault the identification of the formations is somewhat doubtful. The limestone which appears in the railroad cutting near the station at Copper Flat dips rather steeply toward the southwest and outcrops as a band about 250 feet wide for nearly three-fourths of a mile toward the northwest. If this is the Joana limestone, and if there is no important dislocation parallel with the strike, the shale on the southwest must be the Chainman shale, that on the northeast the Pilot shale; and the tongue of limestone beyond the Pilot area the Nevada limestone. This interpretation, which is the simplest of several that suggested themselves, necessitates a fault to terminate the band of Joana limestone upon the northwest.

STRUCTURAL RELATIONS OF PORPHYRY INTRUSIONS.

The principal zone of intrusion from east to west lies across the axial trends of the broad structures of the district, and these structures have been modified only to a moderate degree by the injection of the igneous material. It is believed that the intrusions occurred after the rocks of the region had been considerably warped and probably after some of the faults had been developed.

The porphyry mass north of Lane appears to be a sill, that is, an intrusive sheet following the bedding of the invaded formations. Only the upper part of the sill has been exposed by erosion, so that its thickness can not be determined, but the remnants of the original limestone roof have such attitudes that the overlying rocks can hardly have been sharply arched above the intrusive mass, as they would have been above a typical laccolith, and it is likely that the thickness of the body is less than 1,000 feet. Though the porphyry mass crosscuts the sedimentary formations locally, in general the intrusion appears to follow in a rude way the parting between the Ely limestone and the underlying Pilot shale. Toward the northwest, in sec. 35, the edge of the porphyry lies only about 1,600 feet from the top of the Ely limestone, as shown on the geologic map (Pl. II). Obviously the full thickness of the Ely formation, which is believed to be not less than 2,500 feet, can not be present between these two boundaries, so that the existence must be assumed of structural features which have not been worked out.

The general parallelism of the Ely beds with the upper surface of the intrusion is well exhibited along the contacts which rise from Lane Valley toward Elijah Hill, and to the east and northeast. The actual contacts are obscured by accumulations of talus, but the beds of limestone undulate with the irregularities in the upper surface of the porphyry.

As the material of any intrusive sill has necessarily been derived from a deep source, it follows that aside from faulting such a mass must have a connection with that source by means of a cross cutting body. Other things being equal the greatest possible alteration connected with the intrusion of a magma may be expected to occur near those parts of the rock that have the most direct connections with the igneous hearth or reservoir, and the least metamorphism should take place adjacent to parts of the mass that are remote from or indirectly connected with the magmatic reservoir. In the sill here discussed the main feeder, and probably the only one, is to be sought along the north side of the principal zone of intrusion, which trends diagonally across Lane Valley. In this locality the limestones and shales adjacent to the sill of porphyry show a considerable degree of metamorphism, and the porphyry itself has been in part greatly altered and charged with pyrite. Toward the north, however, there is an abrupt decrease in the intensity of metamorphism, and in secs. 6 and 36 the invaded rocks are practically free from alteration and the porphyry is unchanged, except by weathering.

As regards the principal zone of intrusion, the suggestion that direct connection with the source of supply is favorable to maximum metamorphism in and around igneous intrusions would lead to the expectation of finding the porphyry bodies of this zone to have, in the main, crosscutting relations with the invaded sediments. This is in a general way true, though locally where the sedimentary rocks are highly inclined some of the intrusive bodies follow the stratification. Examples of this relation occur on the north side of the valley opposite the Joana tunnel and to the north of Pilot Knob. On the east the intrusive masses are surrounded at the surface by Nevada limestone; south of Lane the porphyry body occurs in the midst of Chainman shale; the two large masses to the west penetrate the next higher formation, the Ely limestone; and just east of the rhyolite area there are minor dikes in the Arcturus limestone. Thus from east to west there is a marked transgression from lower to higher formations and therefore in general a crosscutting relation along the trend of the intrusive zone, as far as the northward trending syncline. Beyond the syncline the beds adjacent to the Copper Flat and Weary Flat intrusions are lower in the stratigraphic column, but toward the west there is again a gradual transgression to higher horizons.

So far as mining operations and exploration by drilling have afforded information, the walls of the porphyry intrusions stand at rather high angles as a rule, though locally there are great irregularities. In the Ruth mine, at the shaft, the contact of the porphyry with the sediments which lie to the south and southeast is inclined about 45° NW., but 1,000 feet to the west, within the Kearsarge claim, the relative positions of the wall at the surface and underground show it to be nearly vertical. Essentially vertical walls are indicated also by drill hole on the Minnesota and Butcher Boy claims of the Copper Mines Co., and by the position of porphyry contacts in the underground workings from the Minnesota shaft. At the Copper Flat pit the south wall of the intrusive mass dips steeply toward the north, but the north wall, which is less well exposed, appears to stand nearly vertical. This intrusion occupies a prominent dislocation break between a south block of Ely limestone that dips steeply toward the northeast, and a north block of limestone and shale which dips toward the southwest. West and north of Liberty pit the continuity of this body of porphyry is broken by the downdropped block of rhyolite, and as already stated its northern boundary can not be accurately determined in the vicinity of the fault.

The Weary Flat intrusion and the smaller one situated north of Pilot Knob represent a branching of the principal zone of intrusion. Both of these bodies are surrounded by aureoles of metamorphism and in many places the igneous rock itself carries films of pyrite, from which it may consistently be inferred that these masses had direct connection with the general magmatic reservoir. Discordance of structure in the sedimentary formations also indicate definitely crosscutting relations of the invading rocks. This discordance is apparent from the presence of Nevada limestone north of the porphyry area, the strikes of which trend from southeast to northwest, the occurrence of the Chainman formation on the east and west, and the failure of the two intervening formations to appear anywhere in juxtaposition with this intrusive mass. The smaller body appears to crosscut the formations in the southeastern part of the area, but on the north to wedge out along the parting between the Nevada limestone and the overlying shale.

Excavations along the northern boundary of the Weary Flat intrusion indicate that the wall stands nearly upright. A steep contact is also visible on the Lexington claim, at a shaft in heavily pyritized shale just north of the wagon road near the center of sec. 8. In the Butte-Ely Gulch crosscutting relations are indicated by the fact that the porphyry boundaries are transverse to the general strike of the stratified rocks.

In the western part of the main zone of intrusion the difficulties in the way of determining the structural relations of the porphyry bodies are even greater than elsewhere. As the invading and the invaded rocks are not only highly metamorphosed but strongly weathered as well, and as the rocks are largely concealed by mantles of rock waste, details of distribution can be worked out only imperfectly from surface observations, and the trends and dips of stratification are not locally determinable.

The mine workings and drill records show that the porphyry which occurs between the Bunker Hill shaft and the Old Glory shaft is a tabular mass, locally divided by included slabs of country rock. The maximum width of the porphyry mass is about 650 feet between Bunker Hill and Brooks shafts, and it appears to dip toward the southwest. The attitude of the hanging wall can not be adequately determined from data at hand, but the footwall in the Brooks and Morris workings has an inclination of about 50°. In the Morris mine, where the porphyry is separated by limestone inclusions, hanging walls in two places were observed to dip 60° and 65° SW. In the Old Glory mine, where porphyry bodies are present on all five levels, their walls are either nearly upright or inclined rather steeply toward the southwest. The attitude of the invaded rocks is in general indeterminate. Even in the Old Glory workings, which are largely in metamorphosed limestone, the bedding is almost entirely obliterated. Indications of stratification that were observed suggest northwesterly strikes and southwesterly dips, so that it is probable that the Bunker Hill and Morris intrusions follow more or less closely the stratification of the steeply upturned Ely formation.

Little can be made out concerning the structural relations of the porphyry which outcrops on Old Glory Hill, but its compact area and irregular outline suggest a generally crosscutting relation to the invaded rocks, which are so fully altered and so poorly exposed that their bedding can not be recognized. Only on the 1,000-foot level of the Alpha mine, and in the Old Glory adit, can the attitude of the sedimentary rocks adjacent to this intrusive mass be observed. The most northerly point attained on the 1,000-foot level of the Alpha mine lies approximately 150 feet south of the outcrop of the porphyry wall. Here the bedding of the metamorphosed limestone strikes northwest and dips about 40° SW. On the surface the porphyry boundary also strikes approximately northwest, but the wall evidently does not conform to the stratification, for if it did the porphyry would be present in the Alpha workings. In the Old Glory adit distinct lamination is observed in metamorphosed and fully weathered material, which lies between a mass of porphyry 200 feet wide and the porphyry exposed at the breast of the tunnel. The contact of the last-mentioned mass of porphyry is situated a short distance west of the porphyry edge as seen on the surface. In the tunnel the contact dips steeply toward the southwest, and the relative positions of the wall here and on the surface correspond with this observation.

In the vicinity of the Veteran mine the structural relations of the intrusive porphyry are obscure. Not only is the area occupied by the rock very imperfectly known but in the mines it is impossible in places to distinguish the altered igneous rock from other materials. The mass, however, appears to be a stocklike body of irregular shape somewhat broken by inclusions of country rock. Its axis is inclined toward the northwest, in which direction the body plunges beneath massive jasperoid. On the working level of the mine the contact between the porphyry and the jasperoid lies about 320 feet to the northwest of and about 370 feet below the position which it occupies at the surface.

The extent and intensity of metamorphism in this neighborhood are especially notable in view of the small area occupied by the porphyry. Although the area of the outcrop is less than 10 acres, the porphyry is flanked on the southwest, west, and north by about 70 acres of jasperoid, that has been produced by the silicification of limestone.

METAMORPHISM.

PROCESSES OF ALTERATION OF THE ROCKS.

The transformations and changes of constitution which the rocks of the district have undergone will be described and discussed under the general head of metamorphism, two very different kinds of which are distinguished. Under igneous metamorphism are embraced all those alterations which attended and followed the intrusion of the monzonite porphyry. These alterations affect both the invaded limestones and shales, and also to a very noteworthy extent the igneous rocks themselves. To this kind of metamorphism is to be attributed the formation of primary metalliferous deposits which occur in various relations throughout this district. The second kind, atmospheric metamorphism, includes weathering, or decomposition and leaching by oxidizing surface waters; and cementation, or changes involving the deposition of material taken in solution during the process of weathering. The enriched copper ores of the district have resulted from the decomposition of sulphides and the solution of copper in the zone of weathering, and the redeposition of the copper as chalcocite on the primary sulphides in the zone of cementation.

IGNEOUS METAMORPHISM.

METAMORPHISM OF THE LIMESTONES.

General character.—Noteworthy alterations of the sedimentary rocks of the district are practically confined to the vicinity of the porphyry masses along the principal zone of intrusion. The limestones which are present in this zone are those of the Nevada, Joana, Ely, and Arcturus formations, and in different localities all of them have suffered more or less intense alteration.

No constant differences in the metamorphic products of the several limestone formations are noted; all of them seem to have been equally susceptible to alteration. In any locality the degree of alteration usually increases with the proximity of the igneous rock, but in different places the width of the altered aureole may be narrow or wide. In places essentially unaltered limestone occurs within a few hundred feet of an intrusive mass but elsewhere marked alteration extends fully half a mile from the igneous rock.

The principal changes affecting the limestones comprise: (1) Simple crystallization accompanied by loss of color, which results in white fine-grained marble; (2) silicification, or metasomatic replacement by silica, which yields jasperoid; (3) the development of lime-bearing silicate minerals; (4) the formation of bodies of pyrite or of pyrite and magnetite.

Alteration to marble.—Marbleization is extensive in the eastern part of the district, where limestones belonging to the Nevada formation are rather steeply upturned and intruded by masses of porphyry. On the south side of the canyon the limestones exhibit their usual dark-drab hue, but on the north side they have lost their coloring and have been very generally marbleized within a band about half a mile wide, which extends toward the east nearly half a mile beyond the most easterly outcrop of porphyry. Extensive alteration of the same sort occurs within the area occupied by Nevada limestone to the north of Weary Flat. Here silicate and jasperoid alteration occurs locally along the immediate boundaries of the porphyry intrusions, and a compound set of jasperoid reefs outcrops on the northwesterly trending ridge in the eastern part of the Nevada limestone area. Elsewhere within an east to west zone, half a mile in width, the limestone is very generally whitened and crystallized, the alteration becoming less marked as the distance from the porphyry area increases. Simple marbleization affects less extensive areas in the Ely limestone, though such alteration is noteworthy in several localities, particularly to the south of the upper end of Lane Valley and near the Boston-Ely shaft.

In this sort of alteration the only ascertainable change of composition is due to the elimination of the carbonaceous material which gives the blue to nearly black colors to the unaltered limestones of the district. The process by which the carbonaceous material has been removed is not understood, but its elimination may have been effected in some way by heated waters which permeated the rock and caused its crystallization.

Alteration to jasperoid.—The name jasperoid, proposed by Spurr,[1] is here used for material which consists essentially of quartz deposited in metasomatic replacement of limestone. In view of the fact that the term jasperoid has been long in use it is here given preference over "blout," which has been employed by Lawson in his discussion of the geology of the district.[2] The two terms are not exact equivalents, as blout is used for bodies of siliceous material which are regarded as replacement products of porphyry as well as for silicified limestones.

In this district the jasperoids in their unoxidized condition usually carry considerable pyrite, and in places they contain chalcopyrite as well. The silica takes the form of quartz as a rule, though chalcedony is common either in fractures or more generally filling interspaces which are thought to be due to incomplete occupation of the original volume of the limestone by the first formed replacing minerals. On the other hand, in some occurrences the jasperoid is composed largely of chalcedony. In any specimen the quartz grains are apt to be of uniform size, and most of them are very small, so that the jasperoids are characteristically very dense. The quartz invariably exhibits minute cavities, which though empty as a rule may exceptionally be partly filled with a liquid. In some specimens also the quartz grains contain small inclusions of fluorite, apatite, and calcite. In certain material from the Veteran mine brown to green mica is abundant in seams or distributed through the mass of the siliceous rock. This mica carries fluorine. The sulphide minerals occur both in seams and bunches and disseminated through the rock as grains or as irregular aggregates weaving in and out among the grains of quartz.

The jasperoids present prominent rusty outcrops from place to place throughout the central zone of metamorphism. The principal occurrences are contiguous to masses of porphyry, but in places this sort of limestone replacement is found well away from exposures of the igneous rock. Outlying jasperoid masses are commonly more or less reef-like in form, and some of them are walled by essentially unaltered limestone. In the eastern part of the district there is considerably less jasperoid than in the central and western parts.

Alteration to calcium silicates.—Metamorphism of limestones involving the formation of silicate minerals may be observed in many places within the general zone of igneous alteration, generally in close association with intrusive bodies of porphyry, but in several places well away from the boundaries between areas of the sedimentary and igneous rocks. Silicate alteration of limestone is not so important as jasperoid alteration. The principal localities where garnet has been deposited on a large scale are in the vicinity of Jupiter Ridge, south of Lane Valley, and in the valley of Ruth Gulch, east of the Ruth shaft. The minerals which occur as metamorphic products in limestone include white and brown mica, tremolite, pyroxene, epidote, scapolite, garnet, pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, molybdenite, quartz, magnetite, and hematite. Of these the most common are garnet and tremolite among the silicates, pyrite and chalcopyrite among the sulphides, and quartz and magnetite among the oxides. The presence of silicate alteration is somewhat obscured by the rusty nature of weathered material in places where sulphide minerals were originally present.

Bodies of pyrite and magnetite in limestone.—Throughout the Ely district pyrite, commonly with associated chalcopyrite and magnetite, is an essentially constant component of the products of igneous metamorphism. Wherever the porphyries have suffered sericitization, wherever the shales have been essentially altered, and wherever the limestones have been jasperized or

[1] Spurr, J. E., U. S. Geol. Survey Mon. 31, pp. 219-220, 1898.

[2] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 324, 1906.

changed to garnet or tremolite, pyrite is more or less regularly disseminated through the mass of the rock and locally segregated in seams and in nests of minor size. Chalcopyrite and magnetite, though not ubiquitous, are common, the chalcopyrite in altered igneous and sedimentary rocks alike, the magnetite more characteristically in the altered sediments. The metallic minerals thus generally distributed may be rudely estimated to comprise from 5 to 10 per cent by weight of a very great bulk of the altered rocks.

In addition to the great masses of altered rock that carry disseminated pyrite, chalcopyrite, and magnetite, there are a few deposits in which the metallic minerals are more closely segregated. The deposits of this sort have not been fully explored, so that little is known concerning them. Fuller information may lead in the future to the recognition of several types among the deposits which are here considered together.

In the eastern part of the district, on the south side of Robinson Canyon, a considerable mass of brown iron oxide has been explored by short tunnels situated on the east side of the prominent knob of Joana limestone, which rises above the 7,100-foot contour in the NW. ¼ NE. ¼ sec. 20, T. 16 N., R. 63 E. The deposit has a maximum observed thickness of about 30 feet and appears to be a tabular mass, conformable to the stratification, which lies betweeen the Joana limestone and the subjacent Pilot shale. Portions of the material in the upper part of the bed are rather siliceous, but for the most part the material is rather dense limonite. Although the compactness of the material gives it a different appearance from the usual type of limonite derived from the oxidation of pyrite, it seems more likely to have been formed in this way than in any other which might be suggested. If the inference is correct the original pyrite body, which would seem to have been nearly free from gangue, must have been formed as a result of metasomatic replacement of limestone or of shale. The neighboring rocks are not notably metamorphosed, but in the general vicinity there are a few jaspery veins and gash fillings which carry copper carbonates where they have been opened by shallow prospects.

On the south side of the canyon at the lower end of Lane Valley a large mass of spongy brown iron oxide comes to the surface on the Joana claim. This material is undoubtedly gossan derived from pyrite. The adit which connects with the Aultman shaft passes through it for a distance of 190 feet, then through white marble for 120 feet, and through another mass of gossan for a distance of more than 300 feet. The shape of these bodies of limonite has not been determined. The limonite is reported to carry a little gold and many years ago a pocket of rich ore occurring at the outcrop was worked out.

On the north side of the valley east of Lane somewhat similar gossan has been explored on the Great Western claim, where the original pyrite constituted a replacement of Joana limestone.

Just north of Lane, on the Commodore claim, a body of limonite forms a bed deposit at the base of a mass of limestone which is underlain by shale. This limestone is regarded as the Ely limestone. It is sufficiently evident that the layer of limonite, 8 feet or more in thickness, is the oxidized product of an original mass of pyrite, but it is not evident whether the sulphide replaced the limestone or the underlying shale.

Just west of Copper Flat station irregularly shaped masses of gossan may be noted in the otherwise unmetamorphosed Joana limestone, which is well exposed along the tracks of the Nevada Northern Railway, and somewhat similar masses occur in the same formation north of the railroad on the Sunbeam and Clipper claims. On the Clipper claim the gossan gives place to partly oxidized massive pyrite within 30 feet of the surface. In close proximity to the body of sulphide there are irregular reefs of ferruginous jasperoid.

In the western part of the district a smaller number of heavy sulphide deposits are known, though many may exist which have not been discovered. The most prominent occurrence of nonsiliceous gossan west of Weary Flat is on the Reipe claim, where a shaft sunk through spongy limonite penetrated a heavy mass of pyrite. A diamond-drill hole, which was put out under this shaft from the Old Glory 300-foot level, is reported to have disclosed a large mass of nearly solid pyrite.

The only gossan bodies which have been at all extensively explored are those which were found in sinking the Alpha shaft of the Giroux Co., and here, though the several levels have been opened down to a total depth of 1,200 feet, the workings are not adequate to fully show the shape or attitude of the masses. On the surface near the Alpha shaft there are a few small outcrops of rusty jasperoid, more or less stained by copper minerals, but there is no exposure of nonsiliceous gossan in the vicinity. The shaft penetrated crumbly weathered jasperoid, and below this passed into a heavy body of rather massive limonite. The bottom of this limonite lay some distance above the 500-foot level, where a drift toward the south-southwest passed into similar material 200 feet from the shaft and continued in it for somewhat more than 100 feet before encountering a hanging wall. The same body was reached 250 feet from the shaft, on the 600-foot level, where it had an apparent width of 110 feet.

On the 710-foot level the shaft penetrates a second body of limonite, and the same material extends along the drift 200 feet toward the south and then 150 feet toward the southwest, where a footwall was encountered, the dip being to the east or southeast. This wall extends along the drift to a point more than 600 feet distant from the shaft. The hanging wall is nowhere exposed. What is apparently the same body of limonite was opened again on the 1,000-foot level and was followed north of the shaft for 200 feet and to the south for 100 feet. On and above this level the gossan gives place locally to rich copper ores, which continue to the bottom of the mine 200 feet below.

The limonite masses can hardly have been derived otherwise than from bodies of pyrite, which probably were replacement deposits in the limestone. The completeness of oxidation to a depth of 1,200 feet is worthy of remark.

Two occurrences of magnetite are to be noted. One of these was developed several years ago by a shaft on the Josie claim about half a mile west of Copper Flat station. The form and attitude of this mass of mineral is not known. The material observed on the dump is composed largely of magnetite with an intermixture of green copper minerals in amounts sufficient to make an ore of attractive appearance. On the geologic map of the district this locality is shown as surrounded by Chainman shale, but there are no outcrops, and the country rock may be limestone.

The other body of magnetite occurs north of the Giroux concentrator on Pilot Knob. Here there are some heavy outcrops of almost solid magnetite interspersed with spongy limonite, rusty jasperoid, and showings of copper carbonate, forming in the aggregate a lode or reef about 100 feet wide and nearly 400 feet in length from east to west. Though the deposit is very poorly exposed and has not been sufficiently explored to reveal its unweathered portions, it is evident that it originated through the replacement of limestone. It occurs at the south end of a long ridge, where beds of the Joana limestone standing in vertical position are cut off by a fault that trends nearly due east, so that they abut upon a body of shale.

METAMORPHISM OF THE SHALES.

Within the principal zone of intrusion the carbonaceous and limy shales of the Pilot and Chainman formations were rather generally converted into pyritiferous hornstones as a result of igneous metamorphism, very moderate alteration being observed, however, on the west side of the Weary Flat intrusion of monzonite porphyry.

As a whole the shales appear not to have received important additions of silica, as did the metamorphosed limestones, but they have been greatly enriched in sulphur, perhaps considerably enriched in iron, and, locally at least, have received additions of copper. Pyrite is a constant constituent of the altered shales, and the oxidation of this mineral results in rusty outcrops as a characteristic feature.

In the eastern part of the district the shales of the Chainman formation have been intensely altered on the north side of the valley east of Lane and on the south side of the valley west of Lane, in the vicinity of the Saxton shaft, and toward the west as far as outcrops of the formation extend. Unweathered material is found at very few localities so that no comprehensive study of the altered shales is possible. Under the microscope, specimens of dense hornstone from the dump of the Revenue shaft are found to be composed of felty or finely granular wollastonite, epidote, calcite, pyrite, and magnetite, and specimens of baked shale from a shaft on the Queen of the West claim, about three-eighths of a mile northwest of the Saxton shaft, contain quartz, epidote, pyroxene or hornblende in process of alteration to serpentine, and much pyrite.

Although the shales are generally altered in the country south of Lane Valley, the intensity of the metamorphism decreases notably as the distance from the axis of the principal zone of intrusion increases, so that in the southern part of the shale area southwest of the Saxton shaft the only noteworthy change in certain beds of black shale is a strong impregnation with pyrite. Such material may be seen at a prospect situated east of the wagon road west and a trifle north of the center of sec. 13. On the ridge just east of this locality limy beds in the shale have been altered to a dense garnet rock, though the overlying Ely limestone is not essentially metamorphosed.

The gold ores of the Chainman, Aultman, and Revenue mines come from a blanket deposit which occurs between the Joana limestone and the overlying Chainman shale. This relation and the moderate alteration of the shales in the vicinity indicate that the ores were thus localized because the shales, which are relatively impermeable, caused the deflection of the metamorphosing and ore-depositing solutions along this stratigraphic horizon.

In the western part of the district the shales do not exhibit the more intense phases of metamorphism over extensive areas, except in the vicinity of the Copper Flat intrusion of porphyry and adjacent to the portion of the Weary Flat intrusion which extends south into Butte-Ely Gulch. In Butte-Ely Gulch considerable doubt exists regarding the identity of the Chainman shale and the Ely limestone, so that in mapping a line has been drawn arbitrarily to represent the boundary between the two formations. If this line represents the distribution of those formations approximately, considerable masses of the shale have been converted into jasperoid, but in view of the existing uncertainty in regard to the actual structure this point must be left in doubt.

Material from a pit on the Oro claim just south of the Nevada Northern track and about 1,200 feet north of the edge of the Copper Flat intrusion furnishes the only information at hand concerning the mineral composition of the more intensely altered phases of the shale in this part of the district. The rock is a very fine grained aggregate of quartz and white mica (sericite), with a little zoisite, a few flakes of brown pleochroic mica and a little calcite. Limonite distributed through the rock represents formerly existing pyrite.

Though no material of economic value has been developed within the shale areas lying north of the Copper Flat intrusion and east of the Weary Flat area of porphyry, several shallow shafts and a few drill holes show that the shales carry a truly tremendous amount of distributed pyrite. In prospecting by means of churn drills on the Peacock claim considerable masses of iron sulphide were penetrated and material from certain horizons is reported to have given assays showing 1 per cent of copper.

The pyrite-bearing shales occur contiguous to the principal zone of intrusion and, though the rocks retain their original drab to black color, their pyritization is undoubtedly an effect of igneous metamorphism. The solutions which effected this metamorphism appear to have come, not from the porphyry masses now exposed, but from a much deeper seated source, which contributed heat, water, and substances such as sulphur and copper, and probably iron, long after the igneous rock had become fully crystalline.

At several localities near Reipetown the porphyry contains considerable pyrite, deposited in joint cracks, and to a certain extent disseminated through the rock adjacent to such cracks. Along the eastern side of the porphyry mass much stronger pyritization may be inferred from the rusty nature of the weathered products, which are here entirely distinct in character from the gravelly material which covers the surface in places where the porphyry has not been essentially metamorphosed. In correspondence with the foregoing observations, there is a very marked difference in the amount of introduced material in the shales on the east and west sides of the Weary Flat intrusion. On the east, where the igneous rock itself is heavily charged with pyrite, the shales adjacent to the contact are heavy with the same mineral, but on the west, where the porphyry carries almost no pyrite, the shales next to the intrusive mass carry little iron sulphide. The pyritization of the shales was thus probably contemporaneous with that of the porphyry of Weary Flat and therefore much later than any direct and immediate effects which this igneous mass may have exerted on the sedimentary rocks.

The lack of strong alteration is especially noteworthy in the shales along the western border of the Weary Flat area of porphyry, where a drill hole (No. 22 of the Giroux series) situated about 50 feet from the edge of the porphyry encountered drab shale which is not at all indurated and which carries very little pyrite. Farther north along this boundary, in a shaft near the center of the west side of the Lexington claims, heavy masses of pyrite have been penetrated.

Impregnation with pyrite without the development of silicate minerals is a feature of the black shales of the Chainman formation near Veteran village. These shales are well exposed in a railroad cutting on the summit between Kimberly and Veteran, though here they carry less pyrite than is shown by material from drill holes situated west of the cutting on the Blue Jacket claim.

The Pilot shale is not extensively metamorphosed adjacent to the porphyry mass which lies north of Pilot Knob, but material on the dumps of the Taylor shaft shows much pyrite, and specimens of dense hornstone are found to consist mainly of granular pyroxene and a little quartz and calcite.

METAMORPHISM OF THE PORPHYRY.

Nature of the alterations.—Examination of different types of metamorphosed porphyry shows that although much of the rock is greatly seamed by quartz and sulphide-bearing veinlets, or by films of pyrite, other portions are quite or nearly free from such infillings; yet both sorts of material are thoroughly altered in bulk, and generally highly impregnated with pyrite accompanied by chalcopyrite. The solutions which caused the alteration were so penetrating that after being metamorphosed large masses of porphyry, essentially lacking in fracture fillings, carried chalcopyrite in such quantities that a slight enrichment has been adequate for their conversion into commercial ores. However, the content of chalcopyrite in the metamorphosed porphyry is ordinarily higher where the rock was considerably crushed and filled with quartz prior to its complete alteration than where the only alterations are those due to permeation of the rock. Perhaps also the rock minerals have undergone, in general, somewhat more complete alterations where vein stuff occurs than elsewhere. All occurrences considered, the order of the mineralization seems to have been: (1) Permeation of the rock by solutions capable of producing alteration; (2) formation of veinlets, usually of quartz or quartz with a little orthoclase and biotite mica carrying distributed pyrite and chalcopyrite. Some of the veinlets carry a medial film of pyrite, the formation of which corresponds closely with (3) the deposition of pyrite films in joint fractures. These three sorts of mineralization may be observed together in material from the open pits of the Nevada Consolidated Co., from the Butte-Ely shaft, and from the porphyry mines of the Giroux Co. In other material from the same localities and from the Veteran mine the first and second alterations are noted without the third; in material from Weary Flat and from the Eureka shaft on the Ely-Central property, the second and third alterations are most prominent, and in material from the McDonald-Ely shafts in the eastern part of the district alterations which seem to be related to the third class are mainly in evidence.

It will be understood that strict classification in accordance with this outline is not feasible because the succession of processes, though doubtless progressive on the whole, may have overlapped in detail.

All phases of mineralization have involved metasomatic changes through the mass of the porphyry. These changes are incipient or least marked in material which is seamed with pyrite films but not veined with quartz. Such moderate alteration may be observed in porphyry from several shallow openings near Reipetown, and from shafts on the McDonald-Ely property. In specimens of slightly altered rock the only noteworthy differences from entirely normal porphyry are the presence in the groundmass of a few grains of calcite and a little pyrite, and in one slide a few grains of chalcopyrite and a little epidote. Other specimens, when considered together, show progressively increasing changes which principally involve the groundmass of the rock, but also extend to the plagioclase crystals and exceptionally to the large phenocrysts of orthoclase. Alterations of the groundmass and of the plagioclase may or may not proceed hand in hand as to degree for some specimens exhibit considerable development of sericite in the plagioclase though the hornblende of groundmass is essentially unchanged; others exhibit a reverse relation; and still others show alteration of both plagioclase and hornblende.

The least alteration involves on the one hand the development of sericite in the plagioclase, usually in the central or more calcic part of the crystals that show zonal growth, and on the other hand incipient decomposition of hornblende and the formation of epidote or chlorite. Such alteration of hornblende is commonly accompanied by the formation of a little pyrite, and as more and more of the hornblende disappears the amount of pyrite is apt to increase. Calcite is a common companion of epidote or of chlorite derived from hornblende. Examples may be noted in which grains of magnetite originally inclosed in the hornblende remain in its alteration products.

The alterations which have been mentioned may be observed in porphyry that exhibits an entirely normal crystallization of the orthoclase and quartz of the groundmass, similar to that of the unaltered rock that occurs within the intrusive area of Weary Flat. Such changes in this material are most probably the result of chemical reactions brought about by solutions that permeated rocks which had reached a state of essentially complete solidification. However, in many specimens in which the introduction of disseminated pyrite has been the prime incident of alteration, the pyrite occurs in rather large part with the orthoclase and quartz of the groundmass, and where it is thus associated the impression is conveyed by examination under the microscope that the pyrite was deposited before the last of the interstitial quartz and orthoclase. However criteria have not been discovered to prove this suggested relation against the alternatives that the orthoclase and quartz of the groundmass may have been partly reworked by the altering solutions, or that the pyrite may have been deposited by replacement of grains of orthoclase.

The alterations of the porphyry which are of the greatest interest to the formation of copper ores of the disseminated type are those which have been produced through the permeation of the rock mass by magmatic solutions. These alterations comprise, in different stages, the progressive destruction of hornblende, of plagioclase, and of magnetite, and the formation in their stead of mica, including the white variety of felty habit commonly called sericite and a brown variety allied to biotite; the deposition of pyrite and chalcopyrite, and of calcite. Titanite is decomposed and titanic oxide separated, but apatite commonly survives unaltered. Orthoclase phenocrysts are commonly not attacked, though under very strong alteration they change into sericite or break up into small grains. The orthoclase of the normal groundmass and the quartz which accompanies it have been dissolved and redeposited as an aggregate of finer grain, commonly with the addition of brown mica and characteristically with the addition of distributed grains of pyrite and chalcopyrite. Thus the groundmass of thoroughly altered porphyry has a granulated appearance quite distinct from that of the normal rock. The quartz grains of the reformed matrix commonly contain cavities partly filled with a fluid. Where the rock is extremely altered the primary phenocrysts of orthoclase and the orthoclase of the secondarily crystallized groundmass have been replaced by sericite, and the biotite has been bleached, so that the final product of alteration is a felt of sericite flecked with grains of sulphite and of quartz. Pyrite and chalcopyrite occur mainly in the altered groundmass but are also found in the sericite aggregates, and rarely ever in the large orthoclase crystals.

Alterations of the kind described have involved the more or less complete abstraction of lime and soda and the partial elimination of magnesia, iron, and alumina. Hand in hand with these losses there has been a marked gain in potash, in sulphur, and in water of constitution.

Chemical changes in metamorphosed porphyry.—As the losses and gains of substance due to metamorphism of the porphyry can be determined only qualitatively by a comparison of the mineral composition of the normal and of the altered rock, several chemical analyses have been made to furnish a quantitative measure of these chemical changes. The most significant

Chemical changes in metamorphosed porphyry from Ely quadrangle, Nev.

	35		203			102			153			154		
	a.	b.	a.	b.	c.	a.	b.	c.	a.	b.	c.	a.	b.	c.
SiO_2	57.48	155.7	60.37	158.1	+2.4	64.11	161.5	+ 1.1	64.73	163.8	+ 8.1	74.62	188.0	+32.3
Al_2O_3	17.85	48.4	15.96	41.8	−6.6	16.52	41.7	− 6.4	14.41	36.3	−12.1	10.23	25.7	−22.7
Fe_2O_3	3.40		.51			.41						None.		
FeO	3.46		1.80			1.07								
Fe		13.8		8.3	−5.5		3.8	−10.0	2.89	7.2	− 6.2	1.94	4.8	− 9.0
MgO	2.02	5.5	1.63	4.3	−1.2	1.85	4.6	− .8	.76	1.9	− 3.6	.83	2.1	− 3.4
CaO	6.60	17.8	4.12	10.7	−7.1	1.40	2.5	−15.3	.44	1.1	−16.7	Trace.	.0	−17.8
Na_2O	3.07	8.3	3.13	8.2	− .1	1.64	4.1	− 4.2	.70	1.7	− 6.6	.33	.8	− 7.5
K_2O	4.16	11.2	5.07	13.3	+2.1	8.26	20.8	+ 9.6	7.84	19.8	+ 8.6	6.57	16.5	+ 5.3
H_2O+	.55	1.5	1.34	3.5	+2.0	.58	1.4	− .1	1.94	4.9	+ 3.4	.69	1.7	+ .2
H_2O-			.92	2.4	+2.4	1.71	4.3	+ 4.3	.82		+ 2.0	.26	.5	+ .5
TiO_2	.71	1.9	.71			.75	1.9	None.	.57			.42		
CO_2	.04	.1	.74	1.9	+1.8	.48	1.2	+ 1.1	None			None.		
P_2O_5	.21		.47			.40			.10			.06		
F	.04		Undet.			Undet.			Undet.					
MnO	.29		.05			Undet.			None.			Undet.		
BaO	.07		.11			Undet.			.04			Trace.		
FeS_2			3.11			.32								
$CuFeS_2$			.20			.95								
S					+4.3		1.27	+ 1.27	2.83	[a]7.4	7.4	2.01	5.0	+ 5.0
Cu					+ .1		.8	+ .8	1.96	4.9	4.9	1.57	3.9	+ 3.9
SO_3									.22			Undet.		
	100.15					100.08			100.25			99.55		
Specific gravity	2.71		2.62			2.54			2.52			2.52		

[a] Total sulphur.

35. a. Analysis of monzonite porphyry corrected for water below 110° C. Compare tabulation on p. 139. b. Constituents in grams per 100 cubic centimeters of rock.

203. a. Analysis of partly metamorphosed porphyry from Ely Central Eureka shaft. Compare tabulation on p. 139. b. Constituents in grams per 100 cubic centimeters of rock. c. Comparison with 35b, showing apparent loss or gain of each constituent.

102. a. Analysis of ore porphyry from Veteran mine. Rock fully metamorphosed but free from vein filling. b. Constituents in grams per 100 cubic centimeters of rock. c. Comparison with 35b showing apparent loss or gain of each constituent.

153. a. Analysis of porphyry ore from Copper Flat mine. Compare tabulation on p. 110. b. Constituents in grams per 100 cubic centimeters of rock. Specific gravity assumed to be the same as determined for 154. c. Comparison with 35b, showing apparent loss or gain of each constituent.

154. a. Analysis of siliceous variety of porphyry ore from Copper Flat mine. b. Constituents in grams per 100 cubic centimeters of rock. c. Comparison with 35b, showing apparent loss or gain of each constituent.

method of comparing analyses representing any such series of changes as these rocks have undergone, where there is no evidence of general change in volume of the material, is to convert the percentage statement of the analysis into a table showing grams of each constituent in 100 cubic centimeters of volume, by multiplying each percentage figure by the specific gravity of the rock, pore space included. Such a comparison, which is presented in the table on page 57, brings out clearly the chemical changes involved. Only in case of specimen 154 is there any probable error in direct comparison, through the possibility that some of the added quartz was formed as fracture filling, which means that less than the assumed 100 cubic centimeters of original rock is represented.

Aside from the quartz filling in specimen 154 the apparent additions of silica are within the probable errors of the calculation, the accuracy of which depends on the accuracy of the specific gravity determinations and is subject to the assumption that the composition of the original material would have tallied with the analysis representing the unaltered rock of the district. Had the analysis given by Lawson been used instead of the one representing specimen 35, the comparison would have indicated for altered porphyry of specimen 102 a loss of silica amounting to 5.7 grams per 100 cubic centimeters in place of 1.1 grams gain. Correspondingly the indicated changes in silica for specimens 153, 154, and 203, would have been respectively −3.4 grams instead of +8.1 grams, +21.8 grams instead of +32.3 grams, and −9.1 grams instead of +2.4 grams.

In general, then, the metasomatic alteration of the porphyries involved no important loss or gain of silica. If anything there has been a slight loss of silica from the rock, and an aggregate gain only where deposition occurred in fracture spaces. There have been, however, consistent losses of alumina, iron, soda, and lime; and varying losses of magnesia. The most remarkable gains have been in potash, sulphur, and copper, and a little carbon dioxide (CO_2) has been added. The carbon dioxide does not appear in specimens 153 and 154, because these materials have been acted on by the solutions which effected secondary enrichment by the deposition of chalcocite. Consideration of specimen 203 in comparison with the other analyses points to the fact that the oxides were removed in the order of lime, soda, magnesia, alumina, and the oxides of iron.

In view of the noted changes in chemical composition it is of interest to compare the mineral compositions of these rocks, which are given in the following table:

Mineral composition of normal and metamorphosed porphyry from Ely quadrangle, Nev.

	[a] 35	203	102	153	154
Quartz	10.00	11.00	23.30	31.00	48.00
Orthoclase	24.50	28.00	33.60	36.00	29.00
Albite	24.00	25.00	9.40		
Anorthite	19.20	5.00	.00		
Hornblende	15.00	[b] 12.00			
Apatite	.51	1.00	1.00		
Sphene	1.76	1.70			
Magnetite	4.00				
Biotite			13.00	5.00	5.90
Sericite		6.00	16.00	18.00	11.00
Kaolin		3.00			
Calcite and fluorite	.15	1.70	1.3		
Pyrite	.13	3.10	.30	[c] 3.83	2.22
Chalcopyrite		.20	1.00	1.83	1.63
Chalcocite				1.66	1.25
	99.25	98.70	99.00	97.32	99.00

[a] Numbers are those of the series in table on p. 57. [b] Hornblende, chlorite, epidote, and biotite. [c] $FeS=3.18$; $Fe_7S_8=0.65$.

A general conclusion, deducible from the mineral changes brought about by metamorphism of the porphyry, is that if silica is assumed to have been essentially constant, the formation of secondary mica sets this oxide free to form quartz. In specimens 153 and 154 a small proportion of the albite molecule may exist, but the minor residue of soda has been assigned to the micas. Depletion of soda has evidently been at the expense of the original plagioclase, and depletion of lime at the expense of plagioclase and hornblende. In general, the gain in potash has not been sufficient to balance molecularly the losses of lime and one-third of the soda together, in the change of anorthite and albite molecules to sericite, and has been considerably less than would be required to form sericite with alumina from these sources and from the decomposition of the hornblende, so that the loss of lime, soda, and magnesia has been accompanied by a loss of alumina. This loss of alumina could hardly have ensued except under progressive alteration, such as would have occurred from reactions produced by percolating solutions, for it would seem that if solutions capable of depositing orthoclase existed in any place where alumina was being freed from a previous combination, the excess would be immediately bound in the form of mica, in which the molecular ratio of alumina to potash is three times as great as in orthoclase.

Relation of metamorphism to channels of intrusion.—The occurrence of bodies of porphyry which have been affected by igneous metamorphism is essentially coincident with the distribution of the intrusive rock within the principal zone of intrusion and outside of this zone only normal or unaltered porphyry is found. The absence of general alteration in outlying intrusions is illustrated by the rock of the great sill which occurs north of Lane Valley, and by a large part of the intrusive mass of Weary Flat. The Weary Flat intrusion is considered to have essentially the form of a stock or a batholith. On the south, that part of the mass which falls within the principal zone of intrusion, has been strongly metamorphosed, and altered rock is also found in a band a few hundred feet wide along the east side, whereas the remaining two-thirds of the mass retains the normal characteristics of a magmatic crystallization product in spite of having received locally a notable addition of pyrite in the form of joint filling.

Certain broad deductions are warranted from the special relations of the metamorphosed porphyry as thus briefly stated. It can be shown from the observable relations between new and original minerals, and in places from the occurrence of introduced minerals in fractures, that the greater part of the deep-seated alteration took place after the magma had completely solidified, and it may be taken for granted that the agents which effected the deep-seated alteration must have originated outside of the masses which have been subjected to such fundamental transformation involving marked losses and gains of substance. The agents of metamorphism can not have been other than hot aqueous solutions, the outside source of which may be traced by a consistent train of reasoning to deep-seated magmatic material. The argument may be concisely stated thus: The masses of igneous rock that occur along the principal zone of intrusion came up as magmatic material along a great rift which afforded a passage from a deep-seated reservoir to the superficial portion of the lithosphere. Though here strongly localized, this migration of material was an incident of rather wide-reaching crustal adjustments, and portions of the moving magma found their way into the broken formations on both sides of the main fissure, forming flanking dikes or taking the shape of sills. The intrusive bodies gradually cooled and crystallized. The last minerals to form were orthoclase and quartz, and there are indications, at least locally, that the metamorphism of the porphyry masses may possibly have begun during this final stage of what may be termed the primary crystallization; that is, solutions capable of depositing pyrite and chalcopyrite and of altering plagioclase and hornblende to mica may have circulated through some parts of the porphyry masses during the final stages of crystallization.

It is certain that metamorphosing and vein-forming solutions in considerable volume penetrated some of these bodies of porphyry after their groundmass had been formed. But this occurred only in those masses which lie along the principal zone of intrusion, and this fact points unerringly to a deep-seated source for the active metamorphosing solutions, corroborating other less direct lines of evidence, which may be built up from a consideration of the substances which were carried by the circulating waters. Masses of porphyry which were situated directly over or very near the rift through which the magma entered would most likely be traversed by waters emanating from the magma reservoir, whereas masses which had passed some distance from the main channel of supply would not be penetrated by solutions rising from the magma.

THEORY OF IGNEOUS METAMORPHISM.

DEFINITION OF THE TERM.

The term igneous metamorphism is here used to cover all those changes of texture, mineral constitution, and chemical composition which are effected in rocks through the action of heat emanations or of material emanations from bodies of magma or of igneous rock. As thus defined, the term includes contact metamorphism and, in large part, many cases of hydrothermal metamorphism as these terms have been used by Lindgren.[1] It is broad enough to include also alteration resulting from the action of ordinary ground waters heated and set into active circulation by masses of igneous rock.

CHARACTER OF THE ALTERATIONS.

The principal zone of porphyry intrusion extends for 7 miles through the Ely district with a width of one-half mile to nearly a mile. Within this zone and for irregular distances on the flanks of the numerous separate intrusions the sedimentary formations, including limestones and shales, have been variously changed from the normal facies which are exhibited in situations at greater distances from the porphyry masses. Along this zone the masses of intrusive rock themselves have been metamorphosed to a great extent. The distribution of the altered sedimentary rocks is so definitely limited to a zone comprising the medially disposed intrusive masses that no extended argument is required to support the conclusion that the metamorphism is causally related to these igneous rocks. However, as will be more fully stated further on, the relation is not entirely a direct one as regards the bodies of porphyry which appear at the present surface, for it is held that the alterations were effected by hot solutions expelled from deep-seated masses of igneous material, of which the observed intrusive bodies are offshoots. In the vicinity of minor intrusions that lie well away from the principal zone there is usually almost no alteration of the wall rocks, and a similar lack of alteration is noted around a considerable area of porphyry north of Lane Valley.

The changes in the limestones comprise (1) loss of color and crystallization to white fine-grained marble; (2) silicification with the formation of jasperoid usually carrying large amounts of pyrite; and (3) the development of silicate minerals, including garnet, tremolite, pyroxene, and scapolite. These silicates are ordinarily accompanied by abundant pyrite, by minor amounts of other metallic sulphides, and commonly by magnetite. In a few places considerable masses of limestone have been more or less completely replaced by large bodies of pyrite and magnetite, usually carrying some chalcopyrite.

Metamorphic effects in the shales consist principally in the development of mica, lime-bearing silicates, and pyrite throughout the mass of the rock. These changes, which produce marked hardening, are usually most complete near the intrusive masses, but in a few places shales only a short distance from porphyry contacts exhibit almost no alteration.

The metamorphism of the porphyry masses throughout the main zone of intrusion is one of the most striking features of the district. In comparison with normal or unchanged porphyry the rock of the altered masses shows a marked difference of composition, certain substances such as soda, lime, and magnesia having been largely depleted, whereas considerable amounts of potash, silica, and sulphur, and minor amounts of other substances, including copper, have been added. These chemical changes are accompanied by fundamental alterations of certain of the mineral components of the rock and by marked changes in its physical character. The most characteristic feature of the altered porphyry is the large amount of sericite which was developed during the process of metamorphism.

AGENTS OF IGNEOUS METAMORPHISM.

The action of heated aqueous solutions is regarded as the cause of deep-seated metamorphism within the Ely district, and the source of these solutions is sought within the earth's crust. The distribution of the products of metamorphism points to an obvious connection

[1] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 124, 1905.

with a set of porphyry intrusions along what is here called the principal zone of intrusion, but the connection appears to be less direct than would be suggested by casual consideration. The porphyry masses which are exposed within the area of metamorphism are thought to be of insufficient size to warrant regarding them as the source of the materials which have been introduced into the invaded rocks, or of the heat which was required to effect the observed mineral transformations, or yet as the source of the great volume of transfusing water, which must be predicated as the carrier both of the exotic materials and of the heat or energy required for the alterations that have taken place on so grand a scale. Furthermore, the porphyry masses along the main zone of intrusion have themselves suffered alteration, involving great losses and gains of substance, so that the metamorphosing agencies were certainly in large part of an origin extraneous to these masses. In fact there is reason for the suggestion that the bodies of magma which were projected into the observable portion of the earth's crust were not particularly rich in eliminable constituents. This intimation is based on the remarkable lack of metamorphism adjacent to outlying portions of the intrusive sill which outcrops over an extensive area north of Lane Valley.

The observed bodies of porphyry may be regarded as comparatively minor offshoots from a very large reservoir of igneous material. This material migrated into the situations which it occupies while in a molten or magmatic condition. Considerable amounts of water were contained in the magma, and the temperature of the system exceeded the critical temperature for water so long as the magmatic status persisted. The magma is thus considered to have a water-silicate solution. Escape of the magmatic water ensued perhaps in part directly as a result of the reduction of pressure as the molten rock moved to higher positions, but mainly, it may be thought, as a concomitant of subsequent crystallization. Obviously any escape of water from a rock magma increases the concentration of radicles capable of uniting to form mineral compounds, and, so long as the temperature does not rise, greater concentration tends toward saturation and therefore to the separation of minerals from the solution. Crystallization is induced also by loss of heat and consequent lowering of temperature, in which case the remaining fluid, or mother liquor, becomes more and more aqueous with the progress of crystallization. These two tendencies—namely, loss of water and loss of heat—must operate together during the gradual crystallization of any body of water-bearing magma, with the result that the greater part of the original water is eventually expelled. Waters thus derived have been called magmatic, juvenile, or telluric in contradistinction to atmospheric or meteoric waters.

Because loss of heat immediately subsequent to the migration of the great body of magma would be ordinarily most rapid nearest the earth's surface, it may be supposed that crystallization began and was first completed in the higher portions of the magmatic reservoir, and went on progressively to greater and greater depths, a condition which would insure a long-continuing supply of water.

Emphasis is laid on the conception that the solutions which have effected intense and extensive metamorphism in the district were derived not from the porphyry masses open to observation, but from the same general source as the magma which was injected to form these masses.

Direct downward connection with the main reservoir seems to have been a prerequisite for any strong metamorphism of the porphyry, and the country rocks are not strongly altered elsewhere than adjacent to altered masses of the igneous rock.

The magma of the extensive sill that outcrops north of Lane Valley did not give off emanations adequate to cause any noteworthy alteration of its limestone roof, and in outlying portions of the sill the porphyry itself has not suffered metamorphism. But adjacent to the main zone of intrusion, where the cross-breaking feeder of the sill is situated, the limestone of the capping shows considerable metamorphism and the porphyry itself is greatly altered, the changes in the porphyry being in part like those which affect the same rock elsewhere throughout the intrusive zone. Here there can be little doubt that the metamorphic changes in the limestone were brought about by the same solutions that caused the alteration of the porphyry, and it is obvious that these solutions came from a source outside of the immediate mass of igneous rock. The conclusion that in general little if any alteration of the sediments was produced by solutions emanating directly from the intrusive bodies now within the range of observation, is probably true, although it admittedly lacks definite proof. The rock of the Lane sill is essentially the same in mineral composition as the rock of the Weary Flat stock intrusion, and the unaltered rock of other masses in the intrusive zone is similar. Thus, in the only place where the effects of outside agencies can be eliminated the invading magma was not effective in producing metamorphism, and probably a similar lack of metamorphosing ability may be assumed in other places.

The waters issuing from the deep-seated magma were accompanied by substances likewise contributed by the silicates in solution in water, and some of these substances have become fixed in the products of metamorphism. The escaping materials may have been mutually dissolved, though it is convenient to regard water as the solvent and the other substances as solutes. When first released from the magma these aqueous solutions may have been above the critical temperature (365° C.), and therefore in a vaporous or gaseous state. Solutions of this sort have been commonly called pneümatolytic by students of metamorphism and ore genesis.

These gaseous solutions, if such was their state, pressed outward and upward from the place of origin toward situations of lower pressure. They permeated not only the contiguous sedimentary formations but also the intrusive bodies, giving up heat until their temperature was so reduced that they could assume the liquid state. In this state they continued their migration toward situations of lower pressure, until their solutes had been largely deposited and their waters had merged with those of the ordinary ground-water circulation, or until they had reached the earth's surface in the form of hot springs. At all stages these waters were capable of producing alterations in the rocks which they traversed, depositing certain substances and removing others. At the higher temperatures they caused the formation of silicate minerals in earthy limestones and in limy shales, and, with the introduction of silica, formed such minerals locally in limestones which were originally free from earthy impurities. These silicates were formed not only adjacent to the walls of the intrusive masses but in many places well away from the igneous bodies. The formation of the lime-bearing silicates everywhere involved the decomposition of calcite and the elimination of carbon dioxide. Wherever silicate minerals, including garnet, epidote, tremolite, and diopside, were developed large amounts of pyrite were introduced, and smaller amounts of magnetite and sulphides of other metals than iron. It would be difficult to prove that some of the jasperoid of the Ely district may not have been produced at temperatures as high as those which obtained during the formation of garnet and tremolite, but if it be assumed that the formation of these silicates by metathesis, involving the substitution of silica for carbon dioxide, occurred above the critical temperature for water, then part of the jasperoids can be shown to have been formed at lower temperatures. This conclusion is drawn from a consideration of fluid inclusions in the quartz grains in many specimens of jasperoid, which indicates that the quartz was deposited in the presence of aqueous solutions in a liquid state and at a temperature somewhere between 200° and 350° C.

The formation of the jasperoids involved the solution and removal of calcium carbonate and the concomitant deposition of silica, metallic sulphides and iron oxide. The process implied by this change is not metathesis, though it falls under the accepted definition of metasomatosis as given by Lindgren: "That variety of metamorphism which involves a change in the chemical composition of rocks by the addition or subtraction of substance."

The bodies of porphyry now exposed along the principal zone of intrusion have served as channels for the escape of portions of the magmatic emanations from deeper situations. In part the solutions may have permeated and moved through the igneous rock prior to its complete crystallization, but principally it is judged after the rocks had become entirely solid. In places access of the solutions was facilitated by the development of close-spaced fractures in the porphyry, but even where fractures are wide spaced or absent the rock was completely permeated by the waters and its whole bulk subjected to alteration. With little doubt these solutions were chemically similar to those which effected the siliceous replacement of the limestones, for in both rocks brown mica was a product of the transformation. The suggestion has been made[1] that the formation of metasomatic biotite denotes high temperature, and may point to a close sequence between igneous intrusion and subsequent mineralization. It would appear that the solutions effecting the alteration of the porphyry masses were heated to about the same temperatures as those which formed the jasperoids, for quartz grains in the granulated porphyry matrix are characterized by similar fluid inclusions.

TEMPERATURE OF THE METAMORPHOSING SOLUTIONS.

The solutions which effected the metamorphism of the rocks within the Ely district were certainly hot, as is apparent from a consideration of the silicate minerals, such as garnet, tremolite, and mica, formed in the limestones, and the secondary mica produced so extensively in the porphyries, for these minerals are developed only at high temperatures. The cavities partly filled with liquid, which are present in quartz grains in the jasperoids, in the veinlets in porphyry, and in both secondary and primary phases of the groundmass in the igneous rocks, also afford unequivocal evidence that the permeating solutions were hot. These inclusions in quartz, which occur in cavities that commonly have the form of "negative crystals," show a liquid and a gas, the liquid estimated to fill not more than 90 per cent and not less than 75 per cent of the space in any cavity. It is a warrantable assumption that when the quartz was formed the liquid in any cavity was so expanded as to fill completely the space now occupied in part by vapor. If the liquid were water the proportions of liquid and vapor indicated would be attained respectively at temperatures of about 160° and 270° C., when the increase in volume[2] due to heat would cause the water to fill the cavity. In this connection G. F. Becker has plotted the density curve (fig. 2) for water between 4° C. and the critical temperature, 365° C. If we neglect the slight expansion between 4° C. and the mean temperature of the atmosphere the curve shows directly the minimum temperature of the inclosure corresponding to the observed proportions by volume of water and water vapor in a cavity. Two examples will indicate the manner of interpreting the curve. Water filling any inclosed space at $t=365°$ will fill 0.43 of the same space at $t=4°$; and water filling such a space at 160° will after cooling occupy 0.9 of the same space, and the vapor bubble will occupy 0.10 of the space.

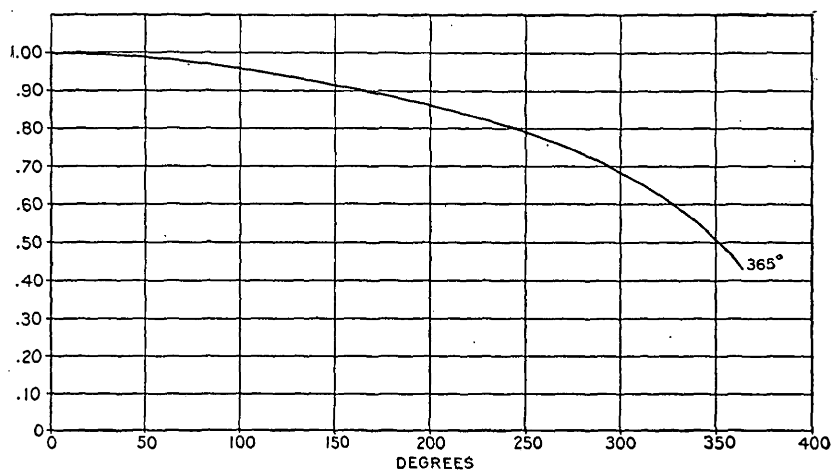

FIGURE 2.—Density curve for water from 0° C. to the critical point, 365° C. The change in density of quartz is relatively so small as to be negligible, being at 100° C. about 0.9963 of its density at 0° C.

The applicability of the curve does not extend beyond the indication of minimum temperatures, and the actual temperature of inclosure is indeterminate, because the compressibility of water, though small at low temperatures, increases rapidly with rise of temperature, and because, under adequate pressure, water gas above the critical temperature may have the same density as the liquid would have at any assumed temperature below 365° C.

Many of the cavities in quartz from the Ely district contain a cubical crystal, the presence of which indicates that the liquid is not pure water but a highly saline solution. The crystals are possibly the mineral sylvite, the chloride of potassium, for potash is known to have been abundant in the metamorphosing solutions. The temperatures of inclosure would be some-

[1] Lindgren, Waldemar, Metasomatic processes in fissure veins: Am. Inst. Min. Eng. Trans., vol. 30, p. 645, 1901.

[2] Data for these calculations are given in Physical tables, p. 96, Smithsonian Institution, 1911. The critical temperature for water now accepted is 374° C. (Holborn); but the change would affect the diagram inconsiderably.

what higher, and perhaps considerably higher, for saline solutions than for water, because the rate of expansion of such solutions at high temperatures is lower than that of water. This relation was pointed out by Sorby[1] in a classical research, in which the subject of fluid inclusions is extensively treated. A bibliography of discussions relating to fluid inclusions is given by Chamberlin.[2]

Although the problem of temperature finds no definite solution, the writer is strongly inclined to the belief that the metamorphism and sulphide deposition took place within a temperature range from 200° C. to 350° C. Between these temperatures the vapor tension of water[3] free from dissolved salts, or the pressure necessary to hold water liquid, varies from 15 to about 167 atmospheres.

CHEMICAL CHARACTER OF THE METAMORPHOSING SOLUTIONS.

The chemical character of the metamorphosing and ore-forming solutions can be only approximately determined from a consideration of the substances deposited by them. Obviously as the solutions must have abstracted certain materials from the rocks and have deposited others, their composition was continually changing, and at any particular time and place the solutes present could have been only in part derived from the original magma, the complement having been taken up on the way. The original constitution of the solutions may be roughly made out, however, from the materials which have been introduced into the altered rocks. Of such added substances the ones most strongly in evidence are silicon, sulphur, iron, and potassium. Less abundant are carbon, copper, molybdenum, lead, zinc, silver, gold, fluorine, probably chlorine, phosphorus, selenium, tellurium, palladium, and platinum. These substances certainly, and others presumably, were present in the solutions which are regarded as having emanated from the deep-seated reservoir of magmatic material. Substances which may be presumed to have been present, but which are not recognizable through having become fixed as components of minerals, or which, if so found, might have been contributed by the rocks undergoing alteration are sodium, calcium, magnesium and aluminum, elements which have been abstracted from the porphyries where these rocks are altered, and which, with carbon dioxide from limestone, were taken up by the waters in transit.

Stated in terms of compounds and radicles, without strict adherence to theories of dissociation, the principal dissolved substances of the original solutions may be regarded to have been SiO_2, H_2S, KSH, HCO_3, F, Fe, and Cu. At first thought the character of the solutions would seem to have been alkaline, for potassium, which forms a strong base, was present in relatively great amounts in association with such weak acid as H_2SiO_3, H_2S, and HCO_3, but there may actually have been a great excess of carbonic dioxide in the igneous emanations in which event the solutions would at the start have been not alkaline but acid.

It should be borne in mind that the nature of the original solutions probably differed from place to place and from time to time, and that changing character was a consequence of alterations effected, so that the foregoing inferences concerning the chemical constitution of the metamorphosing solutions are inferences in the aggregate. Consideration of alterations in the porphyry masses alone would lead to the omission of iron as an introduced substance, for these rocks have suffered a distinct loss of this metal, but the amounts introduced into the altered limestones and shales make it certain that iron must have been an original constituent of the magmatic solutions. Doubt would also be thrown upon the supposition that silica has come in from an outside source, for the quartz that occurs in veins in the porphyry could very well be considered as redistributed silica, derivable, for instance, from the alteration of albite to sericite, which sets silica free. Here again the enormous bulk of the jasperoids within the field forces acceptance of the conclusion that there has been on the whole a great accession of silica and that it must have been introduced by the metamorphosing solutions.

[1] Sorby, H. C., On the microscopical character of crystals, indicating the origin of minerals and rocks: London Geol. Soc. Quart. Jour., vol. 14, p. 462, 1858.

[2] Chamberlin, R. T., The gases in rocks: Carnegie Inst. Washington Pub. 106, 1908.

[3] Preston, Thomas, The theory of heat, p. 385, London, 1894.

It is to be observed that the phenocrystic orthoclase is the one mineral of the normal porphyry that has survived the effects of metamorphism without change of constitution. Its persistence may be taken as evidence that throughout the period in which the solutions were active they were continually saturated with respect to this mineral, for otherwise the orthoclase, like the plagioclase, would have been decomposed. The solutions were then of such composition that they would have deposited orthoclase with any slight change, as of temperature, that tended to lower their capacity to hold this mineral.

DEPOSITION OF THE PRIMARY SULPHIDES.

The deposition of pyrite and chalcopyrite in disseminated grains and crystals throughout great masses of porphyry, jasperoid, limestone, and shale when broadly considered, was merely an incident of the very complete metamorphism of these bodies of rock. This metamorphism was probably effected by heated solutions rich in alkalies and carbonic acid, which arose from a deep-seated reservoir of igneous magma and penetrated the rocks of the district. The escape of these solutions occurred after the now metamorphosed bodies of porphyry had consolidated, but, it is conceived, at a time not long subsequent to this consolidation. The source of the porphyry magma and the source of the solutions which deposited the primary sulphides is regarded as one and the same.

From the alterations which have been imposed on the original minerals of the porphyry it is held that the solutions were hot. The temperatures appear to have been above 200° C., and they may have been considerably higher, but it is thought not above 400° or 500° C. (See p. 64.)

No firmly grounded deduction free from doubt can be drawn in regard to the alkaline or acidic nature of the solutions which have effected the metamorphism and metallization of the rocks at the time they emerged from the magma, though it can hardly be doubted that the metallic minerals were deposited when an alkaline or neutral condition had been attained.

The metamorphic effects to be observed in the porphyry masses, when considered without reference to the great bodies of jasperoid which have been formed by siliceous replacement of limestone, might be explained as the result of alterations which could be brought about by solutions that contained less than an excess of dissolved carbon dioxide or even less than would have been required to form bicarbonates with all basic radicles not balanced by other acid radicles. Such a solution would have alkaline properties. On the other hand it is difficult to conceive of a chemical system consonant with the formation of the enormous masses of sulphide-bearing jasperoids, involving the removal of an equal bulk of limestone, which did not carry great amounts of free carbon dioxide. Obviously any important excess of carbon dioxide or, we may say, of carbonic acid would result in giving the solutions an acid character.

From well-established data it is a comparatively simple matter to devise a scheme to show that waters rich in alkali radicles and containing sulphide and bicarbonate radicles, the bicarbonate radicles not in excess, could transport copper, iron, and other metals, and to indicate how necessary changes in the state of the solution due to cooling and to reactions between the solution and the minerals of the porphyry masses through which it moved would tend to precipitation of pyrite and chalcopyrite within the rock.

Such a scheme may start with the observation of many investigators[1] that metallic sulphides, including those of mercury, iron, and copper, are to a considerable extent, soluble in solutions that carry alkali sulphides. This solubility is due to the formation of complex sulphide

[1] Publications on this subject are listed below in chronologic order:

1. LeConte, Joseph, and Rising, W. B., Mineral vein formation now in progress at Sulphur Bank, Cal.: Am. Jour. Sci., 3d ser., vol. 24, pp. 23-33, 1882.
2. LeConte, Joseph, Mineral vein formation at Steamboat Springs, Nev.: Am. Jour. Sci., 3d ser., vol. 25, pp. 424-428, 1883; Genesis of metalliferous veins: Am. Jour. Sci., 3d ser., vol. 26, p. 1, 1883.
3. Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, p. 430, 1888.
4. Doelter, C., Einige Versuche über die Löslichkeit der Mineralien: Min. pet. Mitt., vol. 13, pp. 428-435, 1888.
5. Koninck, L. L., and Ledent, M., Wirkung der Schwefelalkalien auf die Lösungen der Metalle der Eisengruppe: Zeitschr. angew. Chemie, 1891, p. 202.
6. LeConte, Joseph, Discussion of Pošepný, Franz, The genesis of ore deposits: Am. Inst. Min. Eng. Trans., vol. 24, pp. 996-1006, 1895; also Pošepný, Franz, Genesis of ore deposits, 2d ed., pp. 270-281, 1902.
7. Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: Econ. Geology, vol. 2, p. 18, 1907.
8. Knox, Joseph, A study of the sulphur anion and of complex sulphur anions: Faraday Soc. Trans., vol. 4, pp. 29-50, 1908.

ions, as is shown for mercury in the presence of sodium sulphide by Knox,[1] who finds also that the solubility of the sulphide, and therefore also the concentration of the metal in the sulphide solution, increases with the concentration of the hydroxide ion, or in other words increases with increase of alkalinity. Since in any solution and especially in one carrying strong basic radicles, such as potassium, and weak acid radicles, such as sulphide or bicarbonate, hydrolysis produces the free hydroxide ion, and, as hydrolysis decreases in degree with fall of temperature, the alkalinity would decrease through simple cooling, the complex ions would break down in proportion to decreasing alkalinity, and metallic sulphides would be precipitated.

Other effects to the same end would be decrease of alkalinity, due to the deposition of potassium in the form of orthoclase, which has been shown to have taken place during the alteration of the porphyries and in the exchange of calcium, magnesium, and iron out of the rock minerals for potassium originally in the solution, as seen in the destruction of plagioclase and hornblende and the formation in their places of biotite and sericite. The accession of iron from the rock minerals undergoing decomposition would also tend to break down the complex ions and therefore to the precipitation of the metallic sulphides.

The foregoing analysis seems to be in accord with established chemical principles and might be accepted as a very good theoretic outline of the chemistry of the disseminated ores in the porphyry if it were not for the obvious requirement that a sound theory should apply also to the deposition of the same sulphides in the other rocks of the district. In fact, the suggestion of originally alkaline solutions seems to lead to very different results from those deduced above when the attempt is made to apply it to the formation of the pyrite-bearing jasperoids. Here several of the principal reactions of those which seem to be necessary would tend to increase any existing alkalinity and therefore would lead to greater solubility of the metals. Although it is impossible to rate the different effects in order to offset them against each other, decreasing temperature, as before, would diminish the degree of hydrolysis and to this extent would decrease alkalinity. The abstraction of alkalies from the solution and their deposition as components of mica, a common constituent of the jasperoids, would also diminish the alkalinity of the solution, though this effect must have been of minor importance because the jasperoids contain very small amounts of sodium and potassium.

As opposed to the factors just noted the dissolving of calcium carbonate, which originally constituted the rock that has been replaced, would bring about what might seem to be a relatively great increase of alkalinity. This would follow as far as this compound could be dissolved as such and also as the result of solution involving double decomposition between calcium carbonate and salts already held dissolved. Such a reaction as the decomposition of calcium carbonate by alkali bicarbonates may well occur to a very considerable extent under conditions of elevated temperature and high pressure, and even at atmospheric pressure and temperature the presence of sodium and potassium chloride in a solution increases the solubility of calcium carbonate.[2] In either of the indicated reactions—

$$CaCO_3 + 2KHCO_3 = Ca(HCO_3)_2 + K_2CO_3, \text{ or}$$
$$CaCO_3 + 2KCl = CaCl_2 + K_2CO_3$$

the result of dissolving calcite would be to materially increase the alkalinity of the solution. If, then, alkaline solutions are considered to have been the agents which dissolved the limestones, these solutions would have become more and more alkaline, so that on the face of things their ability to carry metallic sulphides in solution would be increased rather than diminished by reactions which resulted in the removal of calcium carbonate and the concomitant deposition of silica.

If, as opposed to the foregoing considerations, we consider the metamorphosing solutions to have originally contained an excess of carbonic dioxide, the results of chemical action on the porphyry and on the limestone both tend in the same direction—that is, in both cases the acidity of the solution is reduced, because basic radicles are continually passing into the solu-

[1] Knox, Joseph, op. cit., p. 31.

[2] Cameron, F. K., and Bell, J. M., The action of water and aqueous solutions upon soil carbonates: U. S. Dept. Agr. Bur. Soils Bull. 49, pp. 52, 56, 1907.

tion and neutralizing the acid which it contains. Now in the case of alkaline solutions containing unoxidized sulphur radicles, the formation of double metal-alkali compounds is favored by high concentration of the hydroxid ions, because this results in high concentration of the sulphur ion as opposed to the hydrosulphide ion, which is shown by the scheme $SH' + OH' \rightleftharpoons H_2O + S''$. In acid solutions containing the same radicles, the corresponding equilibrium would be $S'' + H' \rightleftharpoons SH'$. This is to say, the concentration of sulphide ions is suppressed because of the high concentration of hydrogen ions. Thus in an acid solution double sulphide compounds would not exist.

For the transportation of iron[1] and copper by solutions carrying sufficient carbonic acid under pressure to give an acid reaction, and at the same time carrying unoxidized sulphur radicles, it appears that we must appeal in the main to the principle that the solubility of the metallic sulphides, like that of most salts, increases with rise of temperature. Suppression of the sulphide-ion concentration, in the presence of free acid, would be an assisting factor in rendering the sulphides soluble, but one which may not be regarded as of controlling importance. The influence of salts other than sulphides in the solutions would tend to increase the solubility of the sulphides, but it is not apparent that such increase would modify the solubility to a different extent at different temperatures.

In the presence of electrolytes such as are believed to have been present in the solutions (salts of different bases with the acid radicles Cl, F, SO_3, and HCO_3) it does not seem possible that the sulphides could have been dissolved in a colloidal state. Furthermore, it seems probable from known properties of colloidal solutions that sulphides thus dissolved would not be able to pass through rock masses after the manner which is obviously possible for salts held in true solution, especially under the conditions of molecular mobility which obtain at elevated temperatures.

The foregoing considerations lead to the conclusion that if the original solutions were strong carbonic acid solutions they must have contained copper in concentrations which can only be thought of as extremely small, much more minute than concentrations which would be possible in alkaline solutions.

It follows from the fact that the amounts of lead and zinc which are contained in the rocks of the district are so much less than the amount of copper that the actual concentrations of these metals in the solutions must have been still smaller than that of copper. Iron was present in relatively high concentration compared with any of the other metals. There is no apparent way of estimating the actual concentration of unoxidized sulphur radicles and molecules, including sulphide and hydrosulphide ions and un-ionized compounds, in the metamorphosing solutions. However introduced, sulphur in the altered rocks, amounts to an enormous aggregate, approximately one-half by weight of the total sulphides present, so that in comparison with the concentration of any single metal the total concentration of sulphur radicles must have been high. The point concerning which no adequate evidence presents itself is whether the solutions may have contained more or less unoxidized sulphur than would be adequate to form sulphides with the heavy metals present. That there may have been a deficiency of available sulphur at times and in places is suggested by the facts that iron-bearing mica was formed in much of the metamorphosed porphyry and in the jasperoid masses; that magnetite was rather abundantly formed during the alterations of limestones and shales; and that garnet containing iron was formed locally in the limestones, all these minerals being essentially contemporaneous with the metallic sulphides.

We may follow some of the changes which would take place in a solution of the sort that has been assumed during its passage through masses of the country rocks. The movement of the solutions may be satisfactorily assigned to differences in pressure which necessarily exist between situations adjacent to a source of heat and situations at a distance from such source. Obviously the general direction of the movement would be upward, for the final relief of pressure would be at the earth's surface.

[1] Marcasite or mixtures of marcasite and minor amounts of pyrite may be precipitated from acid solutions.

In traversing the rocks the solutions would encounter silicate minerals in the porphyries and in the shales, and calcium carbonate in the shales and limestones. The dissolved carbonic acid would be utilized in decomposing these minerals, and the acidity of the solution would be correspondingly reduced, so that eventually any portion of the solution would necessarily come to have an alkaline reaction. Hand in hand with decreasing acidity, the solutions were losing heat, because they were traveling away from the source of heat and presumably also as a result of the principal chemical reaction taking place. With fall of temperature the solubility of the metallic sulphides is diminished, so that the solution must eventually become saturated with them. After this condition has been reached further gradual cooling will lead to continuous deposition of sulphide minerals so long as the alkalinity does not rise above the point where the formation of double sulphide molecules would occur and prevent further precipitation. It even seems possible that decreasing alkalinity, due to diminishing hydrolysis in the cooling solution, might actually offset the supposed gain in alkalinity attributable to the increasing total concentration of bases in the solution.

On the principle that the introduction of ions like those already in the solution tends toward saturation and precipitation of molecules which could be formed and which are difficultly soluble, the accession of iron through the decomposition of iron-bearing minerals in the rock, would bring about precipitation of pyrite in advance of chalcopyrite if both metals had been previously held in solution as sulphides. Such contributions of iron were undoubtedly made as the result of the decomposition of the original hornblende and magnetite contained in the porphyry masses undergoing alteration, and also through similar decomposition of minerals contained in the shales.

The conclusion that the altering solutions were alkaline in character at the time the sulphide minerals were deposited is in harmony with the work of Allen[1] and his collaborators on the synthesis of certain metallic sulphides, including pyrite and marcasite. It is shown that the formation of pyrite is particularly characteristic of crystallizations from alkaline solutions, and it seems probable that chalcopyrite is deposited only under the same condition, and never from strongly acid solutions.[2] The occurrence in the pyritized rocks of orthoclase contemporaneous in origin with the metallic sulphides seems also to afford strong corroboration of the hypothesis of alkaline conditions. The synthetic studies of Bauer[3] indicate that this mineral does not crystallize from its simple solutions but only from solutions containing an excess of bases. Presumably the formation of mica is limited by the same condition.

Attention has been directed to the fact that locally the altered porphyry carries considerable pyrite which occurs in the form of films deposited along joints. (See p. 55.) By examination of material from the ore pits the observer may satisfy himself that the deposition of the pyrite of films followed closely after the deposition of the pyrite and chalcopyrite which is disseminated through the rock and through the quartz-orthoclase veinlets. That is to say, there was no time interval between the earlier and the later deposition. The conclusion is almost obvious that some very different condition or set of conditions had come into play to permit a sudden change in the nature of the mineral deposition. It is difficult to devise any scheme which would connect the changed conditions with changes originating within the rock masses in which the deposition occurred. Changes which could be so connected would be almost of necessity so gradual that their effects would tend toward a similarly gradual change in the products of reaction. We are thus led to the belief that there must have been a revolutionary change in the character of the solutions just before the epoch during which the pyrite films were deposited, and we are brought back to a consideration of a deep-seated body of magma undergoing crystallization and presumably passing through critical stages, on either

[1] Allen, E. T., Crenshaw, J. L., and Johnson, John, The mineral sulphides of iron: Am. Jour. Sci., 4th ser., vol. 33, pp. 169–236, 1912. Allen, E. T., and Crenshaw, J. L., The sulphides of zinc, cadmium, and mercury: Am. Jour. Sci., 4th ser., vol. 34, pp. 341–396, 1912.

[2] Senarmont, H., Expériences sur le formation de minéraux par voie humide dans les gites métallifères concrétionnés: Annales chimie et phys., vol. 32, pp. 129–175, 1851. Chalcopyrite was prepared by heating a solution containing ferrous and cuprous chlorides, sodium polysulphide, and an excess of sodium bicarbonate. See also Allen, E. T., and Crenshaw, J. L., The sulphides of zinc, cadmium, and mercury: Am. Jour. Sci., 4th ser., vol. 34, p. 383, 1912.

[3] Bauer, Emil, Bildungsverhältnisse von Orthoklas und Albit: Zeitschr. physikal. Chemie, vol. 42, p. 573, 1903.

side of which the products of differentiation might be very different. Though the subject can not be followed further at the present time the bringing together of facts of the kind here presented will in the future give a better understanding of the activities of rock magmas and a fuller concept of the derivation of ore-forming solutions from them.

CHANGES OF TEMPERATURE OF THE METAMORPHOSING SOLUTIONS.

In the preceding section the deposition of primary sulphides is represented as having been very closely connected with gradual cooling of the active solutions. Three general causes may have been capable of bringing about this lowering of temperature; namely, the transfer of heat from the hotter solutions to the originally cooler rocks; conduction; and the heat effects of chemical reactions between the solutions and the minerals of the rocks.

If the rocks are assumed to have been cooler than the solutions, then, whatever the original difference in temperature may have been, at any point chosen for consideration, when a sufficient volume of the solution had passed, a constant temperature would be established. This temperature would be lower than the original temperature of the solution, and in situations farther and farther away from the source of emanation the temperature would be lower and lower. The temperature gradient would correspond with the loss of heat by conduction through the complex system comprising the rock and the solution present in its pores; and the distribution of heat would be essentially the same as would be attained, after sufficient lapse of time, if a system having the same conductivity but lacking the traversing solutions were to receive heat from below at the same rate. As the coefficient of conduction would be low, the difference in temperature between two points a few feet or a few tens of feet apart would certainly be very slight; but chemical equilibria are in general very delicate, and there is perhaps no a priori reason why very minute temperature changes may not be regarded as adequate to have caused the deposition of metallic sulphides from the transporting solutions. It is obvious, however, that prior to the attainment of a steady temperature at any chosen point the gradient of falling temperature for the solution would be greater than it could ever be afterward, and it is conceivable that a great part of the observed metamorphism was brought about during the time when the rocks were coming to a maximum temperature under the effect of heat contributed by the permeating solutions.

Though for the purpose of analysis the effects of conduction and transfer of heat from the solution to the cooler rock have been presented singly, it is fully realized that any actual lowering of the temperature of the solution would be bound up with the heat effects of chemical reactions between the solutions and the minerals of the rocks.

The suggestion may be made that the probable aggregate effect of mineral changes induced in the rock would be to transform available or free energy into intrinsic or latent energy, which would be distributed between the changed solutions and the newly formed solid compounds, with the result that the temperature of the system would fall. This reasoning is in consonance with the law of degradation of energy and the law of mobile equilibrium. The first of these laws is thus stated by Mellor:[1]

> Every change which takes place in nature does so at the cost of a certain amount of available energy. If the intensity factors of a particular form of energy in a system are not equal, the system will be in a state of unstable equilibrium. Such a condition will not be permanent, and energy will flow, so to speak, from one part to another until the different intensity factors become equal.

The second law Mellor[2] states as follows:

> Change of temperature will disturb the state of equilibrium of a system and induce a transformation whose thermal sign is opposed to the change of temperature. Cooling favors a reaction accompanied by an evolution of heat; heating favors a reaction accompanied by an absorption of heat.

The foregoing suggestion could be tested for specific cases if the heat effect of dissolving the principal minerals involved in the metasomatic alteration could be determined, the solvent used conforming in type to the solutions which have brought about the observed mineral trans-

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[1] Mellor. I. W., Chemical statics and dynamics, p. 27, 1904. [2] Idem, p. 401.

formations. In order to correspond with natural conditions all determinations would be made at elevated temperatures. A definite case would be the comparison of normal and metamorphosed porphyry from the Ely district. Examples of the metamorphosed porphyry contain nearly 30 per cent of mica, which has been formed at the expense of original hornblende and plagioclase. The problem resolves itself into a determination whether metamorphism of a unit volume of the normal rock to form a unit volume of the altered rock has involved liberation or absorption of available heat or energy. We may take as a convenient volume for purposes of calculation 100 cubic centimeters of each rock, as for example of samples 35 and 102. (See p. 57.) Now, it is found that 100 centimeters of sample 35 contains, respectively, of hornblende, anorthite, albite, and quartz, 40, 52, 40, and 27 grams; and the same volume of sample 102 contains, of mica, albite, and quartz, respectively, 72, 24, and 58 grams. Since separation from solution must result in a heat effect of opposite sign equivalent to that when a mineral is dissolved, we may eliminate common weights of quartz and albite, which leaves for consideration for sample 35, of hornblende, anorthite, and albite, 40, 52, and 16 grams; and for sample 102, mica 72 and quartz 31 grams. If the deposition of pyrite and chalcopyrite in the rock represented by sample 102 is left out of consideration, the energy change resulting from the metamorphism of sample 35 to produce sample 102 is represented approximately by the energy change involved when hornblende, anorthite, and albite pass into solution and mica and quartz are deposited, the proportions of the several minerals by weight being 40, 52, 16, 72, and 31.

Evidently, the aggregate energy change in a system such as the one presented must be built up from separate determinations of the respective heats of solution of the minerals concerned. To make the necessary determinations would be a tedious undertaking, but results could be attained which would be of great value in the chemical investigation of the processes of metamorphism.

Determination of the heats of solution of silicate minerals by any direct calorimetric method would seem to be out of the question because of the long time required to effect solution. However, from the relative concentrations of saturated solutions of any substance determined at two temperatures the heat of solution may be calculated,[1] and this method would seem to be entirely feasible for the estimations required in the problem which has been outlined.

For the formation of jasperoid from limestone it would seem possible to ascertain experimentally whether the replacement of calcium carbonate by silica takes place with absorption or with evolution of heat. This would involve determinations of the heat effects of solution of calcite and of quartz at appropriate temperatures. Calculations made from data[2] in hand lead to the result that at ordinary temperatures replacement of calcite by an equal volume of quartz would result in the evolution of 2,600 small calories for each gram molecule of calcite replaced. The reliability of Foote's solubility determinations for calcite as a basis for calculating the heat absorbed when calcite passes into solution may be open to question, particularly as the object of the investigation was to evaluate the relative stabilities of calcite and aragonite, and as Foote himself did not make this calculation. Even if the replacement should actually take place at ordinary temperatures with evolution of heat, at the temperature which obtained during the metamorphism of the limestones of the Ely district the heat reaction may have been one of absorption. Theoretically it would seem that the aggregate effect of the reactions involved in the alteration of the rock must have tended toward the lowering of temperature. The opposite assumption, that the sum of the reactions of metamorphism resulted in a rise of temperature in the system, apparently leads to the conclusion that metamorphic processes once started would be self-perpetuating, whereas we have every reason to believe that contributions of energy from without are required to bring about chemical transformations in rock masses, and when such contributions fail, metamorphic action comes to an end.

[1] Van't Hoff, J. H., Vorlesungen über theoretische und physikalische Chemie, Heft 1, Die chemische Dynamik, p. 31, 1901. Nernst, Walter, Theoretical chemistry, 6th English ed., p. 664, 1911.

[2] Foote, H. W., Über die physikalisch-chemischen Beziehungen zwischen Aragonit und Calcit: Zeitschr. physikal. Chemie, vol. 33, 1900, pp. 740-759. This investigation furnishes data for computing the heat of solution of calcite at 17° C. Mulert, Otto, Über die Thermochemie der Kieselsäure und der Silikate: Zeitschr. anorg. Chemie, vol. 75, pp. 207-210, 1912.

DISTRIBUTION AND RELATIVE ABUNDANCE OF THE METALS.

Within the Ely district the metals deposited as sulphides include iron, copper, lead, zinc, and molybdenum. Deposits that carry iron and copper and minor amounts of molybdenum but no lead or zinc occur medially within the belt of intense metamorphism, whereas deposits that contain lead and minor amounts of zinc in addition to iron and copper are disposed in the outer parts of this belt. All the sulphide deposits carry a little gold and silver, but these metals are associated in greater proportions with the less abundant lead and zinc than with the more abundant iron and copper.

From a consideration of the zonal features which are shown by the horizontal section due to erosion it seems natural to think of the whole mass that was metamorphosed and mineralized by the solutions that rose along the intrusive belt as having comprised a core and an overarching saddle-like envelope. In the core, where during the principal epoch of mineralization the conditions were presumably more favorable for the retention of the metals by the solutions, pyrite, chalcopyrite, and molybdenite were deposited by themselves, whereas in the envelope, where the dissolving power of the solution had been reduced, galena and sphalerite were deposited in addition to pyrite and chalcopyrite. In the main the sequence in which the deposition of the several sulphides was inaugurated is the same as the order of their abundance in the primary deposits of the district taken as a whole. This correspondence leads to the suggestion that the principal control in determining the order of inaugural deposition of the sulphides was the relative concentrations of the metal radicles in the mineralizing solutions.

If it is assumed that the solutions, just prior to the deposition of any sulphides from them, carried the metals in proportions that were about the same as the proportions of the metals in the sulphide deposits of the district, an expression for the relative molar concentrations may be obtained by dividing the proportional abundance (by weight) by the respective atomic weights of the elements. Thus a rough estimate of the proportions of the metals iron, copper, lead, zinc, and molybdenum, gives the respective ratios 10,000 : 1,000 : 20 : 2 : ± 2; and corresponding molar concentration ratios are, approximately: 18,000 : 1,100 : 10 : 3 : 2. Had all the sulphides been equally soluble under the conditions that existed at those depths where the first sulphide precipitation occurred, with due respect to the assumptions that have been made, the mineral first deposited would undoubtedly have been pyrite, and as dissolving power diminished the several sulphide minerals would have appeared in an order entirely conformable with the foregoing sequence. The actual departures from this order are that the first deposition of molybdenite occurred well within the core and thus ahead of the first deposition of the now more abundant galena, and that less abundant sphalerite and more abundant galena were first deposited almost contemporaneously.

These relations may be taken to indicate that the specific solubilities of sphalerite and of molybdenite were extremely low in comparison with the solubilities of the older sulphide minerals, under the conditions obtaining when the mineralization of the district occurred. In view of their relative abundance and the peculiarities of their distribution it seems safe to conclude that the order of increasing solubilities of the several sulphide minerals was molybdenite, sphalerite, galena, chalcopyrite, and pyrite.

In general the deposition of each of the sulphides continued onward from the time and outward from the place of its initial deposition, so that in the exterior part of the mass that was undergoing metamorphism or infiltration, that is in the part that has been denoted as the envelope, all of them were being deposited together.

The absence of lead and zinc in the metamorphosed materials of the core points to the conclusion, otherwise supported by a consideration of the films of pyrite which are free from chalcopyrite that occur in the bodies of mineralized porphyry, that there was a sudden change in the character of the solutions just before the close of the epoch of mineralization, a change which, as stated elsewhere, is believed to have had its origin in the magma system from which the mineralizing waters are supposed to have been derived. If there had been a gradual dying out of the mineralizing activities without any discontinuity of process it would seem that with decreasing power of solution a time must have arrived when deposits of galena and sphalerite would have been superposed on the earlier formed deposits of pyrite and chalcopyrite.

Because the whole process of mineralization thus appears to have occupied a definite and rather short interval of time, and because no evidence has been found in the paragenesis of the metal-bearing minerals to indicate that there were progressive changes in the character of the original solutions (previous to the first sulphide deposition) the principal assumption on which the foregoing argument is based is thought to be warranted, namely that the mineralizing solutions had about the same composition throughout the principal epoch of mineralization.

METAMORPHISM DUE TO ATMOSPHERIC AGENTS.

GENERAL CHARACTER.

Alterations in the rocks which are traceable to the action of surface waters and dissolved gases including oxygen and carbonic dioxide will be discussed under weathering and under chalcocite enrichment (p. 76). The whole process is included by Van Hise[1] under the term katamorphism, comprising changes within the shallow zone (as compared with deep-seated alterations, which he denotes by the term anamorphism) and is divisible into weathering and cementation. In the Ely district the effects of weathering are strongly in evidence along the principal zone of intrusion, where the rocks were heavily impregnated with metallic sulphides during the epoch of igneous metamorphism. Throughout this zone essentially all the outcropping materials are brown, red, or yellow because of iron oxide stains that result from the decomposition of pyrite. The rocks are weathered to different depths, depending on circumstances of permeability and underground drainage, but in any locality at some definite depth there is a sharp transition from more or less porous discolored material into material which is more compact and of a very different aspect because its component sulphides have not suffered oxidation. This sharp transition is conspicuous in the mine pits, where the red to yellow capping contrasts with the grayish ore on which it rests. Cementation is recognized in the secondary copper deposition, which has taken place throughout masses of rock or in lodes beneath the weathered surficial materials. From the relations in space and from the condition of the weathered material it is obvious that the added copper in the secondary ores has been contributed by the material which lies above the ore masses.

WEATHERING.

PROMINENT EFFECTS.

All those changes in the rocks traceable to the direct action of penetrating surface waters may be properly included under weathering, leaving certain indirect effects for separate consideration. Under the action of water, frost, and the sun's heat the normal porphyries have crumbled, shales have disintegrated into soil, and unmetamorphosed limestones have wasted away.

The most prominent feature of weathering in all the previously altered rocks has been the oxidation of the sulphide minerals. Because a very large part of the products of igneous metamorphism carry abundant pyrite in their unweathered state, ferruginous outcrops are characteristic within and adjacent to the principal zone of intrusion, and the upper parts of veins or lodes are everywhere rich in limonite. Where chalcopyrite is associated with pyrite oxidized minerals of copper may be found in the weathered material.

WEATHERING OF METAMORPHOSED PORPHYRY.

The essential physical changes in the weathered metamorphosed porphyry have been a marked gain in porosity and the development of yellow, red, or brown colors in place of the original gray of the unweathered rock. Increased porosity is largely a result of the complete

[1] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, p. 43, 1904.

decomposition of the metallic sulphides, which have been partly carried away in solution and partly converted to hydrous oxides and basic sulphates of iron and basic sulphates and carbonates of copper.

A study of thin sections of weathered porphyry under the microscope gives the impression that chemical changes were essentially absent aside from the direct effect of dissolution of the sulphide minerals and the production of minor amounts of kaolin. Specimens of such porphyry from Copper Flat contain orthoclase phenocrysts which are as clear and fresh as those from the most normal of the porphyry of Weary Flat, and brown mica, though somewhat bleached, has persisted in the same relations that are exhibited in the underlying ore. Still, the chemical analysis of a sample of the capping indicates that there have been certain losses in addition to those which are apparent from the recognizable mineral decompositions. Comparison of the analysis given at the bottom of this page with that of a sample of porphyry ore given on page 57 shows what these more obscure losses of substance have been. The comparison is on the basis of grams of substance per 100 cubic centimeters of rock, and only the principal substances are considered. The figures for specific gravity apply to the rock with pore space included.

Comparison of ore and weathered capping, showing apparent losses.

	Ore porphyry.		Capping porphyry.		Loss in the change (grams per 100 cubic centimeters).
	Analysis.	Grams per 100 cubic centimeters.	Analysis.	Grams per 100 cubic centimeters.	
SiO_2	74.62	188	80.58	18.1	−7
Al_2O_3	10.23	25	8.51	19	−6
Fe	1.94	4.9	1.53	3.4	−1.5
MgO	.83	2	None.	....	−2
K_2O	6.57	16	5.33	12	−4
S	2.01	5	.38	.8	−4.2
Cu	1.57	4	.20	.4	−3.6
Specific gravity	2.52	....	2.25	....	....

Although the comparison presented in the table has no more than a qualitative value, the indicated losses of alumina, magnesia, and potash show that the silicate minerals of the ore are attacked by the acid solutions that are developed when pyrite and chalcopyrite decompose under the action of waters carrying free oxygen.

The average copper content of the capping porphyry is characteristically low in comparison with that of the ore porphyry which lies beneath it. Though data for stating the actual mean ratio are not at hand, it is perhaps in the neighborhood of 1.5. As a consideration of the erosional history of the region shows that the capping porphyry has all been through the ore porphyry stage, the copper which the capping porphyry contains is merely a residuum of a formerly greater content. The greater part of the metal has yielded to solution and has been carried away to be deposited beneath the fully weathered material.

A sample of capping porphyry from the overburden at Copper Flat pit was analyzed in the laboratory of the United States Geological Survey by R. C. Wells with the results tabulated below. The specific gravity of a sample of the rock, including pore space, was determined to be 2.25.

Chemical analysis of capping porphyry.

SiO_2	80.58	H_2O-	0.45
Al_2O_3	8.51	H_2O+	1.29
Fe_2O_3	1.31	TiO_2	.29
MgO	None.	SO_3	.95
CaO	.15	Cu	.20
BaO	.06		
Na_2O	.41		99.53
K_2O	5.33		

The approximate mineral composition of the material, as calculated from the chemical analysis and checked by detailed study of a representative thin section, is given below:

Mineral composition of capping porphyry.

Quartz	58.0
Orthoclase	29.0
Sericite	9.0
Limonite	1.5
Jarosite [1]	2.5
	100.0

Tests of different samples of capping porphyry show that the rock commonly contains noteworthy amounts of water-soluble salts, including sulphates and chlorides of soda and magnesia. Presumably these salts accumulate near the surface, because solutions that rise by capillarity through the porous rock there lose their water as a result of evaporation. The mine waters of the district carry chlorides and sulphates, and water from the Ruth mine carries magnesia.

WEATHERING OF JASPEROID.

The great masses of jasperoid produced by silicification of the limestone beds carry large quantities of disseminated pyrite and locally of chalcopyrite. Under the action of the weather these sulphides have been decomposed, just as they have been broken down where they occur in a porphyry matrix. The material exposed at the surface is typically rust-brown from the presence of oxidized compounds of iron and is characteristically cellular or porous. Where it forms prominent outcrops the unweathered material seems invariably to have carried the sulphides in rather minute grains, but where it breaks into fragments the original jasperoid commonly contained much larger aggregates of the sulphide. Locally material exposed at the surface and fully weathered material encountered in the mines is nearly free from iron stains, though from contained cavities it is evident that pyrite formerly present has been dissolved away.

Much of the jasperoid probably never carried any large amount of chalcopyrite, but in the vicinity of the Veteran mine this mineral seems to have been very generally distributed in the silicified rock along with pyrite. Here the cupriferous leachings from the jasperoid masses during their oxidation undoubtedly contributed to the enrichment of masses of rock which have been profitably mined. Parts of this ore appear to be jasperoid, though other parts are metamorphosed porphyry. So far as observed fully weathered jasperoid does not contain visible amounts of oxidized copper minerals.

Where the jasperoid bodies originally contained rather minor amounts of sulphide minerals distributed in minute grains the outcrops are usually massive, but where the rock carried from 5 to 10 per cent of these minerals the products of weathering are greatly broken, and the surface is usually mantled by angular fragments so that no actual outcrops appear.

WEATHERING OF PYRITIZED LIMESTONE.

Material which is regarded as the product of essentially complete weathering of limestone masses that were partly silicified and changed to lime-bearing silicates, and generally charged with metallic sulphides during the epoch of igneous metamorphism, has been exposed in the Jesse adit of the Old Glory mine and in rifts formed at the surface by caving of worked-out portions of the Veteran mine. The general appearance of material from both localities is identical. It is rather homogeneous, earthy, ocherous, and of rather light weight. In places in the Jesse tunnel a layered aspect is presented, which leads to the conclusion that the material has been derived from a bedded formation. Here it constitutes the capping, more than 200 feet in depth, above sulphide-bearing metamorphosed limestone which has been explored by the lower workings from the Old Glory shaft and which in places has received some enrichment through the deposition of secondary chalcocite.

[1] Part of the sulphur may be present in FeS_2, as remnants of this sulphide may be noted in certain specimens of capping from this locality.

Examination in the field left some doubt at first as to the derivation of the weathered material above the Veteran ore body, partly because the ore mass was for some time thought to have been mainly derived from a porphyry base, but the ore that occurs immediately below the material which has been exposed at the surface is now regarded as enriched jasperoid, and close resemblance with material from the Old Glory mine leaves little doubt that this capping also represents metamorphosed and weathered limestone. This conclusion is borne out by the following chemical analyses, made in the laboratory of the Geological Survey by Chase Palmer:

Analyses of residual material derived from pyritized limestone from the Veteran and Old Glory mines.

	103a	103b		103a	103b
SiO_2	64.83	65.42	H_2O+	4.18	3.99
Al_2O_3	5.34	5.41	TiO_2	.27	.69
Fe_2O_3	15.47	15.03	CO_2	None.	.04
FeO	.13	.13	P_2O_5	.51	.51
MgO	.74	.70	SO_3	.37	.32
CaO	2.27	2.16	MnO	.72	.74
Na_2O	.22	.34	Cu	.19	.13
K_2O	.24	.10			
H_2O-	5.44	4.83		100.92	100.54

103a. Oxidized material exposed at the surface above the east side of the Veteran ore body. The unoxidized material from which it has been derived must have contained much less silica than the jasperoid in which the Veteran ore has been developed.

103b. Oxidized material from the Jesse tunnel, Old Glory claim. The material represents the weathered residuum of limestone which has been heavily charged with pyrite and otherwise strongly altered by igneous metamorphism.

Without calculation of the mineral composition of these materials, it may be said that the composition indicates the presence of somewhat more than 20 per cent of hydrous iron oxide or limonite. As the sulphur present is not sufficient to form gypsum with the lime, and as carbon dioxide is absent, the lime presumably occurs in silicate minerals which have resisted decomposition. The presence of more than 2 per cent of lime and the low potash argues strongly against the suggestion that the material could have been derived from porphyry ore. If it is residual from pyritized and silicified limestone, the principal losses during weathering have been of calcium carbonate, sulphur, and copper.

WEATHERING OF PYRITIZED SHALE.

Throughout the district the shales, even where they are highly charged with sulphides, seem to have suffered decomposition only to very shallow depths. This is, of course, a consequence of their impermeability.

In the eastern part of the district, where shales within the general zone of metamorphism occur on the north side of Lane Valley, east of the town, the pyritized rock breaks down at the surface into angular fragments that are stained a deep chocolate brown by oxide compounds of iron. This material supports only a very scanty vegetation.

Within the shale area which occupies the eastern part of Weary Flat surface exposures are lacking because of overwashed material from the neighboring hills, but here a few excavations show that complete oxidation of pyrite extends, as a rule, to depths of less than 20 feet. The same is true in the railroad cutting on the summit between Kimberly and Veteran, where slightly pyritized shales retain their original black coloring and where alum-like efflorescence shows that pyrite persists within a few feet of the surface. Beyond the western end of this cutting, on the Blue Jacket claim, several drill holes penetrated black, heavily pyritized shale beneath less than 25 feet of oxidized capping.

Where pyrite-bearing shales are in process of weathering gypsum is commonly present as a mineral formed by the action of sulphate solutions on calcite.

CEMENTATION.

In the Ely district the mineral depositions which may be classed under the term cementation are essentially comprised in the formation of chalcocite, the subsulphide of copper. The formation of this mineral beneath fully oxidized material is an indirect result of weathering. Copper-bearing solutions formed in the superficial belt of intense oxidation penetrate downward and deposit chalcocite through chemical reactions between copper sulphate and the sulphides chalcopyrite and pyrite. This deposition of copper involves the reduction of the cupric sulphate furnished by the solutions, but as the sulphide minerals are at the same time oxidized, the cementation process and the weathering process overlap.

The following quotation from the general treatment of the subject of cementation by Van Hise is in large part pertinent to the particular case under consideration.[1]

> The most characteristic reaction of the belt of weathering is solution. In contrast with this the most characteristic reaction of the belt of cementation is deposition in the openings of the rocks. The material deposited is derived from the belt of weathering or from alterations within the belt of cementation itself. Much of the material dissolved in the belt of weathering is continually transferred to the belt of cementation by the downward movement of water. The total amount of material thus derived is not limited to the thin belt which exists at any given time; for as a result of denudation the belt of weathering is constantly migrating downward and encroaching upon the upper part of the belt of cementation, and thus there is never a lack of material for solution which may be dissolved from the upper and transferred to the lower belt.

A further discussion of this process will be found under the heading "Chalcocite enrichment" below.

CHALCOCITE ENRICHMENT.[2]

CHEMICAL REACTIONS INVOLVED.

Since 1900, when Emmons[3] and Weed[4] presented papers dealing with the downward enrichment of sulphide ores,[5] the subject has received perhaps more attention from students of ore deposits than any other single phase in the chemistry of ore genesis. Especially with respect to the enrichment of cupriferous materials by secondary deposition, the problem has been worked out to the extent that the chemical reactions involved may be indicated in a general way at least, besides which we have a fairly good understanding of the geologic conditions which favor or oppose the operation of recognized processes on a scale large enough to produce segregation of copper minerals in bodies of commercial value. The climatic conditions under which the largest or richest bodies of secondary ores have accumulated have not been adequately discussed, so that a full analysis of this part of the subject remains to be made.

The chemistry of downward chalcocite enrichment may be treated by following in imagination the incidents of the journey made by rain water, which falls on the surface, soaks into the ground, and penetrates an existing ore body. The subject is here considered with special reference to the porphyry ores of the Ely district.

Rain water carries in solution the gases of the atmosphere, including oxygen and carbon dioxide. In arid and semiarid regions it contains also noteworthy amounts of common salt, which may be regarded as of wind-blown origin. As these waters pass into the soil and into the porous weathered capping that lies above the ore mass they come into contact with orthoclase and mica and with oxidic compounds of iron and copper (including limonite and its congeners), basic sulphates carrying iron or copper, and basic carbonates of copper. Metallic copper and the red oxide, cuprite, are also fairly common in the overburden. The silicate minerals in the

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[1] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 165–166, 1904.

[2] Spencer, A. C., Chalcocite enrichment: Econ. Geology, vol. 8, pp. 621–652, 1913 (an advance publication of the matter here given). See also Zies, E. G., Allen, E. T., and Merwin, H. E., Some reactions involved in secondary copper enrichment: Econ. Geology, vol. 11, pp. 408–503, 1916. Equations (10), (11), (13), (14), and (16) of the present paper are verified by quantitative chemical work. The reactions between cupric sulphate and both sphalerite and galena are also investigated.

[3] Emmons, S. F., The secondary enrichment of ore deposits: Am. Inst. Min. Eng. Trans., vol. 30, pp. 177–217, 1901.

[4] Weed, W. H., Enrichment of gold and silver veins: Idem, pp. 424–448; Enrichment of metallic veins by later metallic sulphides: Geol. Soc. America Bull., vol. 11, pp. 179–206, 1900.

[5] For the bibliography of this subject the reader is referred to the following papers: Tolman, C. F., Secondary sulphide enrichment of ores: Min. and Sci. Press, vol. 106, pp. 180–181, 1913. Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, 1913; The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, 1917.

capping tend to make the water alkaline,[1] but as they are only slightly attacked this tendency is likewise slight. Of the metallic minerals in the capping, those containing sulphate decompose, being somewhat soluble, the result being to produce and to leave in place limonite and copper carbonates and to furnish small amounts of iron and potash sulphates to the solution. That the copper carbonates, though relatively stable, yield gradually to solution is shown by the much smaller amount of copper in the upper part of the capping than in the lower part. Thus far the dissolved oxygen does not enter largely into the reaction, because most of the minerals of the capping are already fully oxidized. The only exceptions to be noted are cuprite and native copper. Also, the carbonic dioxide has been by no means exhausted.

Everywhere the capping, which is colored characteristically red by ferric-iron compounds, gives place by a short transition to gray or bluish ore. Just beneath the capping the solution encounters material rich in sulphide minerals that are subject to ready oxidation. Here then chemical action between the oxygenated waters and the sulphide minerals ensues, a series of reactions being initiated, of which the culminating reactions involve the deposition of chalcocite. At first the waters contain free sulphuric acid, furnished by the decomposition of pyrite, but gradually the acid becomes neutralized by bases furnished by the gangue minerals and at sufficient depth the solutions become alkaline. If the decomposing minerals are considered the reactions that occur beneath the capping present a succession of oxidations, whereas if considered with respect to the active solution, the changes are, of course, in the direction of reduction. The reactions of the series may be considered in three groups, assignable in a general way to higher, intermediate, and lower positions in the body of sulphide-containing material. In the upper part of a sulphide ore body atmospheric oxygen is the oxidizing agent; somewhat lower down, where free oxygen has been exhausted, ferric sulphate becomes active; and after the oxygen made available by this carrier has been utilized cupric sulphate furnishes oxygen. The action of cupric sulphate on pyrite and chalcopyrite results in the deposition of chalcocite and the consequent enrichment of material carrying the primary sulphides. The formation of secondary chalcocite probably involves a series of transitions or stages, as pyrite—chalcopyrite—bornite—covellite—chalcocite.

The following discussion is incomplete in that the chemistry of the copper minerals that are characteristic of the capping is not considered. Though oxidation in the portion of an ore body that lies just beneath the capping results in the compounding of cupriferous solutions, the fact must not be neglected that here also are formed the relatively stable basic carbonates and sulphates and the even more stable mineral cuprite and metallic copper.

EXPERIMENTAL WORK.

Winchell [2] and Tolman and also Read [3] obtained coatings of chalcocite by treating pyrite with slightly acid cupric sulphate solution in the presence of sulphur dioxide. In experimental work conducted at a temperature of about 200° C. Stokes [4] induced the formation of cuprous and cupric sulphides by treating pyrite with a solution of cupric sulphate slightly acidified with sulphuric acid. The work of Stokes was followed by that of Read, already mentioned, and by noteworthy observations by Sullivan. Pulverized pyrite [5] and chalcopyrite shaken in a dilute solution of copper sulphate caused the solution to lose its color. By contact with 20 grams of pyrite during three days 40 cubic centimeters of solution of cupric sulphate lost 0.04 gram of copper out of 0.097 gram originally present.

The experiments of Sullivan are noteworthy, because they show that pyrite and chalcopyrite can cause the precipitation of copper from sulphate solution at ordinary temperatures without the intervention of a strong reducing agent, such as was used by Winchell, and it is

[1] Cameron, F. K., and Bell, J. M., U. S. Dept. Agr. Bur. Soils Bull. 30, pp. 12 et seq., 1905. Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 478-483, 1916.

[2] Winchell, H. V., Geol. Soc. America Bull., vol. 14, pp. 269-276, 1903.

[3] Read, T. T., Secondary enrichment of copper-iron sulphides: Am. Inst. Min. Eng. Trans., vol. 37, pp. 297-303, 1906.

[4] Stokes, H. N., On pyrite and marcasite; U. S. Geol. Survey Bull. 186, p. 44, 1901; Experiments on the solution, transportation, and deposition of copper, silver, and gold: Econ. Geology, vol. 1, pp. 644-650, 1906.

[5] Sullivan, E. C., Discussion relating to the formation of secondary copper sulphides, in criticism of Read's paper: Am. Inst. Min. Eng. Trans., vol. 37, p. 894, 1907.

sufficiently obvious that the insoluble compound formed must be a sulphide. But the action is ordinarily so sluggish that investigators of the subject have usually failed to get visible coatings on pyrite or chalcopyrite as the result of treatment in the cold with simple solutions of cupric sulphate. However, by subjecting fragments of chalcopyrite to the action of a weak solution of cupric sulphate during three months, Welsh and Stewart [1] obtained a tarnish having the purple tinge of bornite and also "some thin black films."

The writer has found that bornite reacts readily with cupric sulphate and that indigo coatings may be formed on that mineral in a few hours by simply immersing it in a solution of the copper salt. Under prolonged treatment the indigo color first developed changes to a steely blue, which gradually fades until it gives place to the gray color so characteristic of chalcocite. Attempts to obtain similar results with chalcopyrite were not successful when cupric sulphate was used alone, but in the presence of ferrous sulphate this mineral soon becomes tarnished and passes through a series of color changes which repeated observation has shown to occur in a definite and predictable order. First the natural yellow of the mineral darkens slightly, then the surface becomes brownish and has a bronzy tone; then it becomes pink, light purple, darker purple, indigo, and shades of steely blue with gradually lessening depth. The final result is a gray coating of metallic luster, which responds to the Stokes test for chalcocite. In this test a fragment of chalcocite boiled for a moment with 10 per cent solution of ferric sulphate turns blue.[2] Between the blue and gray stages the surface of the mineral becomes yellowish or bronzy, as though the film first developed had been dissolved. In different trials the whole transition has required from 5 to 10 days and in other trials the final chalcocite stage was not attained. The same succession of colors, except the apparent reversion to chalcopyrite, may be obtained by another method, which will be described below. By means of a mixed copper and iron solution spots of blue resembling covellite may be developed on pyrite within a few hours, but so far as observed this mineral does not become uniformly coated as does chalcopyrite. When the natural acidity of a solution containing cupric sulphate was increased by adding a little sulphuric acid, chalcopyrite remained untarnished at the end of four months. Winchell [3] states that fragments of pyrite immersed in an acidified solution of cupric sulphate showed no visible alteration at the end of two years.

Although both bornite and chalcopyrite have been artificially coated with gray films of chalcocite, the gray coatings have been preceded in all successful experiments by indigo-colored films which are regarded as covellite. An unsuccessful attempt was made to form chalcocite directly by treating granulated bornite with a solution containing ferrous sulphate in molecular concentration about four times that of cupric sulphate. In this experiment the solution of ferrous sulphate was freshly reduced. The mineral and the liquids employed were freed from air by ebullition under reduced pressure at 60° C. The apparatus was sealed under exhaust and was cooled before the reagents were brought into contact with the mineral. After the lapse of four days the bornite had assumed a deep indigo color, which is taken to indicate the development of covellite. After three weeks had passed the general tone of the granular powder was gray, but some of the grains still had blue surfaces. At the end of three months the material was removed from the apparatus for examination. Under the microscope most of the grains had the appearance of chalcocite, but certain surfaces showed the color of covellite. A sample of the original mineral contained a little chalcopyrite and specks of covellite, the covellite being present in about the same proportion as in the treated material. It therefore appears that the bornite and chalcopyrite were both coated with chalcocite, whereas the original covellite remained unaltered. Similar results were attained in a solution that carried equivalent concentrations of copper and iron. In both experiments the concentration of the copper salt was about 0.02 of the formula weight of cupric sulphate. Natural covellite was treated with solutions of corresponding composition, but no change of color had taken place at the end of four months.

[1] Welsh, T. W. B., and Stewart, C. A., Note on the effect of calcite gangue on the secondary enrichment of copper veins: Econ. Geology, vol. 7, pp. 785-787, 1912.

[2] Econ. Geology, vol. 1, p. 23, 1903.

[3] Winchell, H. V., op. cit., p. 274.

These observations have led to the suggestion that the change of pyrite or chalcopyrite to chalcocite may be considered as an alteration involving a series of steps, or perhaps even a continuous progression through indefinite compounds or mixtures of iron-copper sulphides. (See table on p. 84.) Discussion of the suggested change of pyrite to chalcopyrite is not offered on account of lack of adequate basis furnished by experiment or observation. On the other hand, the change of chalcopyrite through bornite and covellite to chalcocite may be brought about artificially in different ways, some of which have been already noted, and so far as the writer's experiments have gone it seems to be impossible to change chalcopyrite to chalcocite without traversing the bornite and covellite stages, or to convert bornite into chalcocite except through covellite as an intervening product. Still it seems probable that in nature the covellite stage may not invariably enter into the series, though the chemical environment which would favor the more direct change to chalcocite can not be stated definitely at present. Experimental results with bornite and cupric sulphate indicate that the change covellite to chalcocite may occur, and there is a strong suggestion that the transformation proceeds in such a way that graduated mixtures of the cupric and cuprous sulphides are formed. This suggestion is supported by Graton and Murdoch, who have noted that natural "chalcocite" is not invariably gray, but may show different shades of steely blue, such as might result from minute intergrowth of chalcocite and covellite.

Specimens of copper ore, described by Graton and Murdoch,[1] contain the series pyrite, chalcopyrite, bornite, covellite, and chalcocite, the mutual space relations of the several minerals being such that each mineral of higher copper content appears to have been derived from the alteration of the mineral next below it in the series. Graton and Murdoch state that all these minerals [2] have been observed by them in different parts of a single polished specimen, under examination by means of the reflecting microscope, but that all the copper-bearing phases were not noted about any single grain of pyrite. Mr. Bastin, of the United States Geological Survey, has shown the writer a specimen of copper ore from Gilpin County, Colo., which represents partly altered chalcopyrite. Certain surfaces show chalcocite that apparently lies directly on the chalcopyrite. On the other surfaces, and evidently of later origin, are complex films which carry covellite outside and a substance resembling bornite beneath. In different places may be noted bronzy effects, grading in tone from the normal color of bornite to a purple hue intermediate between that of bornite and covellite, as though bornite had been plated over with a translucent film of the indigo mineral. Similar color effects are obtained, according to Read [3] by treating chalcopyrite with copper sulphate solution in the presence of sulphur dioxide. "The enriched sulphide was dark green in color; during the month it had become successively bronzy, purple, and dark steely blue." This statement is open to the interpretation that the surface of the film deposited on the chalcopyrite passed through the stages bornite and covellite and that some chalcocite was formed.

The colors observed by Read and present in the specimen from Gilpin County referred to above may be readily obtained by another simple procedure, and the observer can hardly fail to conclude that the colors noted indicate the formation of the minerals bornite, covellite, and chalcocite. If any member of the series chalcopyrite, bornite, covellite is touched by a piece of iron while it is immersed in a solution of cupric sulphate the mineral changes color almost instantly, and in a short time becomes coated with the mineral next above it in the series. The brilliant indigo of covellite changes to the dull gray so characteristic of chalcocite, bornite assumes a blue color unmistakably like that of covellite, and chalcopyrite takes on a bronzy hue resembling that of bornite. Furthermore, within a very short time the bronze plating on chalcopyrite gives place to or is hidden by a film of covellite, then within an hour or so the surface turns to a chalcocite gray, and finally metallic copper is deposited. When pyrite is used in place of a cupriferous sulphide the iron throws down a plating of metallic copper rather quickly, but by scraping away the metal and again placing the mineral in contact with iron in

[1] Graton, L. C., and Murdoch, Joseph, The sulphide ores of copper: Am. Inst. Min. Eng. Trans., vol. 45, pp. 126–181, 1914.
[2] Compare relations of bornite as described by Sales, R. H., Econ. Geology, vol. 5, p. 682, 1910.
[3] Read, T. T., Secondary enrichment of copper-iron sulphides: Am. Inst. Min. Eng. Trans., vol. 37, p. 300, 1907.

the solution it is possible to obtain deposits of copper sulphides. In this way spots, some nearly the same color as chalcopyrite and others bronzy like bornite, may be developed on pyrite along with unmistakable films of covellite and of chalcocite. If copper is used instead of iron the results are essentially the same with chalcopyrite, bornite, and covellite. For instance, covellite may be coated with chalcocite by contact with copper in a solution of cupric sulphate. It is obvious that the speed of reaction may be varied by employing different metals as inductors, or by employing minerals to cause electrolytic action. Very satisfactory results have been obtained by placing in a solution of cupric sulphate a polished specimen of intergrown chalcopyrite and pyrrhotite. Here a pinkish bronze color resembling that of bornite appeared within a few days, but gradually changed to purple, to deep purple, and finally to indigo-blue. On the most reactive grains the covellite color was fully developed in about 8 weeks, but the surface in general became blue only after 12 weeks, and even then certain areas were still bronzy. At the end of four months no gray color had developed to indicate the formation of chalcocite, but the color was a paler blue than that of natural covellite.

It may be suggested that the results described, which were obtained under ordinary temperatures, actually epitomize the course of reaction between the primary sulphides and copper salts held in oxidized solutions penetrating from the surface. Even if the means employed to produce the results in a short time are not comparable with those involved in natural processes, perhaps the conditions under which the experiments were made may be considered to be less unnatural than those prevailing in mineral syntheses effected under high temperatures.

As in nature coatings of covellite and of chalcocite are found on grains of pyrite without observable films of other members of the series between the primary and the secondary mineral, the contention might be made that intermediate products have not been involved in the change, and that the suggested step process is therefore disproved. This conclusion does not necessarily follow, because intermediate phases may exist in films too thin to be observed, or if formed they may have disappeared through conversion into some mineral higher in the series. However this may be, it would seem that the true course of the chemical action between pyrite and chalcopyrite on the one side and cupric sulphate on the other can be determined by sufficiently detailed investigations in extension of the experiments made by Sullivan, which are referred to on page 77. In future work the effects of ferrous and ferric sulphates and of sulphuric acid in known concentration should be determined.

SOURCE OF OXYGEN.

Before taking up the threefold series of reactions leading to chalcocite deposition it is of interest to inquire whether the oxygen dissolved in rain water could alone have effected the oxidation of the mass of material which has contributed the secondary copper now contained in any given ore body. This query may be answered in the negative. The ore body at Copper Flat, which is assumed to average 1.5 per cent copper, carries as much added or secondary copper as could be furnished by the complete leaching of 400 feet of primary material that contained 0.5 per cent copper and about 100 feet of existing cap rock that still contains at least 0.5 per cent copper in oxidic minerals, so that the total depth of material which has been oxidized to produce the present mass of chalcocite ore can not have been less than 500 feet. It is assumed that all of this 500 feet of material passed through the chalcocite stage, so that a good part of the copper has been several times dissolved and redeposited. If this assumption is made the amount of oxygen required would be the same as the amount necessary to oxidize 500 feet of ore such as now exists. By considering the amount of oxygen that water can absorb by contact with the air under atmospheric pressure at 7,000 feet elevation and at the present mean annual temperature of the region, it is found that, even if precipitation in the past has been 25 per cent greater than at present, and that as much as 60 per cent of the rainfall could have penetrated to the ore body, the oxygen required to oxidize 500 feet of ore like that now existing would require the contributions of rainfall during a longer period than physicists and geologists are willing to allow for the entire age of the earth.[1] Although all the assumptions

[1] Becker, G. F., The age of the earth: Smithsonian Misc. Coll., vol. 56, No. 6, pp. 1-28, 1910. This is the most recent review of estimates made by different methods. Becker regards 60,000,000 years as the figure most nearly in accord with the data now in hand.

made tend to a minimum, the time required, as calculated in this way, is still so inordinately great as to demand a different hypothesis in regard to the manner in which oxygen has been delivered to the place of sulphide decomposition. It is thought, therefore, that a large part of the oxygen must have been derived from air that circulated through the oxidized capping. The pore space in this material amounts to more than 10 per cent of the total bulk of the rock, and there can be no doubt that when the cellular openings are not water-filled they must be occupied by air. It would seem, then, that the greater part of the oxidation must take place when the sulphides are merely moist rather than when they are flooded, because then the water could receive oxygen from the air in contact with it at the same rate at which oxygen was being taken out of solution by the reactions of oxidation. Thus the water would remain saturated under conditions of partial pressure imposed by the proportions of the different gases contained in the subterranean air. Within a short distance beneath the completely oxidized and porous capping the rock becomes much less pervious, and here the solutions would be present only as capillary films essentially filling the interspaces and therefore leaving no room for air to penetrate. This train of reasoning may be carried one step further. Even if some air does penetrate the sulphide ore body the circulation would be comparatively sluggish, and as all the supply must pass by the sulphides in process of oxidation it is apparent that the oxygen might be entirely depleted, so that the gases reaching the ore mass would be merely carbon dioxide and the inert constituents of the atmosphere.

OXIDATION BY FREE OXYGEN.

Beneath the capping the sulphides first reached by waters that carry dissolved oxygen are pyrite and chalcopyrite. Just at the top of any porphyry ore body grains of these minerals persist after the removal of chalcocite coatings which they carried when the bottom of the capping was slightly higher than at present. Here, too, occurs some pyrite that never carried more than the slightest coating of chalcocite.

These sulphides are, of course, readily decomposed by the oxygen-bearing solution. The partial oxidation of pyrite with ferrous sulphate as a product has been indicated by Gottschalk and Buehler [1] by means of the two equations:

$$FeS_2 + 4O = FeSO_4 + S$$
$$FeS_2 + 6O = FeSO_4 + SO_2$$

The complete oxidation of pyrite may be considered as taking place in some such manner as is outlined by the foregoing equations and the following series,[2] in which equation (3) is derived from (1) and (2).

$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4 \qquad (1)$$
$$2FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O \qquad (2)$$
$$2FeS_2 + 15O + H_2O = Fe_2(SO_4)_3 + H_2SO_4 \qquad (3)$$

For chalcopyrite, equations essentially analogous to (1) and (3) are:

$$CuFeS_2 + 8O = FeSO_4 + CuSO_4 \qquad (1a)$$
$$2CuFeS_2 + 16O + H_2SO_4 = Fe(SO_4)_3 + 2CuSO_4 + H_2O \qquad (3a)$$

Part of the ferric sulphate formed at the upper surface of the body, where free oxygen is present, decomposes to form basic iron sulphates and hydrated iron oxide; another part may

[1] Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 7, p. 16, 1912.
[2] Stokes, H. N., On pyrite and marcasite: U. S. Geol. Survey Bull. 186, pp. 15, 19, 1901.
Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 179, 1905. (Lindgren gives an extended bibliography relating to pyrite oxidation.)
Allen, E. T., Sulphides of iron and their genesis: Min. and Sci. Press, vol. 103, pp. 413-414, 1911.
Gottschalk, V. H., and Buehler, H. A., op. cit., p. 16, 1912.
Tolman, C. F., Secondary sulphide enrichment of ores: Min. and Sci. Press, vol. 42, p. 40, 1913.

be supposed to pass downward in solution and to attack pyrite, chalcopyrite, and chalcocite. The formation of iron hydroxide may be represented in different ways; for example, as follows:

$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + 2Fe(OH)_3$$

The equations which have been given indicate that the decomposition of pyrite yields sulphuric acid and ferric sulphate. Under natural conditions solutions carrying these substances come into contact with chalcocite only a short distance below the place where pyrite and chalcopyrite are first encountered. Here, if any free oxygen remains, chalcocite is decomposed and cupric sulphate is formed, as follows:

$$Cu_2S + H_2SO_4 + 5O = 2CuSO_4 + H_2O \quad \text{(4)}$$

The reaction indicated by this equation may be considered as using up the last of the free oxygen which can reach a body of enriched porphyry ore under ordinary conditions. In places immediately below those where the free oxygen has been entirely consumed, ferric sulphate and cupric sulphate are present. Both these compounds are capable of oxidizing the sulphides, but ferric sulphate is more readily reduced than cupric sulphate, and it may be supposed to undergo almost complete reduction to ferrous sulphate before the cupric sulphate can come into play as an oxidizing agent.

OXIDATION BY FERRIC SULPHATE.

Where chalcocite and the other sulphides occur together, and especially where, as in the Ely ore bodies, the chalcocite is in actual contact with pyrite or chalcopyrite in the form of coatings, it is the first mineral to be attacked by ferric sulphate and it acts as a temporary protection against the decomposition of these minerals. The last point has been proved experimentally by Gottschalk and Buehler [1] and fully confirmed by Wells.[2]

According to Vogt [3] the action of ferric sulphate on chalcocite, which would come into play below the shell of nearly complete oxidation, is as follows:

$$Cu_2S + 2Fe_2(SO_4)_3 = 4FeSO_4 + 2CuSO_4 + S \quad \text{(5)}$$

But if the sulphur set free in the nascent state reacts with more ferric sulphate, sulphur dioxide might be formed, and with still more ferric sulphate sulphuric acid will result, and eventually we may arrive at the equation suggested by Weed,[4] which may be deduced from equations (5), (7), and (8):

$$Cu_2S + 4H_2O + 5Fe_2(SO_4)_3 = 10FeSO_4 + 4H_2SO_4 + 2CuSO_4 \quad \text{(5a)}$$

Equation (5a) may be regarded also as summarizing a series of oxidation steps such as the following:

$$\begin{aligned} &Cu_2S + Fe_2(SO_4)_3 = CuS + 2FeSO_4 + CuSO_4 \\ &CuS + Fe_2(SO_4)_3 = S + 2FeSO_4 + CuSO_4 \\ &S + Fe_2(SO_4)_3 = 2SO_2 + 2FeSO_4 \\ &4H_2O + 2SO_2 + 2Fe_2(SO_4)_3 = 4H_2SO_4 + 4FeSO_4 \end{aligned}$$

The same reagent, ferric sulphate, may be considered as acting on pyrite in a manner represented more or less adequately by the following group of equations, where equation (9) is derived by means of equations (6), (7), and (8):

$$\begin{aligned} &FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S \quad &\text{(6)} \\ &S + Fe_2(SO_4)_3 = 2FeSO_4 + 2SO_2 \quad &\text{(7)} \\ &SO_2 + Fe_2(SO_4)_3 + 2H_2O = 2FeSO_4 + 2H_2SO_4 \quad &\text{(8)} \\ &FeS_2 + 7Fe_2(SO_4)_3 + 8H_2O = 15FeSO_4 + 8H_2SO_4 \quad &\text{(9)} \end{aligned}$$

[1] Gottschalk, V. H., and Buehler, H. A., op. cit., p. 31, 1912.
[2] Wells, R. C., Electrical potentials between conducting minerals and solutions: Washington Acad. Sci. Jour., vol. 2, pp. 514–516, 1912.
[3] Vogt, J. H. L., Problems in the geology of ore deposits: Am. Inst. Min. Eng. Trans., vol. 31, p. 166, 1902.
[4] Weed, W. H., Enrichment of gold and silver veins: Am. Inst. Min. Eng. Trans., vol. 30, p. 429, 1901.

Equation (9) is comparable with equation (1). For chalcopyrite an expression similar to (9) is:

$$CuFeS_2 + 8Fe_2(SO_4)_3 + 8H_2O = 17FeSO_4 + CuSO_4 + 8H_2SO_4 \quad \text{(9a)}$$

In the study of places in the ore pits where the decompositions indicated above are in progress the observer must remark the short space that intervenes between capping fully oxidized and the subjacent ore, wherein to casual observation chalcocite shows no sign of having been attacked. So far as the decomposing power of the downward-moving waters depends on the presence of free oxygen, that power appears in general to be almost spent within a shell of material scarcely more than 3 feet thick, though a certain amount of impoverishment may be going on to a considerably greater depth through the action of ferric sulphate on chalcocite (equations (5) and (5a)). It should be noted, of course, that the under surface of the oxidized capping is very irregular as a natural result of fractures in the ore mass. A cross section of the surface between the capping and the ore resembles the exaggerated profile comparing mountain heights which is shown in our older school geographies.

PARTIAL SUMMARY OF CONCLUSIONS.

The foregoing discussion should make clear the following points: First, that waters from the surface which penetrate a body of porphyry ore will decompose strongly the metallic sulphides present so long as they contain or can acquire free oxygen and so long as they contain ferric sulphate. Second, that where chalcocite, pyrite, and chalcopyrite are all present the chalcocite will be largely and perhaps fully decomposed before the other minerals are attacked. Third, that the decomposition of chalcocite, pyrite, and chalcopyrite effects the reduction of ferric salts contained in the solution. Fourth, that the decomposition of pyrite, chalcopyrite, and chalcocite each tends to produce sulphuric acid. Fifth, that the decomposition of chalcocite and of chalcopyrite furnish cupric sulphate to the solution. Briefly, then, when oxygen-bearing waters reach the upper part of the mass of sulphide-bearing rock the consumption of the dissolved oxygen begins at once, and before the waters can progress downward for any considerable distance all this free oxygen is used up in decomposing the sulphides. Within a short distance also, ferric sulphate is largely reduced to ferrous sulphate. So long as free oxygen is present the decomposition of chalcocite will progress until no sulphuric acid remains uncombined. It should be added that cuprous and ferric ions are invariably present in small concentration [1] in any solution containing cupric and ferrous sulphates.

OXIDATION BY CUPRIC SULPHATE.

The progress of the surface waters has been followed to the point where they contain no free oxygen and only a small amount of ferric sulphate, but where they carry ferrous sulphate, cupric sulphate, and sulphuric acid. Thus far on its downward journey it may be assumed that the cupric sulphate has been protected from reduction because at ordinary temperatures and in acid solution it is less readily reduced than ferric sulphate.[2]

Beyond the place where the ferric sulphate concentration in the solution has been reduced to a certain minimum, cupric sulphate comes into play as an oxidizing agent. The sulphides with which the solution comes into contact are chalcocite, chalcopyrite, and pyrite. At ordinary temperatures, in the absence of oxygen, dilute sulphuric acid does not decompose chalcocite, and Wells, in a record of experiments given by W. H. Emmons,[3] says that chalcopyrite and pyrite are probably not attacked under the same conditions. It is to be noted, however, that at high temperatures cupric sulphate reacts with chalcocite [4] to form covellite and cuprous sulphate, and on cooling the cuprous sulphate decomposes, a product of its decomposition being metallic copper. On the other hand, it would appear that cupric sulphate does attack chal-

[1] Stokes, H. N., Experiments on the solution, transportation, and deposition of copper, silver, and gold: Econ. Geology, vol. 1, pp. 644–650, 1906. Wells, R. C., Discussion on secondary enrichment: Econ. Geology, vol. 5, pp. 481–482, 1910.

[2] Stokes, H. N., Econ. Geology, vol. 1, p. 646, 1906.

[3] U. S. Geol. Survey Bull. 529, pp. 59–60, 1913.

[4] Stokes, H. N., op. cit., p. 648.

copyrite and pyrite at ordinary temperatures, so that iron passes into solution as ferrous sulphate, sulphuric acid is formed, and a copper sulphide is deposited. The last part of this statement is supported by the fact that covellite and chalcocite are common products in nature where copper sulphate solutions from the upper zone of oxidation have encountered pyrite and chalcopyrite. Although very little quantitative laboratory work has been done in connection with this subject, the work of Stokes[1] has furnished two equations which aim to represent the changes pyrite to covellite and pyrite to chalcocite in molecular proportions.

Stokes's equation for chalcocite that is formed by replacement of pyrite through the action of cupric sulphate may be built up empirically by the method which has been used in the derivation of equations (3) and (9). (See pp. 81–82.) Thus:[2]

$$2FeS_2 + 2CuSO_4 = Cu_2S + 2FeSO_4 + 3S$$
$$3S + 2CuSO_4 = Cu_2S + 4SO_2$$
$$6H_2O + 5SO_2 + 2CuSO_4 = Cu_2S + 6H_2SO_4$$
$$12H_2O + 5FeS_2 + 14CuSO_4 = 7Cu_2S + 5FeSO_4 + 12H_2SO_4 \qquad (10)$$

In a similar manner the following equation indicating the replacement of pyrite by covellite may be deduced:

$$4H_2O + 4FeS_2 + 7CuSO_4 = 7CuS + 4FeSO_4 + 4HSO_4{}^{3} \qquad (11)$$

As thus derived the Stokes equations appear each to summarize a succession of oxidation effects. It is probable that the complete reactions involve several steps, including the temporary formation of chalcopyrite and perhaps the progressive formation of several mineral species intermediate in composition between chalcopyrite and chalcocite. The minerals of what may be called the pyrite-chalcocite series are given in the following table, in which the order is that of increasing copper content:

Pyrite-chalcocite series.

Mineral.[a]	Formula.	Constitution according to Hintze.
Pyrite	FeS_2	
Chalcopyrrhotite	$CuFe_4S_6$	$(FeS_3)\ (Fe, Cu'')_3$.
Barracanite	$CuFe_2S_4$	$(FeS_3)\ Cu''$.
Chalmersite	$CuFe_2S_3$	$FeS_3\ (FeCu')$.
Chalcopyrite	$CuFeS_2$	$Cu_2S.Fe_2S_3$.
Barnhardtite	$Cu_4Fe_2S_5$	$2Cu_2S.Fe_2S_3$.
Bornite (1)[b]	Cu_3FeS_3	$3Cu_2S.Fe_2S_3$.
Bornite (2)	Cu_5FeS_4	$5Cu_2S.Fe_2S_3$.
Bornite (3)	$Cu_9FeS'_6$	$9Cu_2S.Fe_2S_3$.
Covellite	CuS	CuS.
Chalcocite	Cu_2S	Cu_2S.

[a] The name cubanite has been used in place of barracanite and also in place of chalmersite. Joseph Murdoch (Microscopical determination of the opaque minerals, p. 73) regards chalcopyrrhotite, cubanite (barracanite), and barnhardtite as mechanical mixtures.
[b] C. A. F. Hintze (Handbuch der Mineralogie, Band 1, Abt. 1, p. 905) gives the three formulas here presented in his discussion of bornite. The second formula is the one adopted by B. J. Harrington (Am. Jour. Sci., 4th ser., vol. 16, p. 151, 1903).

No discussion of the minerals standing between pyrite and chalcopyrite in the table is here attempted, but it may be suggested that the other iron-bearing members of the series are formed successively as stages in the production of covellite or chalcocite through the action of cupric sulphate on pyrite or chalcopyrite. The basis for this suggestion has already been given (p. 79). Here the contemplated change, pyrite to chalcopyrite, though not yet adequately verified by experimental work, may be indicated by an equation which is readily deduced by the method employed in arriving at equation (10):

$$8H_2O + 8FeS_2 + 7CuSO_4 = 7CuFeS_2 + FeSO_4 + 8H_2SO_4 \qquad (12)$$

[1] Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: Econ. Geology, vol. 2, pp. 15–23, 1906.
[2] For the first equation see Vogt, J. H. L., Problems in the geology of ore deposits: Am. Inst. Min. Eng. Trans., vol. 31, p. 166, 1902. As intermediate between the first and second equations the following reaction should be considered: $4H_2O + 6CuSO_4 + S = 3Cu_2SO_4 + 4H_2SO_4$. (See Stokes, H. N., On pyrite and marcasite: U. S. Geol. Survey Bull. 186, p. 44, 1901.) For the fourth equation see Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: Econ. Geology, vol. 2, p. 22, 1906.
[3] Stokes, H. N., op. cit., p. 22.

Next, for the changes chalcopyrite to chalcocite and chalcopyrite to covellite, we may have summary equations analogous to (10) and (11), thus:

$$8H_2O + 5CuFeS_2 + 11CuSO_4 = 8Cu_2S + 5FeSO_4 + 8H_2SO_4 \qquad (13)$$
$$CuFeS_2 + CuSO_4 = 2CuS + FeSO_4 \qquad (14)$$

Equation (13) and analogous expressions, which may be deduced to indicate the same final products where barnhardtite or any member of the bornite group is the mineral undergoing replacement, are all reducible to a single expression in which the active part of the mineral molecule is considered to be solely the iron sulphide which it contains. Equation (13) may be written thus:

$$16H_2O + 5Cu_2SFe_2S_3 + 22CuSO_4 = 5Cu_2S + 11Cu_2S + 10FeSO_4 + 16H_2SO_4.$$

As the expression suggests that $5Cu_2S$ has undergone no change, we have by subtraction:

$$16H_2O + 5Fe_2S_3 + 22CuSO_4 = 11Cu_2S + 10FeSO_4 + 16H_2SO_4 \qquad (15)$$

Finally, by algebraically combining equations (10) and (11) or equations (13) and (14), so as to eliminate FeS_2 from the first or $CuFeS_2$ from the second pair, an expression is found for the conversion of covellite into chalcocite :

$$4H_2O + 5CuS + 3CuSO_4 = 4Cu_2S + 4H_2SO_4 \qquad (16)$$

When presented in this essentially deductive manner the chemistry of the secondary copper sulphides centers about the three reactions represented by equations (12), (15), and (16), and these reactions are therefore regarded as particularly worthy of investigation by quantitative work in the chemical laboratory.

ALTERATION OF COVELLITE TO CHALCOCITE.

The supposed change of covellite to chalcocite under the action of cupric sulphate (equation 16) was not established by experiments in which essentially pure natural covellite was used, but, as already stated, the transition ensues where bornite which has been coated with covellite is further treated with a solution of cupric sulphate and the change in color from indigo to gray takes place more quickly in a solution that contains ferrous sulphate in addition to cupric sulphate. The experiment described on page 78 was devised with the expectation that chalcocite would be directly formed without the intervening covellite stage. This expectation was based upon the known reversible reaction between ferrous and cupric sulphates which produces cuprous and ferric ions in the solution:[1]

$$2CuSO_4 + 2FeSO_4 \rightleftharpoons Cu_2SO_4 + Fe_2(SO_4)_3.$$

Though chalcocite was not directly formed, the observed hastening of the final chalcocite stage strongly suggests that the relative concentrations of cupric and ferrous salts in the downward-moving solution may be one of the principal factors in determining whether covellite or chalcocite is to be the end stage in the sulphide enrichment of copper ores. In this experiment the color change from covellite blue to chalcocite gray occurs by gradation through steely blue. The possible import of this succession of colors, which is observed also when natural covellite is touched by iron or copper while immersed in a solution of cupric sulphate has been discussed on page 79.

In addition to the experiments with bornite the attempt was made to change covellite to chalcocite by treating it with a mixture of cupric and ferrous sulphate. In each of the three experiments 1 gram of powdered covellite was treated in a sealed tube with about 55 cubic

[1] Stokes, H. N., On pyrite and marcasite: U. S. Geol. Survey Bull. 186, pp. 44-45, 1901. This reversible reaction was studied by Stokes who says: "It is doubtless to the reduction of the cupric sulphate by sulphur and by ferrous sulphate that the formation of chalcocite from pyrite is to be ascribed."

centimeters of solution from which all air had been exhausted. In one experiment the strength of the solution in copper was about 0.02 formula weight, and in iron 0.17 formula weight; in another experiment copper was 0.02 formula weight and iron 0.017 formula weight; in the third experiment no cupric sulphate was used, and ferrous sulphate was present in about 0.09 formula weight. At the end of three months the mineral showed no notable change in color in any of the tubes. Chalcocite similarly treated with ferrous sulphate solution also remained apparently unchanged.

If the reaction contemplated by equation (16) when read from left to right could be established, the result would be noteworthy in the theory of chalcocite deposition.[1]

$$4H_2O + 5CuS + 3CuSO_4 \rightleftharpoons 4Cu_2S + 4H_2SO_4$$

Inspection of this expression indicates that, in a solution which already contains sulphuric acid in any considerable concentration, covellite rather than chalcocite would be the stable mineral. In other words, a solution of relatively high acidity would tend to the formation and persistence of covellite whereas decreasing acidity would favor deposition of chalcocite. Thus, theoretically, it follows also that where silicate or carbonate minerals are present to take up free sulphuric acid chalcocite would be the more stable of the two sulphides, a conclusion which is in harmony with the very considerable aggregate loss of bases during the alteration of the pyritized porphyry through chalcocite ore to the leached and fully oxidized capping and also with the observed alkaline reaction of the Brooks mine water.

VOLUME RELATIONS IN CHALCOCITE DEPOSITION.

The replacement of pyrite by chalcocite, if considered as taking place according to equation (10), would involve a material increase in volume, whereas the corresponding replacement of chalcopyrite by chalcocite according to equation (13) would occur with a slight decrease in volume. Definite figures can not of course be given to represent these theoretical changes in volume, but if the limits are calculated[2] the figures for the change pyrite to chalcocite show expansion ranging between 54 and 75 per cent, whereas those for the change chalcopyrite to chalcocite show contraction ranging from 6 to 15 per cent. From this it would appear that the replacement of chalcopyrite by chalcocite would take place more readily than the replacement of pyrite by chalcocite if cupric sulphate is the only reagent in the solution to be considered. That chalcopyrite is actually more susceptible than pyrite to replacement by chalcocite is strikingly illustrated by relations noted in specimens of porphyry ore from the Ely mines. Detailed examination of polished surfaces and of thin sections shows that as a rule most of the secondary chalcocite has formed on chalcopyrite. In certain specimens containing no visible chalcopyrite the pyrite has been deeply changed to chalcocite, but where both of the primary sulphides are present and where the chalcopyrite grains are deeply coated with chalcocite, the neighboring grains of pyrite are either covered by very thin films or have not been coated at all. Similar relations of sensitiveness to chemical attack are exhibited under the following experimental conditions: If fragments of chalcopyrite and of pyrite are touched simultaneously by pieces of iron while immersed in a solution of cupric sulphate a very noteworthy effect is immediately apparent on the surface of the chalcopyrite, but the pyrite at first seems to be inert. It is possible by this procedure to form on chalcopyrite a brilliant blue coating, presumably covellite and to withdraw the pieces of iron while the pyrite is still bright and fresh.

From the volume relations which have been indicated and the observed scanty replacement of pyrite by chalcocite in the porphyry ores, the writer believes that in general the replacement of pyrite by chalcocite does not progress unless the active solution contains, in addition to cupric sulphate, some other substance capable of attacking either the pyrite or the chalcocite.

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[1] This has been done by Zies, Allen, and Merwin (op. cit.).

[2] In these calculations the figures used for specific weight are: Pyrite, 4.83 to 5.2; chalcopyrite, 4.1 to 4.2; chalcocite, 5.5 to 5.8.

Many observations indicate that metasomatic replacement of one mineral by another usually takes place in such a way that the new mineral occupies the same space as the old mineral. This relation has been convincingly set forth by Lindgren [1] and by Bastin.[2]

With reference to secondary chalcocite, Ransome [3] makes the following statement:

In the Miami-Inspiration ore bodies of the Globe district many of the specks of chalcocite are solidly embedded in the silicified schist and in veinlets of quartz, so that they have the appearance of being products of the earliest period of mineralization. Yet the evidence here is conclusive that these specks of chalcocite have resulted from the alteration of pyrite and chalcopyrite, and probably in most cases exactly fill the space once occupied by the parent mineral. All stages may be seen from pyrite thinly coated with chalcocite to solid chalcocite.

If the relation of equal volume holds, as it is believed to hold, in the replacement of pyrite by chalcocite it is obvious that not all the changes involved are summarized by the Stokes equation. In replacement by equal volume the product contains less chalcocite than would correspond molecularly with the pyrite that has been destroyed, and it seems that the removal of the excess material must be accounted for as a result of the attack of some reagent other than cupric sulphate. It is probable that the replacement of pyrite by chalcocite is promoted by the presence of a minor concentration of ferric sulphate in the active solution. It is difficult to obtain a visible deposit of copper sulphide on pyrite or chalcopyrite by treatment with a solution of cupric sulphate alone, yet blue coatings may be readily formed on either mineral if ferrous sulphate is added. This fact may have some bearing on the problem under consideration. The reaction is accelerated by heating, but it takes place within a few hours at ordinary temperatures. During the progress of the reaction insoluble iron compounds are precipitated, and after sulphide deposition has taken place the solution responds to the test for ferric iron with potassium sulphocyanide. As already noted (p. 85), ferric sulphate is formed by the interaction of ferrous and cupric sulphates in solution, so that obviously secondary covellite and chalcocite are both formed in the presence of at least minute concentrations of ferric sulphate.

COMPOSITION OF MINE WATER.

Chemical analyses of samples of water from the Ruth and Brooks porphyry mines are given in the following table:

Composition of waters from porphyry mines.

[Parts per million.]

	1	2		1	2
Na	35	33	Cl	8.5	55.4
K	11	27.6	CO_3	[a] 38	
Ca	126	105.7	HCO_3	[a] 117	
Mg	Trace.	26.3	SiO_2	28	94.0
Fe''	19	36.4			
Fe'''	None.	42.0		638.5	976.4
SO_4	256	556.0	Reaction to litmus	Alkaline.	Not stated.

[a] Total CO_3 distributed between CO_3 and HCO_3 in proportions to balance the reacting values of bases and acids. As reported, the analysis shows HCO_3 156 parts per million.

1. Water from Brooks inclined shaft of the Giroux Consolidated Co., collected in September, 1910. The preceding summer had been dry, and the water stood about 230 feet below the surface. A test was made for copper, but the result was negative. Analysis made in the laboratory of the U. S. Geological Survey by Chase Palmer. Immediately after the sample was taken ferrous iron was determined to be 22 parts per million, so that the iron was all in the ferrous state. For this determination the writer is indebted to Mr. A. J. Sale.

2. Water from Ruth mine. Composition calculated to parts per million of ions, from analysis by Harry East Miller, recorded by A. C. Lawson (California Univ. Dept. Geology Bull., vol. 4, p. 332, 1906).

[1] Lindgren, Waldemar, The nature of replacement: Econ. Geology, vol. 7, pp. 521-535, 1912.
[2] Bastin, E. S., Metasomatism in sulphide enrichment: Econ. Geology, vol. 8, pp. 51-63, 1913.
[3] Ransome, F. L., Criteria of downward sulphide enrichment: Econ. Geology, vol. 5, p. 218, 1910.

The analysis of the Ruth mine water was originally stated in the following form:

Analysis of Ruth mine water.

[Grains per gallon of 231 cubic inches.]

SiO_2 + insoluble matter	5.50	$Fe_2(SO_4)_3$	8.78
NaCl	4.88	$CaSO_4$	20.99
KCl	.55	$MgSO_4$	7.61
K_2SO_4	2.96	Organic matter and water of sulphates	6.96
$FeSO_4$	5.77		

In regard to this analysis Lawson[1] says:

It is probable that the proportion of ferric sulphate is higher than is actually the case in the mine, owing to the difficulty of preventing oxidation of the ferrous salt. The result is interesting as an indication of the materials which are being leached from the porphyry by the descending meteoric waters. Another sample of the mine water analyzed in the mine laboratory as expeditiously as possible after collection, by Mr. Herbert Ross, gave results from which it would appear that the iron of the mine water is nearly all in the ferrous state.

The form in which the Ruth mine water analysis is stated does not enable classification of the water, but the Brooks mine water analysis indicates the following characteristics:[2]

Characteristics of Brooks mine water.

	Per cent.
Primary salinity	20.6
Secondary salinity	42.8
Primary alkalinity	00.0
Secondary alkalinity	29.0
Subalkalinity	7.6
	100.0

It should be noted that the mine waters that have been analyzed are in a way the complement of the pyritized porphyry, for they contain in solution the bases which are known to have been leached out of the rock during the processes of enrichment and of ore decomposition.

The high proportion of lime in both of the mine waters indicates that the mines have received contributions of water through percolation from the limestone masses which adjoin the ore masses, because the porphyry ores are essentially free from lime. The indicated absence of magnesium in the Brooks mine water appears to be anomalous, for the analyses of samples 153 and 154 indicate that the ore porphyry of the district carries more of this element than it does of lime (p. 57).

The alkaline reaction of the Brooks mine water bears out the suggestion that has been made (p. 89) that the waters from which chalcocite has been deposited were probably not strongly acid.

CHEMICAL CHARACTER OF CHALCOCITE-DEPOSITING SOLUTIONS.

Among the products of the oxidation of pyrite is sulphuric acid, so that solutions which carry copper from the places of decomposition to those of chalcocite deposition must be distinctly acid when they are formed, and it is well known that waters collected from the upper levels of mines in pyritic ore bodies usually show an acid reaction. However, carbonate and many silicate gangue minerals are decomposed by acids, and when such minerals are long in contact with the descending solution their bases are taken into combination, and the original acidity of the solution gradually disappears. Attention has been directed to the fact that the waters in certain copper mines are less and less acid at lower and lower levels,[3] and are alkaline in some of the deepest workings, and there can be little doubt that this condition is general. A sample of water collected from a point near the top of the water table in one of the Ely porphyry mines was found to be distinctly alkaline. (See p. 87.) Although these

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 332, 1906.
[2] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, p. 13, 1911.
[3] Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, pp. 60, 89, 1913.

observations have led to the suggestion that a reduction of acidity in descending metalliferous solutions may be important in connection with secondary sulphide deposition,[1] it is not obvious merely because solutions in a given case have become alkaline as a result of reaction with gangue minerals that the conclusion must follow that no part of the dissolved copper could have been deposited before the alkaline state had been reached. The opposite contention, that acidity may be necessary for the progress of copper sulphide enrichment, is suggested by Welsh and Stewart,[2] who found by experiment that although chalcopyrite by treatment with a solution of cupric sulphate may be coated with films resembling bornite, the presence of calcite prevents the reaction. These writers state that "the ordinary copper sulphate is acid and the effect of the calcite may be to neutralize this acidity." The present writer has observed that artificial coatings may be readily formed on chalcopyrite in solutions possessing only the slight acidity due to the presence of cupric and ferrous sulphates, but that when a little sulphuric acid is added the mineral remains untarnished. Winchell[3] also states that although he obtained chalcocite in acid solution in the presence of sulphur dioxide, without this reducing agent pyrite was not visibly attacked by cupric sulphate at the end of two years.

From the foregoing observations it appears likely that under natural conditions chalcocite will not replace primary sulphides when the acidity of the cupriferous solutions exceeds some rather small minimum, but that an alkaline condition is not necessary in order that the reaction may proceed.

CHALCOCITE DEPOSITION IN THE PRESENCE OF CALCITE.

At several places in the Ely district chalcocite has been noted in the form of secondary coatings on pyrite and chalcopyrite disseminated through masses of partly weathered metamorphosed limestone lying beneath a surficial shell of fully oxidized material. Considerable bodies of enriched material in altered limestone masses have been developed in the Old Glory mine, where the original matrix of the primary sulphides, though consisting largely of lime-silicate minerals, also comprises considerable calcite. In material of this sort the deposition of chalcocite would appear to be uncommon according to Bard,[4] who states, as a result of his observations, that sulphide enrichment is generally absent where the gangue comprises much calcite. The explanation offered is that copper sulphate reacts with calcite to form copper carbonate, so that only an excess of the copper salt above that required for replacement of calcite can finally appear as covellite or chalcocite.

Welsh and Stewart[2] treated chalcopyrite in the presence of calcite, and also chalcopyrite mixed with quartz, with moving solutions of cupric sulphate in upright tubes so arranged that the lower part of the column was continually flooded. These writers say:

> In the calcite-chalcopyrite mixture the calcite above the water level was distinctly tinged with green, while none of the chalcopyrite showed any change. In the tube containing quartz and chalcopyrite no change above the water level was noted, but the chalcopyrite for 4 inches below this level showed clearly the purple tinge of bornite, and upon closer examination some thin black films were found.

In this experiment the solution draining from the calcite-chalcopyrite mixture still contained cupric sulphate, and the authors suggest that secondary sulphide was not precipitated because the solution may have been rendered alkaline through reaction with the calcite. Whether this explanation is the true one or not, on its face the experiment bears out the suggestion presented by Bard—that the presence of calcite is unfavorable to the deposition of secondary copper sulphides. However, the present writer has found that calcite does not precipitate copper from a solution containing both cupric and ferrous sulphates, and, furthermore, that by means of such a solution pyrite and chalcopyrite may be readily coated with secondary sulphide films in the presence of large amounts of calcite.

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[1] Wells, R. C., discussion of The criteria of downward enrichment, by F. L. Ransome: Econ. Geology, vol. 5, p. 482, 1910. Emmons, W. H., op. cit., p. 60.

[2] Welsh, T. W. B., and Stewart, C. A., Note on the effect of calcite gangue on the secondary enrichment of copper veins: Econ. Geology, vol. 7, pp. 785-787, 1912.

[3] Winchell, H. V., Geol. Soc. America Bull., vol. 14, p. 274, 1903.

[4] Bard, D. C., Absence of secondary copper-sulphide enrichment in calcite gangues: Econ. Geology, vol. 5, pp. 59-61, 1910.

Because specimens of the chalcocite-bearing ore from the Old Glory mine now contain no calcite, the possibility remains that here the secondary sulphide was not actually deposited in the presence of calcite but only in material from which calcite had previously been removed as the result of solution by sulphuric acid. Observations more detailed than those that have been made would be required to determine whether the last of the original calcite disappeared before or after chalcocite enrichment occurred.

RELATIONS OF THE WATER TABLE DURING CHALCOCITE DEPOSITION.

The position of standing water in the porphyry mines of the Ely district changes from time to time. No systematic record of rise and fall is at hand, but in the autumn of 1910 the water in some of the mines was about 30 feet higher than in the autumn of 1909. In general the chalcocitized porphyry, though it lies mainly above the water table, continues downward below the highest position of standing water, and possibly below the levels to which the water top may sink at the lowest stage. It seems probable, however, that no porphyry containing so much as 0.5 per cent of secondary copper occurs at lower levels than those where the top of ground water may have stood during the dry epochs of the Quaternary period. Before the first expansion of the Great Basin lakes and in the interval between the two expansions the climate was probably somewhat dryer than it has been during the present epoch, and the mean position of standing water may have been for considerable periods from 50 to 100 feet lower than it is now. In the Alpha mine, where the ore bodies are not of the disseminated type but are rather of the nature of compact segregations, the water table is now fully 200 feet higher than it has been formerly. Here oxidation has penetrated more than 1,200 feet below the surface, though the natural level of standing water is at a depth of about 1,020 feet. On the other hand, during those epochs when the Great Basin lakes were in flood stage the water level in the porphyry ore masses certainly stood much above its present mean position. Deposits of iron-copper sinter that occur near some of the mines furnish good evidence that the chalcocite ore was once at least submerged to a height so great that part of the products of its oxidation escaped into the surface drainage. This event is correlated on physiographic evidence with the first Quaternary humid epoch, when rather steady streams undoubtedly flowed in the district, and as the next later humid epoch seems to have been wetter than the first, the ore bodies may have been submerged a second time. If the later flood stage of the ground water was higher than the earlier, the top of the ore body would have been below water level, a supposition which would account for the lack of sinter deposits in the swales which were eroded during the second humid epoch. Presumably similar alternations of low and high water were characteristic of late Pliocene time, when the principal segregation of chalcocite is believed to have occurred.

It would seem that a considerable body of sulphides lying above the water table would offer the best possible conditions for the retention of copper taken into solution by oxidizing surface waters. This suggestion is based in part on the conception that the speed of reaction between primary sulphides and solutions carrying copper is slow under the most favorable conditions, and presumably extremely slow after grains of pyrite and chalcopyrite have received moderately deep films of chalcocite. A long journey, involving contact with a very large number of primary sulphide grains, would be more favorable to precipitation of a larger proportion of the dissolved copper than a short journey, during which correspondingly few grains would be encountered by any unit volume of solution. A low water table and a high position of the ore top would tend to produce a thick ore body of rather uniform grade from the vicinity of its top to a place somewhere near its bottom. So long as the solutions could be exhausted above standing water the enriched material would grade imperceptibly into the primary material. On the other hand, if copper were not exhausted above standing water, precipitation should continue within a relatively thin shell of material just below the water table, because the solutions in this situation would necessarily move laterally rather than downward, and their flow would be at a diminished rate, permitting much longer contact with reacting primary sulphides in a small mass of material. When the ground water stood well up in material previously enriched, the tendency would be to produce layers of ore carrying more than the average amount of copper. What is possibly the record of a former high stage of ground water is seen in the local occurrence of particularly rich layers of ore beneath 20 to 50 feet of medium-grade material lying just under the oxidized capping.

GEOLOGIC AGE OF CHALCOCITE ENRICHMENT.

In the foregoing sections, which deal with the chemistry of chalcocite enrichment, the idea has been developed that the porphyry ore bodies of the Ely district are currently subject to decomposition in their upper portions and to accretion of copper in their lower portions. A similar downward transfer of copper has undoubtedly been going on in the past, and it is obvious that the present ore bodies are the successors of similar segregations which formerly existed above the places where the enriched material is now found. The rocks along the metamorphosed zone were undoubtedly charged with pyrite and chalcopyrite for several hundred and perhaps for several thousand feet above the present surface, and the earliest formation of disseminated chalcocite ores may have occurred at a time when, as a result of erosion, the masses of pyritized rock first came under the action of oxidizing solutions. This conception would carry the operations of chalcocite enrichment a long way back into the past.

It is held that the volcanic rocks of probable Pliocene age which now occur from place to place within the district formerly extended over wider areas and probably covered the entire ore belt; but the pyritized rocks had been undergoing erosion for a long time before the period of volcanic extravasation, and there can be no reasonable doubt that the processes of chalcocite enrichment had been going on hand in hand with the gradual lowering of the land surface. However, it is not safe to conclude that ore bodies comparable with those of the present existed at any particular time, and it is not possible to state whether or not thick masses of disseminated chalcocite ore existed when the rhyolite lavas flowed out on the old land surface.

The processes of weathering and chalcocite deposition must have been in abeyance during a long period devoted to the erosion of the rhyolite, but when the rocks of the metamorphosed zone had been partly stripped these processes again came into play and have since been operative, except for interruptions that may have occurred when the ore bodies were overtopped by ground water.

On physiographic grounds it seems certain that there has been practically no erosion of the ground above the ore bodies since the beginning of the pre-Lake Bonneville epoch (the first division of Quaternary time) during which great alluvial cones were built up throughout the region about the mouths of lateral canyons that open out into the broad northward-trending valleys. All the secondary copper contained in the present ore bodies had therefore been segregated below the present surface before the close of the Pliocene, and the thick masses of enriched material which exist are due to conditions during the later part of Pliocene time that were prevailingly favorable for the precipitation and accumulation of copper in the form of chalcocite.

Though essentially all of the secondary or added copper now present in the disseminated ore bodies had been brought together before the beginning of Quaternary time it seems almost necessary to believe that redistribution of the metal has since been going on, so that the tops of the ore bodies have been gradually falling lower and lower. No basis has been found, however, for determining what portion of the depth of oxidized capping is attributable to Quaternary decomposition.

ORE DEPOSITS.

HISTORICAL NOTES.

Mining activity in eastern Nevada began in 1862, with the discovery of silver-bearing ore near the Overland Stage Route, at the present town of Austin, Lander County. Within the next four years the Reese River mining district, then organized, was subdivided into no less than 20 districts. Austin, located almost at the center of the State, became the rendezvous and supply point for prospectors whose expeditions in a remarkably short period served to outline the metal-producing possibilities of a very wide scope of country. The difficulties of exploration in a region all of which must be classed as worse than semiarid and much of which approaches total aridity can hardly be overestimated. In spite of all natural obstacles discovery and development of mineral deposits progressed apace and before 1866 productive mines were in operation in several districts near Austin, at Battle Mountain, Cortez, Egan Canyon, and other camps. Eureka district was organized in 1864 and White Pine and Pioche (Ely mining district) in 1865. As early as 1866 an unsuccessful lead furnace had been erected at Eureka, and in 1867 the pioneer mill at White Pine (which worked the ores of the Monte Cristo mine) had begun operations, though under seemingly precarious conditions. Doubts of success were dispelled when the presence of rich silver chloride ores on Treasure Hill was revealed by an Indian in September, 1867. The active prospecting which followed was rewarded by many rich discoveries, and the famous White Pine excitement brought no less than 10,000 to 12,000 people to the district within the next year.

In 1869 White Pine County was created out of Lander County, and its seat was located at Hamilton, the principal town of the district. Serious development was continued in the Eureka and adjoining districts, where a comparatively stable mining industry arose. White Pine, though proving a veritable bonanza, was a short lived one, and the summer of 1872 found merchants and miners in exodus to the camps of the Egan and Schell Creek ranges, including Schell Creek and Robinson districts, the Robinson lying about 40 miles east of Hamilton.

In November, 1867,[1] a company of men guided by an Indian named John, came south from Egan Canyon, making locations near Ice Creek (undoubtedly the same as Murry Creek), which led to the organization of the Robinson mining district on March 16, 1868. The district was named in honor of a member of the party, Thomas Robinson, who previously had been an assayer at Pahranagat.[1]

The following claims are noted: Old England, located December 27, 1867; Elijah, located March 6, 1868; Springfield, located June 1, 1869; and London City. The situation of this group of mines is indicated by that of the still extant Elijah claim, which lies a short distance above Lane on the south-facing slope of Robinson canyon. Ores mined at the time are reported to have assayed from $40 to $185 per ton.

The present town of Lane occupies the site of the former settlement, which appears to have received the name Mineral City in 1868 or 1869.

Three miles east of this place the following claims had been located prior to 1870: Old Kentuck, Eureka, Haphazard, Desert, Louisiana. Of these claims the writer was able to find only the Eureka, which lies one-fourth mile northwest of the mouth of Ruth Canyon.

East of Mineral City a third group of claims is said to have shown a bold outcrop traceable for half a mile. This is presumably the ground covered by the present Joana claim.

Mining activity throughout northern Nevada was greatly stimulated by the completion of the Central Pacific Railroad, which in 1869 effected a junction with the Union Pacific about 40 miles west of Ogden, Utah. Developments in the Robinson district were undoubtedly furthered by this event, and early in 1870 the population of Mineral City numbered about 400.

Raymond[2] states that the principal mines of the district in 1869 were the Isaac, Elijah, Flying Cloud, Old England, and General Gregg. Another mine then active was the Carbonate, 4 miles west of Mineral City (southwest of Copper Flat).

At this time a 10-ton 2-tuyère furnace, 3 by 4 feet in cross section, was erected at the head of Murry Creek. Its first campaign yielded 81 tons of silver-lead bullion valued at $410 a ton. Also in 1869 a 10-stamp mill was put into operation at Mineral City. An item in the Mining and Scientific Press of July 2, 1870, states that three furnaces were under construction in the Robinson district, and in the issue of August 6 the Cummings furnace is reported as in operation, and work in progress on the Carbonate claim of Heffron & McMeans.

In 1871 several claims were under development, among them the Osborn, which had a 70-foot shaft. In December of this year one of the furnaces was started on ores from the Carbonate, Springfield, and Freeborn mines. This was presumably the Heffron & McMeans furnace.

[1] White, A. T., Nevada State Mineralogist Third Bienn. Rept., for 1869-70, pp. 86-87, 1871.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1870, p. 158, 1872.

The nature of the ore occurrences and the geology of the Robinson district are very adequately described by Raymond in his reports on statistics of mines and mining for 1870 and 1872.

In 1872 the deposits of the Cherry Creek mines were discovered, and this camp soon displaced White Pine as the most populous district of the county. Discoveries were made at Ward the same year. In the Robinson district the Canton Mining Co. and the Hays Gold & Silver Mining Co. of San Francisco were formed. The Canton Mining Co. purchased nine claims, at least five of which are extant,[1] and procured one of the previously erected furnaces. The smelting operations of the year are credited with 33 tons of bullion, worth from $250 to $400 a ton.[2] Gold and silver bearing lead ore was discovered on the Emma claim in the west part of the district.

During the winter of 1872–73 the population of Mineral City rose to nearly 600. By the summer of 1873 the Canton Mining Co. had developed a large body of low-grade ore in the Aultman, the main workings of which consisted of a 750-foot tunnel and a shaft 250 feet deep. Ten other shafts on the property were from 30 feet to 130 feet deep. A gold content of $12 to $100 a ton was reported. Several thousand tons of good ore had accumulated on different mine dumps and at the furnace.[3] At this period the output of the Canton Mining Co. included so large a proportion of free-milling ore that a stamp mill was planned. As remodeled during this year the Canton furnace had a capacity of 25 tons of ore per day.

The Hays Gold & Silver Co. developed considerable free-milling ore on their Hays and Katie claims.

Ten tons of 60 per cent copper ore was shipped to San Francisco from the Miami mine. The position of this claim is stated as 2 miles southwest of the Katie South Extension, or Mitten mine, which in turn is said to lie 4 miles southwest of the Hays. These directions seem to be inaccurate because they do not serve to locate any known workings that could have produced the ores described.

In 1873 the Watson Mining & Milling Co., of San Francisco, purchased the extension of the Hays and Katie mines. The company erected a 10-stamp mill for its own and custom work at Mineral City. The ore was treated without chlorination, but the process gave indifferent success.[4]

The production reported by the county assessor during 1873 was $5,076, distributed as follows: Hays, 145 tons, yielding $3,200; Mineral City (last quarter), 35 tons, yielding $1,000; Ward Ellis Co., 20 tons, yielding $642; Watson Tailing, 20 tons, yielding $234.

In 1874 the Watson mill seems to have been engaged mainly in treating ores from Ward, 18 miles south of Mineral City, and from Tamerlane (Nevada mining district), 12 miles east of Mineral City. For this year the Elijah mine is credited with an output of 400 tons of ore, yielding bullion valued at $17,500. The Watson mill was destroyed by fire in April, 1875, an event which seems to have been followed by a period of inactivity extending to 1878. In this year the Selby Copper Mining & Smelting Co. acquired a number of copper claims distributed over an area of 4 square miles. The ores were reported to be self-fluxing and the average copper tenor to be 24 per cent.[5] Several tons of copper ore were shipped to Baltimore via Wells, and an experimental 35-ton water-jacketed furnace was erected. This venture, which was based on mineral bodies exposed at shallow depth, seems to have failed because of an insufficient supply of ore. In the meantime Ward had become the most active camp of White Pine County, taking this prestige away from Cherry Creek. The Osceola gold placers were discovered in 1877 and the rich chloride ores at Taylor in 1880. Production from Osceola reached some importance after the completion of water canals in 1884. In 1881, when Mineral City harbored but two families, the Monitor mine at Taylor was sending ore to Eureka, and erecting its Steptoe Creek mill, which started operations in October. The Argus mill on Willow Creek was installed two

[1] These claims were Minnie Minora, Blackstone, Yellowstone, New York, Springfield, Eldorado, Randolph, Hays extension, and Aultman; Min. and Sci. Press, vol. 27, p. 114, 1873.

[2] Idem, Dec. 16, 1871; Feb. 24, 1872; June 1, 1872.

[3] Idem, vol. 27, pp. 114, 130, 1873. Details of developments, tonnages, and values are given.

[4] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1873, p. 226, 1874.

[5] Whitehill, H. R., Nevada State Mineralogist Bienn. Rept. for 1877–78, p. 157, 1879.

years later. Prior to 1887 these two mills produced about $2,000,000 in silver from the Taylor ores, with contributions from Ward.[1]

In 1886 the Keystone mine in the Robinson district came under development, and in the fall of that year Mr. Featherstone shipped 24 tons of ore to the Eureka Consolidated furnace, part of which returned 270 ounces of silver to the ton. Fifteen tons on hand were expected to yield 300 ounces to the ton.[2]

The Pioche Record of March 15, 1887, states that "the (Keystone) mine at Robinson has produced $30,000 since last fall and during the past two months $10,000."[3] In September shipments of first-class ore were being sent to Eureka[4] and second-class ore to the Monitor and Argus mills.

The production of the Keystone mine is given as follows:[5] For 1887, 326 tons, valued at $14,963; for 1888, 44½ tons, valued at $3,448; for 1889, 400 tons, valued at $13,352; total for the three years, $51,763.

The shell of a Bruckner roaster still remains on the site of the metallurgic works erected near the forks of the Robinson Canyon (probably in 1889) for the treatment of ores from the Keystone and adjacent mines. There was also a smelter, but the small size of the slag pile indicates that its operation was not long continued.

The removal of the county seat from Hamilton to Ely in 1886 seems to have aided in a renewal of interest in the district. The Aultman produced 1,671 tons of free milling ore in 1887, and in 1888 yielded $7,988.[6]

The year 1889 saw the formation of the Ely Gold Mining & Milling Co. This company acquired the Chainman mine and erected a stamp mill in which a dry process of concentration was tested. The pulp treated was said to have carried values of $19 to $22. The mill, at Ely, was eventually run by water power from Murry Creek.

In October, 1889, the Ely Mining Co.'s mill was leased to the owners of the Joana mine, in which a gold bonanza had recently been discovered.[7] This property is credited for 1889 with a production of 1,300 tons of ore that yielded $13,352. Also in 1889 the Robinson Canyon Consolidated Placer Mining Co. was formed for the purpose of working valley gravels between Mineral City and Ely. Two prospecting shafts were sunk in 1889 and a third early in 1890.

The White Pine News of May 3, 1890, states that the "Robinson Canyon Consolidated Co. have been busy for four days and nights sluicing gravel from shaft No. 2 with a good head of water." Capital had become interested, as evidenced by records of mines bonded to outside interests. Hodges & Walbridge, of Pittsburg, Kans., took options[8] which aggregated $150,000.

The Chainman mine of the Ely Gold Mining & Milling Co. was under development in 1890, and at a depth of 250 feet a body of gold ore, carrying $200 to the ton, had been encountered.[9] In 1891 this mine was credited with 1,673 tons of ore that yielded $6,228; in 1892, 1,128 tons yielded $16,773. In 1892 the company installed cyanide works.[10]

The Salt Lake Tribune of September 30, 1892, says:

> The Chainman is improving every day and the big sale is assured in the near future. Superintendent McGill is making a success of the cyanide process and saves up to 95 per cent of values on the Chainman ore. The Florida is being worked by McDonald & Cupid, and Gen. Thomas and partners are working the Robinson and Mohawk.

During the summer of 1895 assessment work was done on the Star, Star of the West, Brooks, and Pilot Knob at "West Camp." These show large lodes of oxidized copper ores, mixed here and there with sulphides.

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[1] For contemporary account of geology and development at Ward, see Min. and Sci. Press, vol. 34, p. 226, 1877. For same at Taylor, see Burchard, H. C., Rept. of the Director of the Mint upon the production of the precious metals in the United States during the calendar year 1883, p. 558, 1884.

[2] Letter dated Oct. 2 in Min. and Sci. Press, vol. 53, 1886.

[3] Min. and Sci. Press, vol. 54, p. 209, 1887.

[4] Reno Journal, Sept. 21, 1887.

[5] Repts. of the Director of the Mint upon the production of precious metals in the United States for 1887, 1888, and 1889.

[6] Idem for 1887 and 1888.

[7] White Pine News, Oct. 19, 1889.

[8] Min. and Sci. Press, vol. 60, pp. 148, 160, 1890.

[9] White Pine News, July 28, 1890.

[10] White Pine News, July 20, 1892.

West of these claims several properties were under development, including the Emma claim, where a body of lead-silver gold ore, rated at $65 to the ton, was developed at a depth of 5 feet.[1]

The Chainman mine was purchased under bond and lease in 1896 by C. D. Lane, and during 1897 mine pumps were installed, a new mill was built at the mine, and a hydroelectric power plant at Ely. The Chainman Co. took options on several properties in the eastern part of the district, including the Golden Revenue and Jupiter groups, ore from the Jupiter group being tested by a mill run in June, 1898. However, these sales were not consummated, and the Chainman option lapsed in November,[2] after an expenditure for payments and plant estimated at $150,000.

The Robust mine was developed during the year, and the property appears to have been equipped with a small stamp mill. Tests with the cyanide process gave favorable results on ore carrying $12 in gold to the ton, and a 50-ton amalgamation and cyanide mill was planned. Copper ore was encountered in the workings and a small tonnage of 25 to 50 per cent ore was shipped to Salt Lake. To compensate for the Lane failure the year 1898 was marked by the coming of Snedaker & Giroux, who took a bond on a property of 18 claims grouped about Pilot Knob, in the western part of the district. Ore was discovered on the Morris claim in April, 1899.

The old company resumed work at the Chainman early in 1899, first turning their attention toward development and later operating the mill. In September the Chainman, Robust, and Huntington mills were all running[3] and reported to be making money.

The Chainman clean-up in November showed from 76 to 83 per cent recovery, and results were regarded as fairly satisfactory.[4]

During 1900 the Ely Mining & Milling Co. developed the Robust group by tunnel and shaft, purchased neighboring claims, and built a 50-ton cyanide mill, costing $35,000.

The Chainman mine was taken over by the Chainman Mining & Electric Co.[5] in consideration of $50,000 cash and two deferred payments, amounting to $50,000.

The Pilot Knob group was bonded to agents of W. A. Clark (with whom Joseph Giroux had previously been associated), and a 20-horse power hoisting plant was installed on the Pilot Knob claim.[6] Verzan & Garaghan shipped copper ore from the Copper Queen claim to Salt Lake.

In 1901 the McKinley Mining & Smelting Co. acquired the property of the Canton Mining Co. and took an option on the Jupiter group, thus securing a majority of the patented mines of the district. The holdings of the company comprised the following claims: Aultman, Saxton, Aurora, Katy C., Diamond, Rosa Lee, Mount Morgan, constituting the Saxton group; Jupiter, Cumberland and Cumberland No. 2, Yellowstone, Cummings, Willard, Union, and Ohio. Under the superintendence of Mr. W. N. McGill sinking was started on the Saxton claim and the main shaft was carried down nearly 200 feet.

Fully 100 miners were employed by the Pilot Knob, Robust, Chainman, and McKinley companies, and considerable individual prospecting was going on. In November, 1901, the shaft of the Copper Flat Mining Co. at Copper Flat had reached a depth of 250 feet, and the Robust shaft of the Ely Mining & Milling Co. was 270 feet deep.

In 1902 the McKinley Co. developed its Saxton claim to the depth of 385 feet and opened underground drifts aggregating nearly 3,000 feet. Native copper was encountered on the 200-foot level. Some work was done on the Aultman. A very flattering report on the property as a whole was made by a prominent consulting engineer in the following year.

In 1902 Gray & Bartley were at work on their inclined shaft on the Ruth claim and the New York & Nevada Copper Co. was organized. During the year this company sunk its main

[1] Min. and Sci. Press, vol. 71, p. 286, 1895.
[2] Idem, Nov. 12, 1898.
[3] Idem, Sept. 23, 1899.
[4] Idem, Dec. 2, 1899. A wet crushing cyanide plant at Ely, Nev.: Eng. and Min. Jour., vol. 72, pp. 753–755, 1901. This is a description of the Chainman mill as planned.
[5] Min. and Sci. Press, Aug. 4 and Nov. 10, 1900.
[6] Idem, Dec. 8, 1900, and Feb. 23, 1901.

shaft at Copper Flat to 450 feet depth, completed 600 feet of underground development, and began work on a concentrating mill at Keystone. This company appears to have absorbed the Copper Flat Mining Co.

In 1902 the workings of the Pilot Knob Copper Co. comprised four shafts, the deepest 300 feet. A body of low-grade ore was developed.

In March, 1902, the new cyanide plant of the Chainman Co. was crushing 150 tons of $10 ore per day, but the process adopted seems to have been unsatisfactory, for in July experiments were in progress for determining the proper treatment of the ore.[1]

In November, the New York & Nevada Co. bought the rights of Murry Creek for $35,000.[2]

In March, 1903, M. L. Requa bought a group of four claims adjoining the Ruth claim previously acquired by him. With this property as a nucleus the White Pine Copper Co. was organized, comprising 15 mining claims, held under a $150,000 bond and lease. The Columbia and Last Hope groups were purchased[3] for $10,000.

The Giroux Consolidated Mining Co., which was organized during 1903, succeeded to the properties of the Pilot Knob Copper Co. and of the Florida Grande Co., operating in Mexico. The Giroux shaft, on Old Glory Hill, reached the depth of 450 feet and showed promising results. Low-grade ore bodies were blocked out on the Morris claim, and the Taylor and Dewey claims were prospected by shafts. Water rights were secured on Steptoe Creek.

The cost of producing copper metal was estimated by the engineers of the New York & Nevada Copper Co. at 6.14 cents on the basis of 1,000 tons of ore a day.[4] At this time the Utah Copper Co. was erecting its concentrator for treating the low-grade disseminated ores of Bingham Canyon, Utah, and though the success of the mine at Copper Flat seemed assured, the credit of the company had been overstrained and the property was attached by creditors.[5]

In 1904 the Giroux Co. let a contract for a 250-ton smelting plant. The Brooks and Bunker Hill and Alpha shafts were started. The White Pine Co. made a geologic survey under the direction of A. C. Lawson, continued development work, and erected an experimental mill.

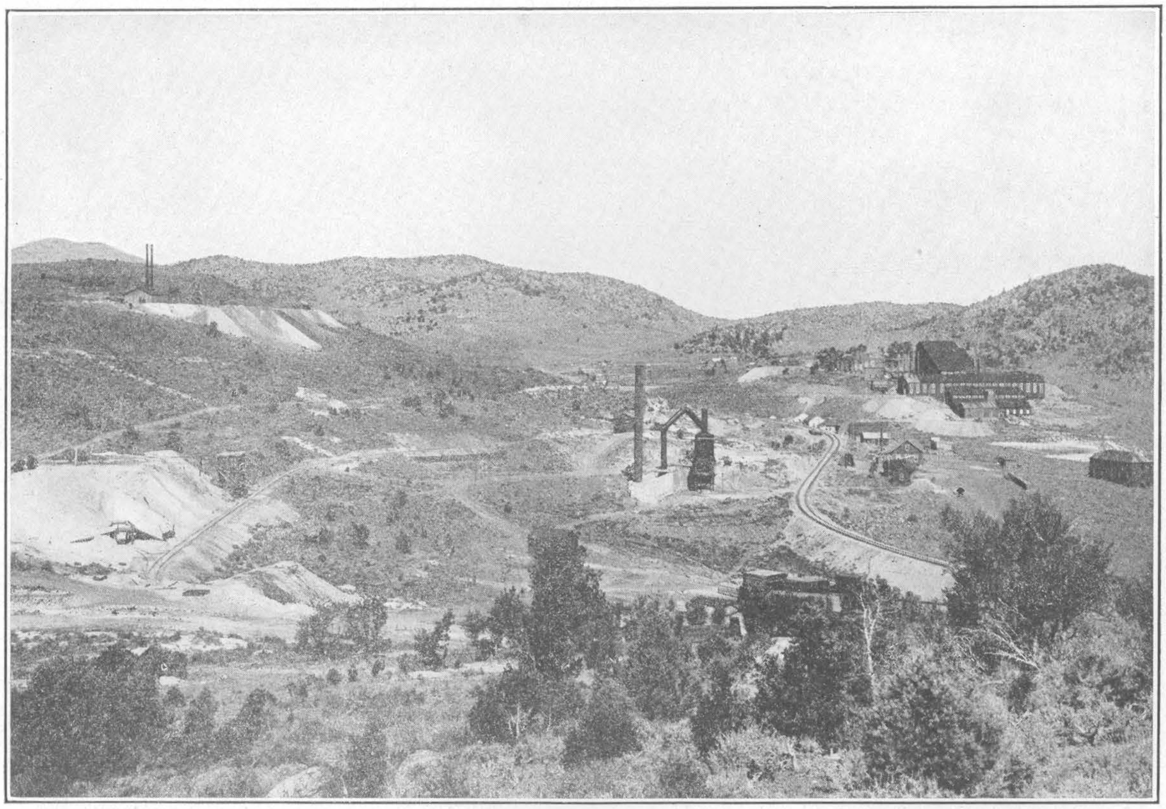
In 1905 the Veteran-Ely Co. was driving the Paul tunnel to develop its property situated near the western end of the mineralized zone. The Butte & Ely Copper Co., the Cumberland-Ely Copper Co., and the Nevada Consolidated Copper Co. were organized.

The Nevada Consolidated Co. brought together the holdings of the White Pine and the New York and Nevada companies in 1905 and early in 1906. Mr. J. Parke Channing examined the properties in 1905, estimating the Ruth and Copper Flat ore bodies as containing 26,000,000 tons of ore. On the basis of this report, and the successful operation of the experimental concentrating plant, construction of the Nevada Northern Railway was immediately begun.

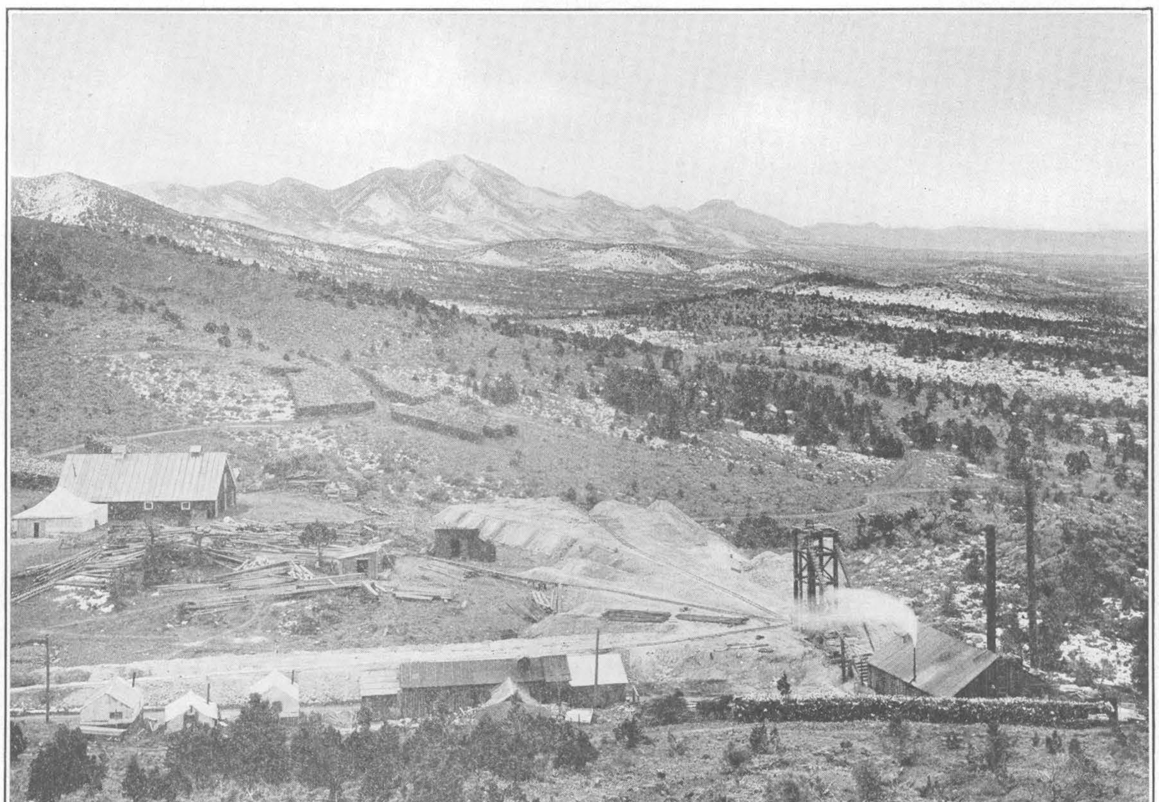
The Cumberland-Ely Co. acquired several groups of claims and water rights on Duck Creek, in the Schell Creek Range, east of Steptoe Valley. This company opened four shafts on the Jupiter group and secured the Veteran-Ely property, wherein the minable ore body was encountered beneath the old tunnel workings in October, 1906.

The first plans of the Nevada Consolidated for a concentrator and smelter were very modest in comparison with the plant which now exists. East of Ely a site accessible by ditch from the head of Murry Creek was selected, and a 1,500-ton plant was contemplated. The project was successively enlarged to capacities of 2,500, 4,000, and 5,000 tons, and finally the present site at McGill was chosen, and an eventual capacity of 10,000 tons a day was provided for. Abandonment of the site at East Ely and the beginning of construction at McGill came about early in 1906, through the acquirement of common control of the Cumberland-Ely and Nevada Consolidated companies by important financial interests, which established the two companies in joint ownership of the Steptoe Valley Mining & Smelting Co., and of the Nevada Northern Railway. The smelter site consists of 8 square miles of territory, the ownership of which precludes

[1] Min. and Sci. Press, July 19, 1902. Wickham, W. H., Cyaniding tests at Ely, Nev.: Idem, vol. 86, p. 134, 1903.
[2] Idem, Nov. 22, 1902.
[3] Idem, Mar. 7, Apr. 4, and Aug. 22, 1903.
[4] Idem, vol. 87, p. 54, 1903.
[5] Stevens, H. J., The Copper Handbook, vol. 4, 1904.



A. GIROUX CONCENTRATOR AND MORRIS NO. 1 AND OLD GLORY SHAFTS.



B. UPPER BASIN OF WHITE RIVER AND WARD MOUNTAIN FROM VETERAN SHAFT.

difficulties which otherwise might have arisen on account of the smelter fumes. The railroad was completed to Ely on September 29, 1906.[1]

The owners of the Giroux properties continued development; a concentrator was completed and a blast furnace essentially finished in 1906. Ore was found on the 700-foot level of the Alpha mine and sinking was continued. The years 1906 and 1907 were boom years in the district. By June, 1906, fully a thousand miners, prospectors, promoters, and speculators had gathered at Ely, where accommodations were very inadequate, and by February, 1907, the population was not less than 6,000. More than 50 mining companies were organized, many of them with Ely-hyphenated names. Among companies still active in 1910 the Ely Consolidated Copper Co. had opened three shafts, respectively 435, 500, and 630 feet in depth. In 1907 the Boston-Ely Mining Co. was sinking its Emma shaft and operating a churn drill. The property of the Butte & Ely Copper Co. was developed by two shafts; that of the Ely-Witch Co. by a tunnel and shaft, and that of the Ely-Revenue by a shaft. The Veteran ore body was blocked out. The Giroux properties were systematically explored and ore bodies blocked out on the contiguous Morris Brooks and Bunker Hill claims. In April, 1907, a serious cave-in occurred in the Alpha shaft and several miners lost their lives. Three men were rescued after more than a month's imprisonment, during which time food was conveyed to them through a 6-inch pump line in the shaft. The Giroux concentrator was put into operation in September. (See Pl. V, *A*.)

The Coppermines Co. was planned as a holding company for the Utah Copper Co., the Nevada Consolidated and Cumberland-Ely companies, but the object was attained in another manner in 1910. The lands of the Coppermines Co., which then comprised about 500 acres adjacent to the Nevada Consolidated and Ely Central holdings, were systematically prospected from 1907 to 1909 without developing workable bodies of ore.

The stormy history of the Ely Central Copper Co. began with its incorporation in 1906, though but little development other than shallow drilling was carried on in 1906 and 1907. The practice of exploring low-grade copper ores by means of churn drills was developed at Ely in 1906 by the management of this company.[2]

In the aggregate enormous sums were expended in entirely worthless assessment work, and though many properties changed hands, prices were influenced more by contiguity to the few successfully developed estates than by any actual showings or plausible indications of ore.

In 1907 Mr. Yeatman, consulting engineer of the Nevada Consolidated, reported the development of nearly 14,500,000 tons of ore, calculated to yield 40 pounds of copper to the ton. By December, 1907, stripping preliminary to mining by steam shovel at Copper Flat had been completed, and the Star Pointer working shaft had been sunk and connected with the Ruth mine by means of a 2,700-foot tunnel.

The working shaft at the Veteran mine was completed in 1907. The Chainman Consolidated Copper Co., which was organized during 1907, took over the old Chainman property minus the Murry Creek water rights, which the Nevada Consolidated seems to have transferred at the time to the East Ely Land Co. This company did considerable development work, including a new vertical shaft on the Chainman claim, a shaft on the Aultman claim, a third on Joana No. 2, and a long adit intersecting the Aultman shaft.

During 1907 and 1908 the Ely-Witch Co. developed its property by 3,500 feet of workings and found some good ore. The near-by Wedge, Jupiter, and Ada claims were explored by the Cumberland-Ely. Other developments were those of the Butte & Ely, the McDonald-Ely, Boston-Ely, Copper Mines, and Ely-Revenue companies and considerable hopeless work was done on outlying properties. The mines branch of the railroad was put into commission in 1907.

The milling of porphyry copper ores began in May, 1908, and the opening of the year 1909 witnessed mining operations in full swing at the Copper Flat and Veteran mines. The

[1] Bullock, W. S., The low-grade copper deposits at Ely, Nev.: Eng. and Min. Jour., vol. 83, pp. 509–511, 1907. Mines and Minerals, vol. 27, pp. 518–520, 1907.

[2] Pheby, F. S., Prospecting with churn drills: Min. and Sci. Press, vol. 93, p. 786, 1906. Hart, C. E., Eng. and Min. Jour., Apr. 27, 1907.

average monthly production of the Copper Flat mines for the year was nearly 120,000 tons of ore, and though the Veteran mine was closed on July 1 because of a miners' strike it furnished 400,000 tons of ore during the 13 months of activity.

Explorations for the purpose of increasing known tonnages of low-grade ore were carried on by the several larger companies during 1909 and 1910, mainly by means of churn drills. The results of this work, though by no means uniformly favorable, did result in developing an aggregate of several million tons of ore, which will eventually be mined.

In 1908 the Giroux property and that of the Butte & Ely Co. passed into the control of the so-called Cole-Ryan interests, and several adjacent properties were purchased. In 1913 the Consolidated Copper Mines Co. was formed for the purpose of consolidating the Giroux Consolidated Mining Co., the Coppermines Co., the Ely Central Co., and the Chainman Consolidated Copper Co.

PRODUCTION.

Complete statistics of production for the Robinson mining district prior to 1902 are not obtainable, but from the scattered records that have been discovered the value of metals produced between 1870 and 1892 is known to have been at least $200,000, and it is likely that the output of the district previous to 1902 had a total value of $500,000 or $600,000.

Statistics have been collected by the United States Geological Survey since 1902, and the metal output of the district, as reported by the producing companies for the years 1902–1915, are shown in the following table. For part of the period the metal content of concentrates was reported by the Nevada Consolidated and Cumberland-Ely companies, so that the actual production of copper has been somewhat less than the figures given would indicate. Smelter returns indicate an output of blister copper from 1908 to 1915, inclusive, amounting to 440,074,000 pounds.[1]

The value of the production is calculated on the basis of the average selling price of the several metals during the year in which they were produced.

Metal production of the Robinson mining district, Nevada, from 1902 to the end of 1915.

Year.	Tons.	Gold.	Silver.	Copper.	Lead.	Total value.
		Fine ounces.	*Fine ounces.*	*Pounds.*	*Pounds.*	
1902	50	43.54	1,000		43,857	$2,900
1903	557	364.27	27,372		220,000	24,530
1904	150	137.54	5,927		192,900	11,707
1907	29			11,814		2,363
1908	430,031	4,568.69	30,385	14,797,295	2,381	2,063,888
1909	1,670,832	17,757.55	77,131	57,479,819	428,884	7,898,195
1910	2,375,032	20,473.51	108,000	63,914,197	180,407	8,606,586
1911	2,776,930	21,057.00	104,107	67,033,547	10,216	8,870,118
1912	3,023,082	22,950.84	78,020	67,373,510	12,160	11,639,595
1913	3,447,812	20,818.04	68,793	71,916,711	15,756	11,619,681
1914	2,749,913	17,044.45	52,729	51,089,921		7,176,459
1915	3,206,133	27,483.29	82,281	64,661,610	654,905	[a] 11,961,699

[a] Including value of 42,651 pounds of zinc.

CHARACTER AND EXTENT OF THE DEPOSITS.

The prominent mineralization of the Ely district is exhibited along an easterly trending zone about 9 miles long and from half a mile to $1\frac{1}{2}$ miles wide. Along this zone extends medially a series of massive monzonite porphyry intrusions. In general the association of mineralization with the porphyry intrusions is clear, but masses of porphyry away from the central zone have affected the country rocks very slightly, and here metalliferous deposits have not been formed in or near the intrusive rocks.

The industrial importance of the district is based on the proved existence in 1913 of perhaps 80,000,000 tons (including ore already mined) of low-grade copper ore carrying very small

[1] U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 615, 1916.

amounts of gold and silver. In addition there are deposits of medium or high-grade copper which have not yet been fully developed, and there are deposits chiefly valuable for gold or for lead and silver.

The low-grade copper ores, here called disseminated ores, are also commonly known as "porphyry ores," though it will be shown that a minor part of the ores which have been mined occur in jasperoid.

The commercial bodies of disseminated ore are chiefly parts of large masses of mineralized monzonite porphyry. They lie directly beneath surficial products of complete weathering and grade downward into material of similar appearance to the ore but which is too low in copper to be mined under present conditions. The ore masses are of blanket form, as their horizontal extent is great in comparison with their thickness. This form is dependent on topography and weathering and has not been determined by stratification or by such layering as is found in crystalline schists or gneisses. Masses of porphyry almost uniformly charged with grains of pyrite and chalcopyrite (primary mineralization) became subject to erosion. As the rock was gradually worn away, successively lower and lower portions of the mass were exposed to weathering. Oxidizing waters of atmospheric origin penetrated the surficial portions of the mineralized rock, attacking the metallic sulphides and converting them in part into soluble sulphates, in part into insoluble oxides and basic sulphates, in the case of iron, or into carbonate and other oxidic compounds, in the case of copper, leaving a ferruginous or gossan-like capping of decomposed porphyry. These waters, which were charged with copper derived from the weathering mass, percolated downward through the mineralized porphyry, and by chemical reaction with pyrite or with chalcopyrite deposited their copper, thus converting the previously subgrade material into ore (cementation enrichment).

The most marked features of igneous metamorphism and mineralization along the mineral-bearing zone, aside from the alteration of porphyry masses, are crystallization of limestone, bleaching of limestones and shales, formation of lime-bearing silicates and of jasperoid, and very general impregnation with pyrite. The total amount of introduced pyrite is very great, and this mineral is almost everywhere accompanied by minor amounts of chalcopyrite. Garnet, epidote, diopside, wollastonite, and tremolite are in places prominently developed. These silicates are invariably accompanied by metallic sulphides, mainly by pyrite, but in many places this mineral has chalcopyrite associated with it. In a few places zinc blende is also present. Galena is not characteristic of garnet-bearing phases of mineralization, though it does occur in a few places. Exploration has not developed any workable deposits of unoxidized copper ore adjacent to intrusive masses, and it seems probable that commercially important bodies of such ore do not exist. Enrichment of partly silicified pyrite limestone has produced ore carrying a maximum of 3 per cent copper adjacent to the mass of disseminated ore at Copper Flat and in the Old Glory mine, and additional ore masses of this nature may be discovered in other parts of the field.

Certain deposits that lie some distance from the invading rock are much larger than the deposits of sulphides in contact with the porphyry masses. Great masses of limestone are thoroughly impregnated with pyrite, which is either free from larger amounts of silica or associated with jasperoid formed by siliceous replacement of the limestone. Certain deposits of this sulphide-bearing jasperoid are more or less veinlike in form, others follow beds in the limestones, and others again are irregular, ill-defined masses. The only large occurrences of disseminated chalcocite in jasperoid that have been encountered are in the Veteran and Boston-Ely mines.

Explorations on the west side of the White River divide in the Giroux, Veteran, and Boston-Ely groups have revealed very deep leaching of mineralized material originally rich in pyrite and accompanied by small amounts of copper. In the Alpha mine such leaching has resulted in the formation of secondary copper ores at a depth of 700 to 1,200 feet. Similar ores in workable masses have not yet been found elsewhere, though they may exist.

North of Ely there are a few outlying deposits of copper ore which contain carbonates, oxides, and chalcocite, and which carry from a few per cent to more than 20 per cent metal. These deposits are fillings of irregular and discontinuous fractures in limestone and are obviously enriched.

Small amounts of gold, silver, nickel, platinum, and palladium are present in all of the Ely copper ores, but of these the gold is most valuable. Gold ores have been worked in the eastern part of the district near Lane and possibly much gold-bearing rock awaits exploration. The auriferous ore bodies of greatest promise are bed deposits, generally conformable to the stratification of the incasing rocks. These blankets lie on limestone and under shale. Only the oxidized portions of the deposits have been worked. Silver is present, presumably associated with carbonate of lead. These ores have been treated by amalgamation together with cyanidation of the sands.

Lead ores carrying silver to the amount of a few ounces to the ton occur in veinlike bodies and also in blanket form. The richer silver ores which were mined during the early years of activity were in the main completely oxidized parts of blanket deposits in limestone. Most of the lead-silver or silver-lead ores and certain rich copper ores show minor amounts of zinc. Some zinc blende occurs with the pyrite, pyrrhotite, and chalcopyrite in the Brilliant workings, but ores valuable mainly for zinc have not been found.

In copper deposits no primary ore has been developed. All the ores mined owe their value to chalcocitic enrichment.

MINERALS OF THE ORE DEPOSITS.

The following list summarizes the occurrence and associations of the principal minerals in the ores and in the metamorphosed rocks:

Copper.—Metallic copper occurs only as a secondary product in the mines of the Ely district. Much of it has been found in association with chalcocite and cuprite in the Alpha mine. Here also minute crystal aggregates of copper occur in company with pyrite in specimens of clay gouge containing quartz, sericite, and kaolin. Copper occurs sporadically in the Veteran mine and has been found in churn-drill holes situated on the west side of the White River divide. At Copper Flat finely divided copper was noted locally disseminated in the partly decomposed rhyolite of the dike which cut across the ore mass that was exposed in 1910. No explanation is offered of the chemistry of the process by which metallic copper was deposited in this disseminated form within the rhyolite, but it must have been precipitated from sulphate solutions resulting from the oxidation of copper sulphide, whether chalcocite or chalcopyrite.

Gold.—All the copper ores contain more or less gold, the porphyry ores carrying 20 to 40 cents a ton. The ores from the Chainman and nearby mines which have been worked for gold are oxidized, more or less siliceous products, rich in cerusite, the carbonate of lead. The primary material doubtless carried galena and pyrite, and the gold is presumably native. Gold is also present in the lead-silver ores of the district.

Quartz.—One of the principal results of igneous metamorphism in the Ely district has been the introduction of vast quantities of quartz. The mineral is a groundmass constituent of the normal porphyry and persists in the metamorphosed phases of the intrusive rock. Locally, where the metamorphosed porphyry has been fractured, there has been an addition of 10 to 15 per cent of silica, which is accounted for by the infilling of seams with quartz, or quartz in company with either orthoclase or brown mica, or both. Large veins that have a gangue of quartz, filling what may have been open fractures, are rare, though examples are noted in the Taylor mine and in the great pit at Copper Flat. In both localities the veins carry both pyrite and chalcopyrite. Garnet and other silicates developed in metamorphosed limestone masses are generally accompanied by quartz. The mineral is, however, most notably in evidence in the great bodies of jasperized limestone which occur throughout the zone of metamorphism.

In all the occurrences quartz must have been formed in the presence of water or aqueous solutions, for in examples of normal porphyry, of metamorphosed porphyry, of jasperoid, and of veins may be found grains of the mineral that show cavities containing liquid and a vapor "vacuole." Some of these cavities contain also minute cubical crystals likely to be sodium chloride or potassium chloride.

These fluid-containing cavities may be of irregular form, but many of them are "negative crystals," which show the bipyramidal form of quartz, and are of course oriented so as to correspond crystallographically with the host. They are so abundant as to be characteristic in the vein quartz and jasperoid quartz. In worked-over quartz in the groundmass of metamorphosed porphyry they can be made out in the study of many thin sections. In the original quartz of the groundmass, however, it is rather unusual to find cavities large enough to be resolved by even high powers of the microscope, though one suspects that almost omnipresent specks in such quartz are really cavities so minute that their nature is not ascertainable.

If it is assumed that the quartz was formed at such an elevated temperature that the cavities now partly filled were entirely full of liquid at the time the mineral crystallized, a consideration of the relative space now occupied by fluid and vapor indicates that the temperature of deposition was probably above 200° and below 400° C.

Chalcedony.—Certain reefs of jasperoid present a very dense flinty appearance, which is due to the fact that they are composed of hydrous silica or chalcedony instead of quartz. The mineral commonly occurs in the jasperoid, generally filling drusy spaces, and as a rule is of later origin than the quartz. In places quartz and chalcedony seem to have been deposited simultaneously, and some quartz to have been deposited after the last of the chalcedony.

Titanium minerals.—Titanite or sphene ($CaSiTiO_5$) is a constant component of the normal porphyry, amounting to 1 per cent or more. In the porphyry ore it is represented by secondary rutile in the form of minute, short, reddish-brown prisms.

Zircon.—This oxide, which occurs in minute prisms in all the normal porphyry, has so resisted alteration that it is found in the concentrates from the milling plant.

Magnetite.—The magnetic oxide of iron makes up about 4 per cent of the normal porphyry, but metamorphism of this rock has been attended by a marked loss of iron, and magnetite is greatly depleted or entirely absent in the ore porphyry.

Magnetite is commonly developed in garnetized phases of altered limestone as an associate of pyrite and chalcopyrite, and in a few places it forms rather massive bodies, as on Pilot Knob, on the Josephine claim, and east of Ruth shaft. Much of the jasperoid carries no magnetite, but the mineral is not at all uncommon in this material. It is said to be a characteristic component in concentrates from the Veteran ores which are in large part enriched pyritic jasperoid.

Hematite.—The specular oxide of iron, hematite, occurs locally in garnetized or in tremolite-bearing limestone, but is by no means abundant.

Limonite.—The name limonite is used loosely as a convenient name for hydrous oxides of iron which are derived from pyrite and chalcopyrite where these minerals have been completely weathered. Yellow, red, and brown staining of outcrops is due to iron oxides of this derivation, and the abundance of such staining marks the district at once as one in which metallic mineralization has been very great. All the bodies of disseminated copper ore are capped by limonitic products of weathering. Heavy limonitic gossans occur in a few localities over more or less solid bodies of pyrite, as in the Joana tunnel, on the Great Western claim in the eastern part of the district, and at a few places in the central part of the mineralized zone. In the western section a heavy gossan occurs on the Reipe claim near Kimberly store, and others occur in the workings of the Alpha mine. Disseminated grains of limonite in kaolin clays of the Alpha mine have the crystalline form of marcasite.

Manganese oxides.—Black pulverulent, almost sooty material, occurring with certain lead ores on the Badger claim south of Copper Flat and in long-abandoned silver mines near Keystone, consists principally of oxide of manganese.

Cuprite.—The brilliant red cuprous oxide (Cu_2O) occurs rather generally but sparingly wherever copper-bearing minerals have been completely weathered and also beneath the fully oxidized zone with chalcocite and native copper. As small crystals it is disseminated through the capping porphyry in places, and in massive form it occurs as an alteration product of chalcocite. In the Veteran mine it is associated with magnetite, possibly as a derivative of chalcocite that had been precipitated upon the iron oxide.

Pyrite.—Disulphide of iron (FeS_2) in the form of pyrite is the most abundant metallic mineral in the Ely district. It is more or less uniformly distributed through all the strongly metamorphosed rocks and may be rudely estimated to constitute from 4 to 8 per cent of their weight. The amounts of sulphur and of iron which have been introduced in the formation of this mineral are enormous. Wherever the limestones have been garnetized pyrite is found, commonly accompanied by pyrrhotite, chalcopyrite, and magnetite. As a rule these minerals are generally though somewhat irregularly distributed throughout the mass of the altered rock, but in a few places compact segregations of considerable size are to be noted. Pyrite is likewise an almost constant component of the great jasperoid masses. Here it is distributed through the matrix of granular quartz, commonly with chalcopyrite and magnetite. In the metamorphosed shales adjacent to the principal zone of intrusion large amounts of pyrite have also been introduced. The pyrite in the metamorphosed porphyry and in the ore porphyry which has been derived from it occurs characteristically in the secondarily crystallized groundmass, though in certain material that represents a rather unusual type of alteration it has replaced hornblende. Wherever the rock is seamed with quartz veinlets these also carry pyrite, and in many places this mineral occurs along joint cracks. The pyrite of the groundmass and that of the quartz veinlets is generally accompanied by chalcopyrite, but the chalcopyrite does not occur with the film pyrite. The development of the film pyrite is regarded as distinctly a later phenomenon than the general sulphide mineralization, and it is of interest to note that films of pyrite in every way like those in some of the mines are abundant in the otherwise unmetamorphosed monzonite in the vicinity of Reipetown. In the elaboration of the disseminated copper ores of the district the pyrite of primarily mineralized material has acted as a reducing agent in precipitating copper from surface-derived solutions, though it has been notably less efficient than chalcopyrite.

Marcasite.—Though marcasite has not been noted in the unoxidized condition, certain specimens of kaolin clay from the 1,000-foot level of the Alpha mine contain disseminated grains of limonite which show crystalline shapes characteristic of this orthorhombic iron disulphide. The marcasite from which these pseudomorphs have been derived is regarded as a secondary mineral deposited from downward-moving solutions which contained ferrous sulphate and free sulphuric acid derived from the oxidation of primary pyrite in higher situations. This theory is in accord with the results of chemical work by Allen, who finds that marcasite can be formed only from acid solutions.[1] Experimental work by Whitman [2] indicates that kaolin causes the deposition of pyrite from ferrous solutions of alkaline reaction, and probably parallel experiments with acid solutions would result in the formation of marcasite. For the case in hand, however, it is not possible to say that the marcasite was formed after the kaolin, and it seems likely that the two minerals may have been of contemporaneous origin.

Pyrrhotite.—The magnetic sulphide of iron, pyrrhotite (Fe_7S_8), is much less abundant than pyrite. It occurs locally in altered limestone, having been noted at the Jupiter shaft, in material from the Brilliant workings, the Old Glory shaft, and the Veteran mine. It is usually associated with garnet, and commonly with pyrite, chalcopyrite, and magnetite. At the Brilliant mine it is accompanied by zinc blende.

Chalcopyrite.—The sulphide of iron and copper, as chalcopyrite ($CuFeS_2$), carries 34.5 per cent of copper. It occurs throughout the district irregularly distributed in masses of garnetized limestone, in smaller amounts in pyritized shales, and locally rather evenly disseminated in jasperoid masses. Where it is disseminated in metamorphosed porphyry and in ore porphyry, this mineral is typically confined to the recrystallized groundmass and to transecting veinlets. In both situations it occurs with pyrite, quartz, orthoclase, and brown mica. In the alteration of metamorphosed porphyry to ore porphyry chalcopyrite has acted as the principal precipitant for chalcocite and may be seen surrounded by rims of the secondary copper mineral. Commonly in any given specimens the chalcocite films that coat grains of chalcopyrite are from three to four times as thick as those that coat pyrite, though the grains of the iron sulphide are uniformly larger than those of chalcopyrite.

Bornite.—The copper-iron sulphide bornite was not noted by the writer in material from the Ely district.

[1] Allen, E. T., Sulphides of iron and their genesis: Min. and Sci. Press, vol. 103, pp. 413–414, 1911.
[2] Whitman, A. R., The vadose synthesis of pyrite: Econ. Geology, vol. 3, p. 465, 1913.

Sphalerite.—The sulphide of zinc, sphalerite or zinc blende (ZnS), is not abundant in the Ely district. The disseminated copper ores are practically free from zinc, and throughout the central zone of intense metamorphism, where the rocks of all sorts are heavily and almost uniformly charged with other metallic sulphides, sphalerite occurs only sporadically and in very small amounts. However, in what may be called the outlying metalliferous deposits, with reference to the principal zone of porphyry intrusion, zinc appears as a rather constant though minor constituent of the ores. Though it is present as carbonate where the ores are oxidized, the zinc was originally deposited in the form of sphalerite in company with galena pyrite and chalcopyrite.

Galena.—The sulphide of lead, galena (PbS), is a primary mineral in several lodes and irregular deposits which are essentially replacement bodies in limestone. Lead-bearing deposits have everywhere suffered superficial oxidation, and as only shallow mining has been done the original galena is largely decomposed to the carbonate, cerusite, to the sulphate, anglesite, or to compound sulphates containing iron as well as lead. The lead ores of the district occur mainly in localities where the general metamorphism of the rocks has been moderate or slight rather than where the rocks have been strongly altered. Thus the porphyry bodies along the main zone of intrusion ordinarily carry no lead, though in a single locality, near the mouth of Ruth Gulch, galena is found with pyrite disseminated through the altered porphyry. Fluorite is a common mineral in the lead deposits, and as a rule the lead ores carry some copper and a little zinc.

Molybdenite.—The sulphide of molybdenum (MoS) is a flaky mineral closely resembling graphite, but of a bluish rather than of a gray tinge. It is a characteristic accessory mineral in the disseminated copper ores, occurring in very minor amounts distributed through parts of the rock, but more commonly in cracks, from which it appears to be a mineral of rather late deposition.

Chalcocite.—The cuprous sulphide, chalcocite (Cu_2S), carries approximately 80 per cent of copper. It is the most important ore mineral at Ely, as it is in many other districts where the copper deposits are of the disseminated type. In this district all occurrences of this mineral are of secondary origin. It is the characteristic mineral of the porphyry ores, in which it occurs to a certain extent in minute specks replacing small grains of pyrite or chalcopyrite, but principally in the form of films surrounding grains of these minerals. Specimens may be noted in which, though chalcopyrite is surrounded by chalcocite, pyrite is not, and as a general rule the films around the chalcopyrite are from three to four times as thick as those around the pyrite. Similar relations are observed in jasperoid which has been converted into ore by chalcocite enrichment.

Chalcocite, both in massive and in sooty form, occurs also in lodes, beneath fully oxidized capping or gossan. Shallow deposits of copper ore, mostly worked out in former years, consisted in considerable part of massive chalcocite more or less altered to cuprite and to copper carbonates. Material of this sort may be seen in several places, notably on the Mammoth claim northwest of Reipetown and on the Copper Queen claim north of Ruth shaft. At these and other localities the secondary copper minerals named above are accompanied by amorphous, earthy or waxy minerals of indefinite composition. Materials of this sort may be related to turquoise, copper pitch ore, and the like.

Chalcocite is one of the valuable minerals of the rich secondary ores such as have been developed in the Alpha mine. Here it is associated with basic carbonate and sulphate minerals of copper, with cuprite, and with metallic copper, all of which are products of its decomposition.

Covellite.—The cupric sulphide, covellite (CuS), is an uncommon mineral in the Ely district, though it may be observed occasionally in specimens of the porphyry ore in the form of coatings on disseminated pyrite and chalcopyrite. In the porphyry ores of Bingham, Utah, however, covellite is a really abundant secondary mineral.

Orthoclase.—The potash feldspar, orthoclase, is a characteristic component of the intrusive monzonitic rocks of the district and of all the alteration products of these rocks, including the pyritized porphyry. The igneous metamorphism which transformed normal porphyry into pyritized porphyry was effected by hot solutions of such a composition that all the siliceous minerals were destroyed and replaced by other minerals with the exception of quartz and orthoclase, and locally the orthoclase was altered in part to sericite. Also during the enrichment of the pyritized rock through the deposition of secondary chalcocite the orthoclase suffered very little alteration, so that in specimens of the porphyry ore this mineral may be recognized in essentially the relations which it held as a component of the unaltered rock. The only notable decomposition is indicated by the presence of very small amounts of kaolin in some of the orthoclase. Even in the capping the amount of kaolin is very small and most of the orthoclase is surprisingly fresh.

Garnet.—Garnet is a characteristic mineral in the altered limestones, and though variable in color is probably all referable to the lime-iron variety, andradite. However, qualitative chemical tests show the presence of alumina in certain specimens. The mineral as a rule has a resinous luster and its colors range from dull red through light brown to honey yellow. No very bulky masses of garnet have been noted, the largest being those south of the Ruth shaft. Its typical occurrence is in massive bunches that show crystal forms in contact with the inclosing limestone. Many of the small crystals embedded in limestone show optical anomalies under the microscope. The most common associates of garnet are calcite, quartz, pyrite, and chalcopyrite, somewhat unusual associates being pyrrhotite, sphalerite, and galena.

Pyroxene.—A pyroxene of undetermined composition occurs in strongly metamorphosed limestone on the north side of the porphyry intrusion east and northeast of Robust mill. The locality is a shaft on the St. Patrick claim. The mineral resembles wollastonite in the hand specimen, but it is probably related to diopside.

Epidote.—Epidote, a yellow-green silicate of lime, alumina, and iron, occurs as a metamorphic mineral in moderately altered phases of porphyry, very generally in metamorphosed shales, and uncommonly in altered limestones. In the porphyry it is secondary after hornblende, plagioclase, and orthoclase. Secondary epidote in porphyry appears to denote incipient or preliminary phases of metamorphism rather than such intense changes as have produced the ore porphyry, which is characterized by brown mica, replacing hornblende and by sericite, replacing plagioclase. In limestone it was noted only along the immediate contact with epidotized porphyry in the vicinity of the Elijah mine north of the upper end of Lane Valley. Examination of a thin section representing the actual contact shows that the epidote in the limestone is accompanied by quartz carrying good-sized cavities that contain vapor bubbles, a saturated solution of some salt, and cubical crystals, presumably of potassium chloride.

Zoisite.—Zoisite is a colorless mineral allied to epidote but lacking in iron. It has been noted only in thin sections of metamorphosed shale.

Biotite.—The brown mica, biotite, is a characteristic mineral of certain facies of metamorphosed porphyry that occur in the Ely district, and it is present in much of the porphyry ore. It is not a common primary constituent of the normal porphyry, and its development has been at the expense mainly of hornblende and partly of plagioclase through the introduction of potassium and the removal of calcium and sodium. The replacement biotite is accompanied by the same mineral developed in the granulated groundmass of the metamorphosed porphyry, and it also occurs as a component of quartz veins. In material from the Veteran mine brown mica forms films in cracks in porphyry, and with quartz it occurs as fillings in brecciated jasperoid. Good-sized flakes of green mica that occur in fractures in jasperoid contain fluorine, and it may be inferred that this element is a constituent of all the secondary mica.

Brown mica is an essential though minor constituent of much of the jasperoid, especially in the western part of the district. It occurs also in the metamorphosed shales.

Muscovite (sericite).—The white mica, muscovite, mainly in the fine-crystalline variety known as sericite, is abundant in the metamorphosed porphyry, and as it is little affected by weathering it persists in the ore porphyry and the capping porphyry. Brown mica occurs in parts of the metamorphosed porphyry, but sericite is characteristic of all varieties of the altered rock. Its most usual occurrence is in the place of original plagioclase crystals, the form of which the sericite aggregates commonly retain. However, in places where the effects of igneous metamorphism have been most intense it replaces all the original silicate minerals of the porphyry. Material from the Zack shaft shows a mixture of fine-grained calcite and sericite, which seems to indicate a partial replacement of limestone by the mica. In gouge clay from the Alpha mine sericite occurs with pyrite, quartz, and calcite.

Kaolinite.—Although the mineral kaolinite has not been identified by the writer in material from the Ely mines, it is supposed to be represented by certain white decomposition products of orthoclase in monzonite and to be the principal component of white clays that are found with some of the richer copper ores which occur in metamorphosed limestone. Kaolinite appears not to have been formed during the sericitic alteration of the rocks but only as a result of weathering processes. In the Alpha mine large quantities of white and yellow plastic clay are associated with chalcocite and with ferruginous materials derived through the complete weathering of pyritized and otherwise metamorphosed limestone. Similar clays occur in some of the other mine workings either as pockets or in weathered jasperoid or as gouges in slightly metamorphosed limestone. Under the microscope the clay substance is usually found to be made up of nearly opaque white or yellow-stained granular aggregates, and even the highest magnification available fails to reveal crystalline grains. Such material contains aluminum but shows no potassium under chemical tests, so that it can not be sericite. It is regarded as either cryptocrystalline kaolinite or an amorphous substance of about the same composition.

These clays are very plastic when wet. In places they appear to be composed almost entirely of the supposed kaolinite, but elsewhere they contain abundant grains of quartz. There is little room for doubt that they have originated through the action of acid solutions on metamorphosed limestone, and it is probable that the rock from which the clays have been derived carried alumina which had been introduced in the form of sericite. This suggestion is based on the occurrence of sericite in a sample of gouge collected on the 1,000-foot level of the Alpha mine, north of the point where the kaolin clays occur, in place where the pyritized limestones are not strongly oxidized. Though extremely plastic when wet, this material carries much quartz in the form of small grains and abundant minute crystals of pyrite, the two minerals being in part intergrown. It also contains some metallic copper and enough carbonate of lime to afford a lively effervescence in dilute hydrochloric acid. When separated from the granular minerals, the plastic portion was found to be a mixture of two materials, one the essentially amorphous substance described above, and the other sericite.

Some of the kaolinic clay carries disseminated pyrite, which may perhaps be regarded as having been distributed through the metamorphosed rock before it was acted on by the acid solutions. Certain samples contain abundant pseudomorphs of limonite after marcasite. Here the marcasite was a secondary mineral deposited from an acid solution either during or after the process of kaolinization.

In the porphyry ores kaolinite is not an abundant mineral, though it might be expected that it would have been formed during the enrichment of these ores as the result of the action of acid solutions on sericite and on orthoclase. In the capping it was developed through the partial decomposition of orthoclase, but even here it is not really abundant.

Chlorite.—The complex hydrous silicate, chlorite, is not a mineral of the ores. It occurs in moderately altered porphyry as a decomposition product of hornblende. In material from the Ely-Central shaft it is developed with secondary uralite in the original crystals of hornblende, and also as films on those joint surfaces which appear to have been rubbed together.

Calcite.—Calcite, a carbonate of lime, is the principal component of limestones. The mineral occurs as a vein filling, usually with quartz and pyrite, and in some places its place is taken by the magnesian carbonate, dolomite. In small amounts it is a constant constituent of metamorphosed porphyry but is not present where chalcocite enrichment has taken place.

Siderite.—The mineral siderite, ferrous carbonate, is noted in unusual varieties of metamorphosed porphyry and as a secondary filling in brecciated jasperoid.

Aragonite.—The mineral aragonite, which has the same composition as calcite, differs from calcite in its crystallization, as it belongs to the orthorhombic instead of the rhombohedral system. In the Ely district it fills parts of certain fault fissures and is a recent deposit in cavities in the veins, as in the Robust mine, where in places it covers the entire roof and walls. It occurs in groups of radiating acicular crystals forming mammillary crusts. Though generally white, the mineral in many places has a delicate green tinge, doubtless due to some impurity.

Cerusite.—The carbonate of lead, cerusite, is a common mineral in fully or partly weathered deposits containing lead, the original mineral being galena.

Anglesite.—The sulphate of lead, anglesite, occurs with cerusite, and yellow products in oxidized lead deposits are probably complex basic sulphates carrying both lead and iron.

Jarosite.—The double sulphate of potash and ferric iron, jarosite, occurs distributed in the weathered capping of the porphyry ore masses in irregular golden-yellow grains. All this capping carries sulphates which are insoluble in cold water, and probably jarosite is accompanied by basic sulphates of iron, of which several varieties are known. The related mineral, alunite, has not been noted in the Ely district.

Gypsum.—The hydrous sulphate of lime, gypsum, occurs where pyrite or other sulphides are undergoing oxidation in the presence of limestone or lime-bearing solutions. It develops in pyritiferous shale exposed to the action of the weather, as on mine dumps, and has been noted in the Veteran mine.

Chalcanthite.—Natural blue vitriol or chalcanthite, a hydrous sulphate of copper, is a common mineral developed on exposed surfaces in abandoned mine workings. It is abundant in all the underground porphyry mines, and also in the Old Glory mine, where the mineralized rock is principally limestone.

Melanterite.—Hydrous sulphate of ferrous iron, melanterite, occurs alone or in company with chalcanthite, forming abundant efflorescences on exposed surfaces in old workings. It accumulates in white curving sheaves of long prismatic crystals, which remind one of the ice columns that commonly develop in a loose moist soil during a quick freeze. This mineral was noted as most abundant in the haulage drift between the Ruth mine and the Star Pointer shaft, where the rock is highly pyritiferous jasperoid. On exposure to the dryer atmosphere outside of the mine the mineral falls to powder and takes on a yellowish tinge through partial oxidation.

Epsomite.—Epsomite has not been recognized as a mineral, but magnesium sulphate was obtained by treating specimens of the capping porphyry with water. In a dry climate rain water penetrating porous material is brought back to the surface through capillarity, there to deposit salts collected during the journey.

Copper minerals of the shallow zone.—In all metalliferous districts yielding copper ores a great variety of stable minerals are developed through processes of oxidation and weathering, minerals which are often dismissed under the general heading of carbonate ores. Among the better known of these minerals are the two basic carbonates, azurite and malachite, and the hydrous silicate, chrysocolla. These minerals are common in many shallow workings in the Ely district. With them basic sulphates and phosphates doubtless occur, though detailed studies are lacking to permit their discrimination. Among the products of weathering are certain waxy minerals allied to turquoise and copper pitch ore, the latter a dark amorphous substance containing manganese.

CLASSIFICATION OF THE METALLIFEROUS DEPOSITS.

The metalliferous deposits of the Ely district are all of epigenetic origin, and with reference to processes of segregation are divisible into primary deposits, formed through or in connection with igneous metamorphism, and secondary deposits in which primary segregations have undergone enrichment connected with atmospheric metamorphism or weathering. Up to the present time no essentially primary deposits of commercial value have been found, and though such may yet be discovered it is not likely that they will ever be extensively worked.

The known ores of the district have been produced by a combination of primary and secondary processes, but as it seems desirable to describe the metalliferous deposits as a whole a classification has been adopted in which types are defined with reference to physical features of primary origin, and which is therefore descriptive rather than genetic. In applying this classification, bodies of ore that have been formed through enrichment are referred to the general types appropriate to the primary deposit from which they have been derived.

The most noteworthy copper enrichment has involved the addition of this metal as chalcocite and the removal of other substances. The process is one of mild oxidation and its products are subject to further change. Under strongly oxidizing conditions, they may be further enriched by the elimination of other materials than copper, as in the formation of carbonate ores, or they may become impoverished through loss of copper. Where deposits containing mixed sulphides are subject to oxidation, enrichment in iron or in lead results almost entirely through the elimination of other substances. In general, gold and silver accumulate with residual iron and lead, so that the oxidized parts of lodes are commonly richer in these metals than the lower part, where the sulphide minerals are unaltered. In the classification here adopted there are two major divisions, one including deposits that contain copper and a very little silver and gold, and the other those that contain chiefly silver and gold as the valuable metals. In the copper deposits, lead and zinc are practically absent, whereas in the silver-gold ores lead is more abundant than copper and zinc is commonly present. When the distribution of the copper and silver-gold deposits is considered it is found that the former occur medially within the principal zone of metamorphism, where rock alteration has been both general and strong, whereas the latter occur on the flanks of this zone, where the rocks are much less altered.

The two grand divisions, based on the contained metals, are subdivided into replacement deposits and open-space fillings, and the replacement deposits are still further divided according to size, form, nature of matrix, and mineral associations. The terms "great-mass deposits" and "minor-mass deposits" have been invented as convenient designations, the first for very large bodies of metamorphic rock carrrying rather thinly disseminated ore minerals, the second for smaller bodies in which the ore minerals are more compactly segregated.

Classification of the metalliferous deposits.

- Copper deposits; ores only where copper has been added to primary materials.
  - Great-mass replacement deposits.
    - Pyritized porphyry masses and their secondary copper ores.
    - Copper-bearing jasperoid masses.
    - Partly silicified limestone masses carrying copper minerals.
    - Copper-bearing garnet rock.
    - Copper minerals in metamorphosed shales.
  - Minor-mass deposits.
    - Replacement deposits.
      - Irregular replacement bodies carrying sulphides and magnetite.
      - Irregular replacement bodies composed mainly of pyrite.
      - Pyritic replacement veins.
      - Pyritic bed deposits.
      - Copper ores associated with kaolin.
    - Quartz veins carrying pyrite and chalcopyrite.
- Silver-gold deposits; primary materials usually lean; enrichment by abstraction.
  - Replacement deposits.
    - Deposits of irregular form.
    - Vein-like replacement lodes.
    - Bed deposits.
  - Fissure veins carrying precious metals.

COPPER DEPOSITS.

GREAT-MASS REPLACEMENT DEPOSITS.

GENERAL CHARACTER.

Throughout the central zone of the Ely district the effects of igneous metamorphism are seen in the intense and thoroughgoing alteration of very large masses of porphyry, limestone, and shale. Though the different rocks have yielded to chemical reorganization and to metasomatic replacement, each in a manner depending primarily on its original composition, yet the resulting products are all heavily charged with pyrite, and in the main this mineral is accompanied by minor amounts of chalcopyrite. In a general way the sulphides are evenly distributed through the altered rocks, but their proportion ranges from perhaps 2 or 3 per cent up to 10 per cent. Thus far no material that has been discovered would lead to the expectation that any extensive bodies of rock carry enough chalcopyrite to warrant mining them and it is only in having furnished material as a basis for enrichment by secondary processes that the pyritic replacements here termed great-mass deposits have any practical importance.

These deposits are classified with reference to the nature of the country rocks, and those in the limestones according to differences in the character of the alteration products.

PYRITIZED PORPHYRY MASSES AND THEIR SECONDARY COPPER ORES.

GENERAL CHARACTER.

The prominence of the Ely district as a producer of copper rests upon the presence of great masses of chalcocite-bearing porphyry ore ranging in copper content from about 1 to about 3 per cent, or from 20 to 60 pounds per short ton. The term "ore porphyry" is used to cover both porphyry ore and subgrade material similar to ore. Just as pyrite porphyry may be substituted for metamorphosed porphyry in discussions relating to the ores, so chalcocite porphyry may be used in place of ore porphyry.

The porphyry ores are secondary ores. (See p. 106.) That is, their present higher metallic content is the result of changes which have been imposed on low-grade copper-bearing rock previously existing in the same localities. The preexisting rock was pyritized porphyry which carried about 0.5 per cent copper as primary chalcopyrite. (See p. 110.) The changes which the pyritized porphyry has undergone in the conversion to ore have been brought about by interaction between the minerals of the primarily mineralized rock and oxidizing waters of atmospheric origin. This genetic relation is obvious, as the ore bodies are subhorizontal, irregular layers that lie beneath highly oxidized products of weathering and rest on entirely unweathered material, which is like the ore in many respects but differs in containing no chalcocite. Thus the ore is an alteration product of pyritized porphyry and the capping is an alteration product of formerly existing ore.

The term primary is here used to denote metalliferous materials produced during the first mineralization of the porphyry. The term secondary follows naturally as a designation for materials which have resulted from later changes involving the partial or complete destruction of any component minerals, the formation of new minerals, and depletion or enrichment with regard to primary metallic contents. Primary and secondary minerals are the characteristic minerals of the respective classes of materials; and primary ores and secondary ores are those containing minerals of corresponding derivation. Obviously, however, secondary ores may contain both primary and secondary minerals.

In conformity with this definition the chalcocite ore might be called secondary in one stage and the capping might be considered as secondary in two stages.

PRIMARY SULPHIDES AND THEIR RELATIONS.

Throughout the more general portion of this paper the term metamorphosed porphyry is used for varieties of the intrusive rock which, when considered in connection with the subject of ore genesis, are particularly characterized by the presence of pyrite or pyrite and chalcopyrite. In what follows it will be sometimes convenient to call these metamorphosed rocks pyritized porphyry. The contained sulphides are primary, according to the foregoing definition, but the pyritized porphyry as a whole is a secondary product based upon the normal or unmetamorphosed rock as original material. (See p. 55.)

In the Ely district great masses of porphyry that occur along the main zone of intrusion were rather uniformly charged with pyrite or with pyrite and chalcopyrite as an incident of thoroughgoing igneous metamorphism. Molybdenite is the only common sulphide in addition to pyrite and chalcopyrite. Though sphalerite and galena are not unknown, they are so rare as to be negligible.

In the substance of the metamorphosed porphyry the primary sulphides, pyrite, and chalcopyrite occur mainly in the orthoclase-quartz matrix which constitutes approximately two-fifths of the mass of the rock, rather than in the spaces originally occupied by plagioclase, hornblende, or in large crystals of orthoclase. However, this rule is not without exceptions, and in some specimens pyrite or chalcopyrite occurs in sericite aggregates which represent original plagioclase crystals and, in the most strongly metamorphosed material, in sericitic replacements of orthoclase. Also essentially unaltered crystals of orthoclase have been found to contain embedded sulphide grains.

Wherever the rock is charged with thoroughly disseminated sulphide minerals it is also seamed, to a greater or less extent, by narrow sulphide-bearing veinlets that are composed of quartz with a little associated orthoclase. The amount of chalcopyrite in the body of the rock appears not to vary appreciably with the spacing of the veinlets, but as the veinlets invariably carry chalcopyrite the aggregate amount of the copper-bearing mineral is greater where they are closely spaced than where they occur at wider intervals.

Throughout the rock and the veinlets as well the pyrite and chalcopyrite generally occur as irregular grains which lack definite crystal shapes, though some of them show crystal faces. The majority of the sulphide grains are minute, most of them having diameters of less than half a millimeter. Many of them occur alone, but they also occur in nests or, as seen in cross sections, individual grains may be joined by narrow necks into chainlike groups. In places the quartz veinlets contain more chalcopyrite than pyrite.

In much of the pyritized porphyry large amounts of pyrite were introduced along reticulating joint fractures after the metamorphism of the body of the rock had been completed, and after the quartz veinlets had been formed. Similar films of pyrite occur also in monzonite porphyry that is exposed in several places in the Weary Flat area near Reipetown, where the earlier stages of metamorphism were not imposed on the igneous rock. Close examination of material containing both quartz veinlets and films of pyrite leads to the conclusion that the deposition of the pyrite closely followed that of the quartz, the connection being shown by the presence of medial films of pyrite in veins which had not been entirely filled prior to the stage during which the deposition of pyrite without gangue minerals was the most prominent feature. This part of the pyrite is not accompanied by chalcopyrite, and a study of the chalcocite ore shows that it has been rather inactive as a precipitating agent for the secondary copper mineral.

A rude estimate, based on a consideration of the material in the Copper Flat pit, indicates that in rock carrying 5 per cent of pyrite perhaps two-thirds of the pyrite occurs as films and in bunches of contemporaneous introduction. (See p. 55.) The pyrite porphyry from the Ely Central Eureka shaft, situated 600 feet east of the pit, carries about 3 per cent of pyrite, nearly all of which occurs in joint films.

The sulphur added during metamorphism occurs principally in union with iron as pyrite and combined with iron and copper as chalcopyrite. The sulphide of molybdenum is of only subordinate importance, and the sulphides of lead and zinc are so rare that they may be left out of consideration. Samples of metamorphosed porphyry and of ore subjected to chemical analysis have been estimated to carry or to have formerly contained from 1 to 5.5 per cent of primary sulphides, or from 0.5 to nearly 3 per cent of sulphur. (See p. 57.) The sulphur content of a large tonnage of ore from Copper Flat averages 3.63 per cent, of which about 3 per cent is assignable to the residual primary sulphides. All these materials carry much film pyrite in addition to the fully disseminated pyrite and chalcopyrite. The development of chalcocite in replacement of pyrite or chalcopyrite involves the production of soluble iron sulphate and consequently the removal of sulphur, so that the ore carries somewhat less sulphur than was present in the pyritized porphyry. If allowance is made for this loss the average sulphur content of the pyritized porphyry previous to its enrichment may have been somewhere near 4 per cent. When calculated back to the normal porphyry this last amount corresponds to a gain in sulphur of about 3.5 per cent, by weight.

From the average ore analysis, after making due allowance for losses incident upon chalcocite enrichment, the loss of iron resulting from primary metamorphism is estimated to have been nearly 2 per cent by weight of the normal porphyry, or about four-tenths of the original iron. If approximately two-thirds of the pyrite was introduced during a late stage of metamorphism, as before stated, then a greater loss of iron must have taken place during the earlier metamorphism, which was attended by the formation of the disseminated sulphides. Previous to the introduction of the reticulating films of pyrite the total amount of iron present could hardly have exceeded 1.5 per cent, which corresponds to a loss out of the normal rock of nearly eight-tenths of the original iron. The very completely metamorphosed porphyry exhibited in specimen 102 (p. 57) shows a loss of 3.6 per cent of metallic iron out of 5 per cent originally present in the assumed base rock, or a depletion of seven-tenths, with which amount the foregoing estimate corresponds as closely as need be expected.

The amount of copper introduced into the pyrite porphyry appears to have ranged from say 0.2 to nearly 1 per cent. Examination of specimens indicates that some of the ore still carries from 1.5 to 2.5 per cent of chalcopyrite, corresponding to 0.5 to 0.8 per cent copper, and as part of the primary chalcopyrite has been converted to chalcocite it is evident that the copper tenor of such material previous to enrichment may have been from 0.7 to 1 per cent or even somewhat more. It is believed, however, that the average copper content of the pyritized rock was probably not more than 0.5 per cent. At several places holes have been drilled through the porphyry ore and well into the underlying rock, and assays of the drill cuttings show the presence of copper, usually in proportions greater than 0.2 per cent and less than 0.7. The average amount of copper in material from 20 holes which represent a section aggregating 2,060 feet was found to be 0.43 per cent.

ORE PORPHYRY.

The ore porphyry of the Ely district consists of pyritized porphyry which has been enriched through the secondary deposition of copper from downward-moving solutions. The enriched material contains secondary chalcocite in addition to primary pyrite and chalcopyrite and minor amounts of molybdenite. The processes of chalcocite enrichment are discussed elsewhere in this paper. (See p. 76.)

As exposed in the mine pits, the porphyry ore presents a very uniform light-gray color. When closely viewed it shows innumerable black specks distributed through a white matrix. The black specks are grains either of chalcocite or of chalcopyrite or pyrite, coated with chalcocite. The white groundmass is found under the microscope to be made up of quartz, orthoclase, and sericite. In much of the material noteworthy amounts of fresh yellow pyrite are visible. Although the sulphide grains that are coated with chalcocite differ greatly in size, most of them have diameters of less than half a millimeter. Pyrite that carries no chalcocite occurs mainly in larger grains and in the form of bunches and seams.

The chemical composition of the porphyry ores is indicated by two complete analyses of specimens (samples 153 and 154) collected from the Copper Flat pit and by a partial analysis which represents a composite sample of all the ore mined from this pit prior to September, 1910. The complete analyses were made in the chemical laboratory of the Geological Survey by George Steiger and R. C. Wells. For the other analysis the writer is indebted to the management of the Nevada Consolidated Copper Co.

Chemical composition of porphyry ore from Copper Flat.

	153	154	Composite.		153	154	Composite.
SiO_2	64.73	74.62	77.35	TiO_2	0.57	0.42	....
Al_2O_3	14.41	10.23	8.77	ZrO_2	.04	None.	....
Fe	2.89	2.02	3.04	P_2O_5	.10	.06	....
MgO	.76	.83	....	BaO	.04	Trace.	....
CaO	.44	Trace.	.51	Cu	1.96	1.57	2.21
Na_2O	.70	.33	....	S	2.83	2.01	3.63
K_2O	7.84	6.57	....	SO_3	.22	None.	Undet.
H_2O-	.82	.26	....				
H_2O+	1.94	.69	....		100.29	99.61	95.51

From these analyses the corresponding mineral composition of the materials represented has been calculated and the approximate results are given in the following table. For the composite ore the silicate minerals have been apportioned in approximately the same ratios as in sample 154, and this procedure indicates the presence of orthoclase and mica in amounts that correspond closely with the proportion of alumina shown by the analysis.

Mineral composition of porphyry ore from Copper Flat pit.

	153	154	Composite.		153	154	Composite.
Vein quartz	10	30	37	Chalcopyrite	1.83	1.63	1.8
Other quartz	21	18	15	Chalcocite	1.66	1.25	1.9
Orthoclase	36	29	25				
Sericite	18	11	13		98.00	99.10	98.5
Brown mica	6	6		Total sulphides	7.00	5.1	8.5
Pyrite	3.51	2.22	4.8				

For the sulphides the figures given are merely approximations, but the amounts of chalcopyrite and chalcocite indicated correspond with the relative amounts of these minerals in many specimens of the ore that have been studied with the aid of the microscope. Though complete analyses of ores from the porphyry bodies in the western part of the district are not available, in general these ores appear to be less siliceous than those of the Copper Flat and Ruth mines, and it is believed that their average composition might correspond with that of sample 153 as given in the foregoing table. The mean copper content of about 13,000,000 tons of porphyry ore mined and treated previous to 1914 was approximately 1.8 per cent. The ores as mined are reported to contain from 4 to 7 per cent of moisture. As a result of oxidation the ore exposed in the mine workings invariably contains some soluble copper sulphate.

The nonmetallic minerals, which constitute the gangue with scarcely recognizable changes, are the same as the minerals of the unenriched pyritized porphyry. They therefore comprise quartz, orthoclase, brown mica, and white mica (sericite). Though present in very small amounts, apatite, zircon, and titantite occur as in the unaltered porphyry, and these minerals are found in the sulphide product of the concentrating mill. Calcite, small amounts of which occur in the primary pyritized porphyry, is not present in the chalcocite ore, having been attacked and carried away during the process of chalcocite depositions. In some of the ore small amounts of kaolinite have been developed as a decomposition product of orthoclase, but the presence of this mineral is by no means characteristic of the chalcocite porphyry. This is the only nonmetallic mineral which has been recognized as having been formed during the sulphide enrichment of the porphyry ores.

In the chalcocite ores the amount of quartz ranges widely because in different places veinlets of this mineral are more or less abundant. Though in some places these veinlets are widely spaced, elsewhere they form closely spaced networks and constitute an important part of the ore masses. As a rule the eye does not readily distinguish between the quartz fillings and their matrix.

The primary sulphides pyrite and chalcopyrite are disseminated in ill-formed grains, or in nested or linked groups of grains, both through the substance of the rock and through the body of the veinlets. Pyrite occurs also in the form of medial seams in some of the quartz veinlets and as films developed along joint surfaces. The occurrence of chalcopyrite in the medial seams of the veinlets has been noted only exceptionally, and the pyrite of the joint films is never accompanied by chalcopyrite. In porphyry ores which carry more than the average amount of iron the excess of pyrite is always attributable to the presence of these films. This statement, however, does not include the Veteran ores, as they are regarded mainly as enriched masses of pyritic jasperoid.

Ore of an unusual appearance is developed in crushed material where pulverized pyrite has been distributed along surfaces of slipping and afterward brought under the action of solutions containing copper sulphate. Such material shows black reticulating films, which on close examination are found to be made up of pyrite dust coated with chalcocite.

In the typical porphyry ore not only is much the greater part of the chalcocite associated with the fully disseminated primary sulphides but most of it occurs with the chalcopyrite rather than with the pyrite. In many specimens containing both pyrite and chalcopyrite the pyrite carries no chalcocite, even though the chalcopyrite is deeply coated, and in general it is found that where both minerals have been coated the deposit surrounding the chalcopyrite is from two to four times as deep as that on the pyrite. The pyrite occurring in films has received comparatively little enrichment.

Although the examination of specimens has been sufficient to show that some of the chalcopyrite grains are entirely replaced by chalcocite, from the ore that has been studied the proportion of grains so changed would be estimated as smaller than it appears to be from an examination of samples of sulphide concentrates.

Because most of the ore is greatly seamed and jointed it shatters readily as a result of blasting. The physical character of the ore is thus especially favorable for mining by means of steam shovels in open pits or by caving and slicing systems underground.

MINOR METALLIC CONSTITUENTS OF THE PORPHYRY ORES.

In the refining of blister copper it is common to find small amounts of nickel, bismuth platinum, palladium, selenium, and tellurium in addition to gold and silver. That all of these elements, with the exception of tellurium, are present in the crude copper derived from the porphyry ores of Ely has been noted by Eilers.[1] From the slimes accumulated in the refining tanks during the refining of 3,000 tons of blister from the Steptoe smelter there were removed for each 100 tons of blister copper: Gold, 169 ounces; silver, 550 ounces; platinum, 1.016 ounces; palladium, 4.402 ounces; nickel, 64 pounds; bismuth, 0.33 pound; and selenium, 110.1 pounds. Though the sulphide molybdenite is a constant component of the ores, molybdenum is not mentioned as one of the metals extracted in refining. Presumably the molybdenite is completely eliminated during the milling of the ores.

The ratios of gold and silver to copper that are given above are higher than those shown by assays of the porphyry ores. Approximately 9,500,000 tons of porphyry ore had a mean content of 37.8 pounds copper, 0.0156 ounce gold, and 0.0712 ounce silver, which figures correspond to 0.845 ounce gold and 3.76 ounces silver per ton of copper. These figures were compiled from data furnished by the annual reports of the Nevada Consolidated Copper Co. for the years 1909 to 1912.

OCCURRENCE AND FORM OF THE PORPHYRY ORE BODIES.

The occurrence of chalcocite-bearing porphyry in the Ely district is confined to what has been termed the principal zone of intrusion. Within this zone, which trends from east to west and is about 7 miles long, there are, besides several small areas, 15 separate porphyry areas of noteworthy extent. (See Pls. II and VI.)

On structural grounds the porphyry masses which thus appear at the surface are regarded as essentially cross-breaking intrusions or stocks, and from their zonal distribution it is sufficiently obvious that the intrusions have occurred along a rather definite line of weakness. The distribution of the chalcocite porphyry is in a general way coextensive with the occurrence of the altered igneous rock along the principal zone of intrusion, though only a part of the material is available for mining. As the rock that carries chalcocite has been enriched in copper by the precipitation of this metal from solutions that originated at the surface, such material grades downward into rock that has not been enriched. The material that contains chalcocite thus occurs as blanket-like bodies between the capping and the rock that has received no secondary copper. The space relations of the three sorts of material are like those of the soil, subsoil, and rock in regions where the soil has been derived through the disintegration of rock in place.

[1] Eilers, A., Notes on the occurrence of the rarer metals in blister copper: Am. Inst. Min. Eng. Trans., vol. 47, p. 217, 1914.

Though the bodies of chalcocite porphyry may be appropriately called blanket bodies, because their lateral measurements are characteristically greater than their thicknesses, and because their characteristic attitudes are subhorizontal, still they hardly have that regularity which the use of the word blanket would ordinarily imply. Instead of being essentially uniform layers the bodies of enriched material differ greatly in thickness from place to place, and locally the irregularities are rather abrupt. Both the upper and the lower surfaces of the ore blankets are uneven, but the irregularities of the bottom are on a larger scale than those of the top, and give rise to the principal changes in thickness.

When considered broadly, aside from local irregularities, the tops of the ore masses generally exhibit gentle slopes, which in each locality appear to indicate the general trend of the underground drainage. Where the porphyry masses that contain the ore bodies have been deeply dissected, as in the Kimbley Hill mass and the mass south of Lane Valley, the upper ore surface rises with the local topography; but where the porphyry masses are not cut by deep valleys the slopes of the top of the ore and those of the ground surface do not correspond. Thus in the Bunker-Morris ground the upper surface of the ore is highest along the northeast side of the porphyry mass, and the inclination is across the porphyry mass, toward the southwest, in which direction the ground rises. In the porphyry mass at the Ruth mine the ore is highest on the east side, where the intrusive rock outcrops well down on the hillside, and the top of the ore slopes gently toward the west. If considered more in detail the upper surfaces of the ore blankets are characterized by sharp irregularities due to downward penetration of wedges and pyramidal or conical masses of the oxidized capping. As a rule these wedgelike masses are narrow angled, and because their dimensions are extremely variable, what may be called the topography of the upper ore surfaces exhibits a very complex relief.

Undulations of the bottom of the ore blankets do not correspond in any systematic way with the slopes of the land surface; some of the deepest sags are under valleys and others are beneath hills. Locally the bottom and the top are nearly parallel; but as a general rule their irregularities are entirely independent. The undulations in the bottoms of the masses of enriched material are well illustrated in the ore body of Copper Flat-Liberty. As a rule the top of the ore body has practically the same width as the mass of porphyry in which it has been developed, but all cross sections are V-shaped, as though the solutions that deposited the secondary copper had everywhere moved from both sides toward the medial portion of the broad dike of porphyry. On a longitudinal section the top profile rises gently from east to west, but the bottom profile is a waving line that has four deep sags beneath a general line nearly parallel with and about 200 feet below the top profile. Along the axis of the deposit the ore is nowhere less than 250 feet thick, and in the sags there are additional masses from 100 to 250 feet deep.

The average thickness of the ore in the Ruth ground is perhaps 150 feet, but further surveys must be made to determine the undulations of the ore bottom that may exist.

Exploration by means of drills of the porphyry mass that outcrops on the Kimbley group of claims has shown that here the blanket of enriched material is from 50 to 200 feet thick. The vertical dimensions of ore masses encountered on the Wedge and Witch properties, east of Ruth Gulch, are not known to the writer, but the intrusions are themselves small and can therefore contain no really large ore bodies. The extensive mass of porphyry that occurs south of Lane has not been systematically drilled, but where cut by the tunnel of the Smokey Development Co. it contains chalcocite, and the thickness of the enriched blanket appears to be about 50 feet.

In the western part of the district, as indicated by assays of material from drill holes, the thickness of the enriched porphyry under Old Glory Hill ranges from 10 or 15 feet to about 200 feet, and in the Bunker-Morris mine the thickness of the workable ore ranges from a few feet to 250 feet or more.

QUANTITY OF PORPHYRY ORE DEVELOPED IN THE DISTRICT.

Because the availability of masses of the chalcocite porphyry as ore depends not only on the copper tenor of the rock but on such features affecting mining costs as the bulk and shape of the bodies and the depth of overburden, it will be readily understood that along the porphyry belt much ore-grade material exists that can never be profitably mined. At present, however, any attempt to estimate the proportion of the known chalcocite porphyry that will eventually be utilized would be unsafe, because methods of ore dressing are becoming more and more efficient, and as the costs of treatment diminish higher mining costs will be permissible, so that in the future copper should be won profitably from ores of moderate copper tenor that occur in masses of relatively small size or from large ore bodies of lower grade than those that are now worked.

According to the annual report of the company for 1913, the amount of porphyry ore developed by the Nevada Consolidated Copper Co. up to January 1, 1915, was more than 70,000,000 tons, of which a total of nearly 69,000,000 tons, having a mean grade of 1.67 per cent copper, is regarded as available for mining. Additional quantities developed by the Giroux Consolidated, Butte-Ely, and Coppermines companies (which in 1913 were merged as the Consolidated Coppermines Co.) are given in the annual report of the latter company for the year ending April 30, 1915, as over 25,000,000 tons, having a mean grade of 1.13 per cent copper, can not be accurately stated. The grand total of disseminated ore developed, including that already mined, thus appears to be in the neighborhood of 95,000,000 tons.

RELATIONS OF THE PORPHYRY ORE TO THE PRESENT WATER TABLE.

Several hundred holes have been drilled in the exploration of the porphyry ore bodies, but as a rule the tabulated records of this work do not include information in regard to the depths at which water was encountered. Though for this reason no systematic discussion of the relations of the water table can be given, the data at hand indicate that along the porphyry belt water stands from 200 to 650 feet below the surface of the ground, and from 90 to 250 feet below the bottom of the oxidized capping. In places where the chalcocite ore is thin from 50 to 200 feet or more of primary or unenriched sulphides are present between the ore and the water table. So far as known, where the ore bodies are less than 100 feet thick their bottoms lie above the water top, while thicker bodies may or may not extend below this level.

In the western part of the district, in the connecting Morris, Brooks, and Bunker mines, the great bulk of the ore lies above the 255-foot mine level, the elevation of which is about 7,000 feet. The water level, though varying from season to season and from year to year, hovers about this level. The records of four drill holes which penetrate the Morris ore body show from 90 to 180 feet of ore above and from 35 to 90 feet below the water level, whereas four other records show ore only above the level where water was standing at the time of drilling.

Data concerning the relations of the water table along the Copper Flat-Liberty ore body are at hand only for localities near the ends of the deposit. At the western end of this ore body water was encountered in holes 78 and 79 of the Giroux series at an elevation of about 6,970 feet. In hole 78, which is the more westerly of the two, the oxidized capping is 160 feet thick; there is no evidence in the assays of important enrichment, and the top of the sulphides lies 105 feet above the water level. In hole 79 the capping is 65 feet thick; the upper 40 feet of the sulphide-bearing rock is evidently enriched, and the total thickness of the pyritic rock above water level is 185 feet. A few hundred feet to the east the chalcocite ore is not less than 250 feet thick, and if the level of standing water is here approximately the same as in drill hole 79 fully half of the ore must be submerged. At the east end of the ore body in the Copper Flat pit water was reached at an elevation of about 6,920 feet, which is about 110 feet below the original top of the chalcocite ore. As the minimum thickness of the body in this section is about 200 feet, approximately half of the thickness of the ore is under water.

In the Ruth mine, where water stands some distance below the 500-foot level, the elevation of which is about 6,700 feet, only a small part of the ore is now submerged. The records of drilling adjacent to the Ruth workings do not give depths at which water was found, but in the contiguous porphyry ground, explored by the Copper Mines Co., the general position of the water table corresponds with that in the Ruth workings, the elevation being about 6,600 feet. As good reasons are elsewhere presented for the belief that the processes of chalcocite deposition are most effective above the water table or just below its top the observed submergence of 50 to 200 feet of chalcocite porphyry is held to indicate that in time past the water has stood much lower than at present.

OCCURRENCE AND COPPER TENOR OF THE CAPPING PORPHYRY.

The chalcocite porphyry ores of the district are everywhere covered by material that has passed through the chalcocite stage but which, as a result of weathering, now contains no sulphides. The copper present in this material is contained in oxidized compounds, including basic carbonates and sulphates, which for convenience may all be called copper carbonates. This oxidized overburden or capping ranges in thickness from perhaps 20 feet to a recorded maximum of 435 feet. Above the sulphide ore bodies in the Bunker-Morris ground the depth of the overburden ranges from 40 to 275 feet, and the average depth, as found in 40 bore holes, is about 100 feet. Above the Copper Flat-Liberty body the range is from a local minimum of 20 feet to a known maximum of about 250 feet; the average depth, as estimated by the engineers of the Nevada Consolidated Co. in 1911, is 102.5 feet, or less than half the average thickness of the minable ore. Above the Ruth ore body the thickness of the capping ranges from about 270 feet at the Ruth shaft to 435 feet in a hole started at a point 210 feet higher than the top of the development shaft. In 14 holes on the Kimbley group the average depth from the surface to the sulphide ore is about 160 feet, the range being between 60 and 240 feet.

From place to place along the porphyry belt notable amounts of copper carbonates have been revealed by shallow excavations in the weathered porphyry, but such occurrences are sporadic and the greater part of the capping, as exposed at the surface, is almost free from copper minerals. Examination of material on the waste dumps of the Copper Flat and Liberty mines shows, however, that copper carbonates are irregularly distributed in the capping, and in places these minerals are so abundant that large masses of the rock carry from 1 to 2 per cent of copper. From data in hand no accurate estimate can be made of the average copper content of the capping, but as surface-derived solutions have contributed so much secondary metal to the ore blankets it is surprising that the aggregate amount of copper remaining in the weathered rock is so great. Unfortunately the tabulated records of drill explorations usually lack details in regard to the copper tenor of the capping. As sulphide ores alone are suitable for the methods of treatment in vogue, such ores were the objective of these explorations, and the weathered material is usually noted merely as "leached porphyry."

However, the records of 27 holes show in detail the vertical distribution of copper in the capping. Of these holes 21 belong to the Giroux series and relate to the Bunker-Morris ground; 4 belong to the Copper Flat series, and 2 belong to the Ruth series. Though the information afforded by these records is not sufficient to exhibit the horizontal distribution of copper carbonates in the capping, the fact is clearly shown that although the vertical distribution is very erratic, on the whole the upper part of the shell of weathered material contains less copper than the lower part. The first rock penetrated to a mean depth of 85 feet is reported in 12 of the 27 holes as barren or as containing only traces of copper; in 4 holes a mean thickness of 80 feet shows about 0.5 per cent copper; in 7 holes a mean thickness of 57 feet shows between 0.5 and 1 per cent; and in 3 holes a mean thickness of 18 feet carries above 1 per cent copper. The records of only 2 holes out of the 27 show less copper in the lower part of the sections than in the upper part. Immediately above the sulphides there is reported in 12 holes a mean thickness of 42 feet of carbonates bearing material containing 1.5 per cent or more of copper; in 3 holes a mean thickness of 25 feet contains between 1 and 1.5 per cent; and in 9 holes a mean thickness of 46 feet contains between 0.5 and 1 per cent of copper. When the foregoing data are combined so as to represent the upper and lower parts of the sections in composite it is found that at the top a mean thickness of 70 feet carries an average of 0.3 per cent copper and at the bottom a mean thickness of 43 feet carries an average of 1.1 per cent copper. The average copper content for the overburden indicated by the records cited is 0.6 per cent.

Although the foregoing calculation does not afford a reliable estimate of the actual proportion of copper in the capping, it indicates that the blanket of weathered porphyry, taken as a whole, may carry nearly as much if not quite as much copper as an equal bulk of unenriched primary material. With reference to the observed accumulation of copper in the chalcocite ore, the significant point to be considered is that in the capping the amount of copper becomes less and less from the bottom toward the surface. In general the superficial 25 feet can hardly carry so much as 0.2 per cent copper, and it may be fairly assumed that the upper 5 feet may carry about 0.1 per cent. A simple calculation shows that if the primary copper in the pyrite porphyry was 0.5 per cent, and if the top slice of the capping carries 0.1 per cent, then with proper allowance for the respective densities of the primary and the weathered rocks, about one-sixth of the original copper remains in the finally leached porphyry. Some such proportion as this may be subject to loss through erosion at the surface.

COPPER-BEARING JASPEROID MASSES.

OCCURRENCE.

So far as explorations have shown there are no workable ore bodies in the district that fully conform with the ideal type of jasperoid ores, meaning ores characterized by chalcocite disseminated through large masses of silicified limestone. There is, however, one deposit in which the ore comprises considerable amounts of jasperoid intricately mingled with porphyry. This is in the western part of the district in the Veteran mine, and this occurrence justifies the introduction of chalcocite-bearing jasperoid as an ore type.

It is thought to be unlikely that any thick and extensive blankets of chalcocite-bearing jasperoid will be discovered, because in general the large bodies of silicified limestone appear to contain little or no primary copper, and in the western part of the district, where chalcopyrite was more or less evenly disseminated in the large body of jasperoid that lies between the Veteran and Boston-Ely shafts, drainage conditions appear on the whole to have been unfavorable.

SECONDARY CHALCOCITE IN JASPEROID.

The Veteran ore body has the same blanket form that is characteristic of the ore bodies that occur elsewhere in the homogeneous masses of porphyry. Above it there is from 200 to 450 feet of fully oxidized material and below it the rock carries no chalcocite, so that it is sufficiently obvious that the chalcocite-bearing ore has originated through a similar process of enrichment to that which produced the porphyry ore blankets.

The chalcocite occurs in the form of coatings on the primary sulphides, and the deposit is characteristically thicker on grains of chalcopyrite than on those of pyrite. The degree of enrichment, both of the jasperoid and of the associated porphyry, was here probably somewhat greater than in the average of the porphyry ore of the district, though it is not possible to really demonstrate this point because the copper content of the primary material is not known. The average grade of the ore appears to have been about 3 per cent, or about 60 pounds of copper to the ton.

In general appearance the jasperoid ore closely resembles porphyry ore, and in material from the Veteran mine it is usually impossible to distinguish the two sorts without recourse to refined methods. By means of the microscope it is found that orthoclase, which is a characteristic component of porphyry ore, is not present in the jasperoid ore. The jasperoid ore is composed principally of minute interlocking grains of quartz, and the only silicate mineral is brown mica, which, however, is not everywhere present. By means of a magnet it is usually possible to isolate magnetite and a little pyrrhotite, and the presence of the pyrrhotite may be taken as fairly good evidence that any otherwise questionable material is jasperoid rather than porphyry.

A sample of jasperoid ore from the Veteran mine was found to have the chemical composition indicated in the following table:

Chemical composition of jasperoid ore from the Veteran mine.[1]

[Chase Palmer, analyst.]

SiO_2	79.11	H_2O+	2.68
Al_2O_3	3.82	TiO_2	.81
Fe_2O_3	.44	P_2O_5	.42
FeO	.69	S	3.01
MgO	1.19	Cu	2.55
CaO	.62	Fe (in sulphides)	2.64
Na_2O	.31		
K_2O	.54		99.64
H_2O-	.81		

This chemical analysis, together with a study of thin sections of the ore, enables the approximate proportions of the several minerals of this particular material to be calculated.

Estimated mineral composition of jasperoid ore.

Quartz	76.0	Chalcopyrite	1.5
Mica	11.5	Chalcocite	2.5
Apatite	1.0	Excess water	2.0
Rutile	.8		
Magnetite	.6		99.7
Pyrite	3.2	Total sulphides	7.8
Pyrrhotite	.6		

The primary material from which ore of this mineral composition was derived may have contained 2.7 per cent of chalcopyrite, corresponding with somewhat less than 1 per cent of copper.

OUTLOOK FOR DISCOVERY OF JASPEROID ORE BODIES.

The jasperoids of the district have not been systematically studied as regards their average content of pyrite or as regards local variations in the proportions of contained chalcopyrite, but it is known that the amounts of these minerals are far from constant. A great mass of jasperoid that is exposed in the haulage-way between the Ruth workings and the Star Pointer shaft, though rich in pyrite, appears to contain no chalcopyrite, and very similar material was noted in cuttings from several drill holes situated at different points on the slopes south of Weary Flat. Although chalcopyrite may be an essential constituent of jasperoid in localities that have not been explored, it is only in the western part of the district that the mineral is actually known to occur in this material. Here, however, information does not extend beyond the observations that in the vicinity of the Veteran ore body the jasperoid is rather generally charged with chalcopyrite and that in the Boston-Ely shaft this mineral occurs where unoxidized cores were found in the generally weathered jasperoid, and the bulk of the rock, which outcrops over an area of approximately 50 acres, may or may not have contained as much copper as is present where tests have been made. But even if chalcopyrite was generally present it does not follow that thick and extensive blankets of chalcocite ore must exist. On the contrary, there is reason to believe that the conditions of underground drainage in this vicinity have been distinctly unfavorable for the enrichment of any really large or continuous masses of material.

Within the general area of the jasperoid the courses of the gulches are toward the south-southwest, but the under surface of the shell of weathered material falls away toward the northwest and so steeply that within the horizontal distance of 1,100 feet that separates the north end of the Veteran ore body from the Boston-Ely shaft the decline amounts to more than 700 feet. In the shaft mentioned water was reached only at a depth below 1,250 feet, and it seems evident that the general movement of the ground water within the jasperoid block has been toward some deep-seated outlet or outlets situated beneath the northwestern part of the jasperoid area.

[1] The sample comprised 25 fragments, taken from the ore bin during the summer of 1910 when the mine was idle.

If within the jasperoid area the bottom surface of the oxidized material is generally as steeply inclined as it appears to be (see Pl. VII) it seems hardly possible that the upper part of the unoxidized jasperoid could have been penetrated deeply by seeping waters, except where the flow may have been locally concentrated in troughlike channels. This conception leads to the suggestion that there may be trough-shaped or funnel-shaped bodies of disseminated chalcocite ore in this ground, but it appears rather unlikely that flat-lying blanket deposits will be found.

PARTLY SILICIFIED LIMESTONE MASSES CARRYING COPPER MINERALS.

Along the zone of general metamorphism there are large amounts of altered limestone which, though quite as heavily charged with metallic minerals as are the bodies of garnet rock or those of massive jasperoid, are only partly and very irregularly replaced by quartz or by quartz and silicate minerals. Such material is generally present in depth where the surface shows smooth slopes mantled by loose and rather finely divided rusty débris. In the western part of the district especially there are considerable areas within which such surface débris is characteristic, and here, in the Old Glory, Veteran, and Alpha mines, the nature of the so-called partly altered limestone may be observed. In material from these workings there are different degrees of jaspery replacement, grading through slightly silicified limestone to dense jasperoid and also the intermixture of silicate minerals with much of the jaspery rock. All the material carries abundant pyrite, and in general, so far as records of assays are at hand, all of it carries some copper (as chalcopyrite), the proportions ranging from 0.3 to about 1 per cent, or as an average not far from the estimated copper content of the jasperoids that occur in this part of the district and also that of the usual pyritized porphyry.

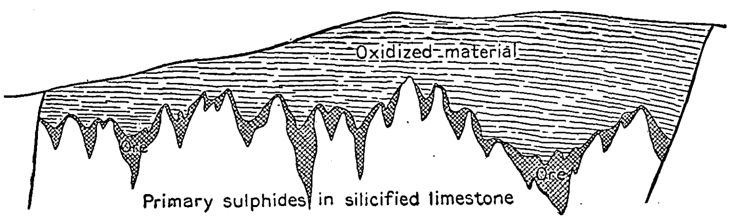
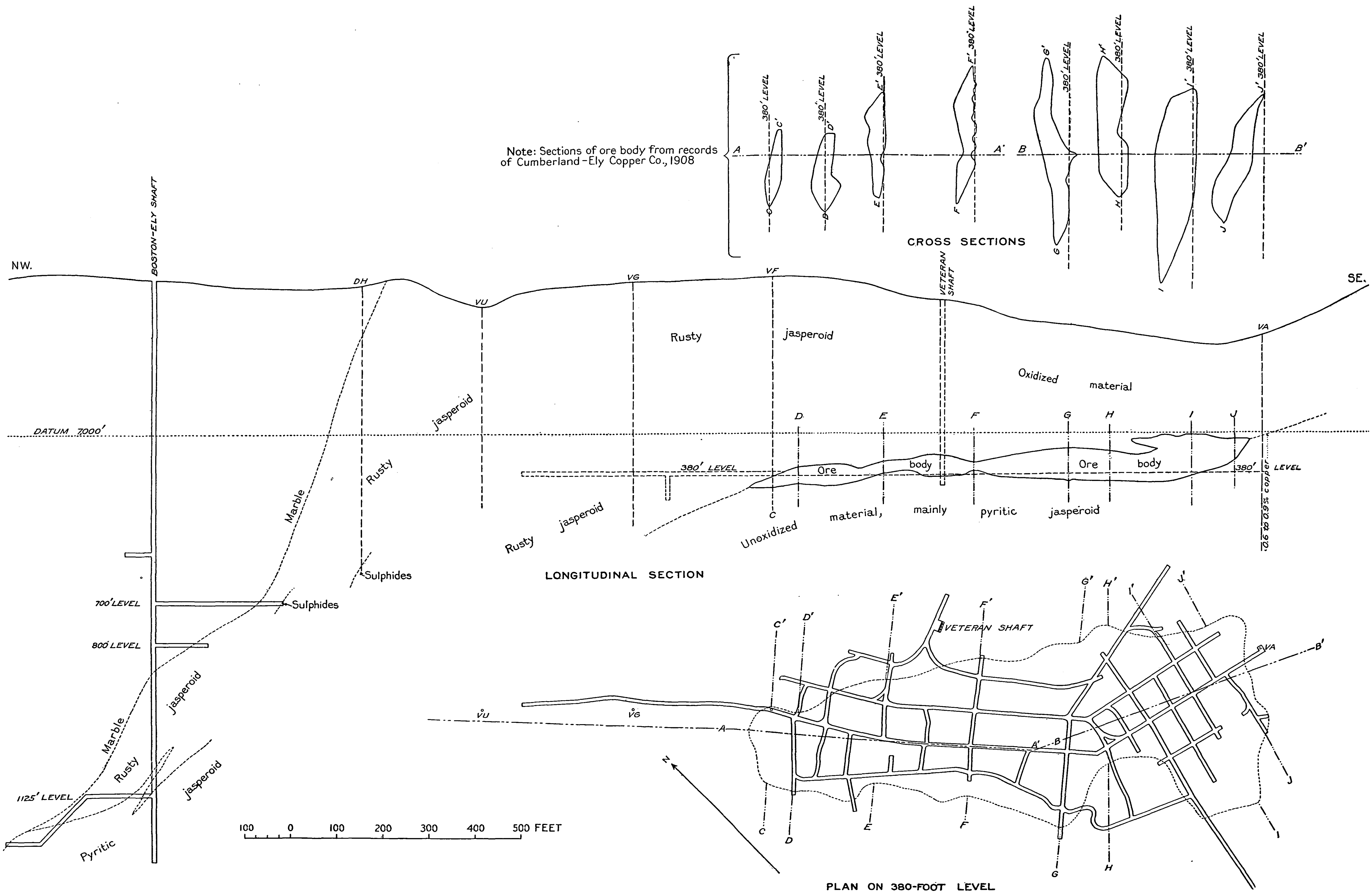


FIGURE 3.—Ideal sketch showing typical occurrence of enriched copper ores in extensive bodies of metamorphosed limestone.

Although the enrichment of these alteration products is noted in the Old Glory mine, the ore masses here are not really large compared with those occurring in porphyry or jasperoid. They have very irregular shapes compared with the ore bodies in porphyry, and in general it seems unlikely that areally extensive ore bodies exist. (See fig. 3.)

The material as a whole is characteristically heterogeneous, and it is all very dense and impervious so long as none of its contained calcite or sulphide minerals have been dissolved or oxidized. Thus it seems that the penetration of downward-moving solutions is dependent primarily on the presence of rifts or fractures to which ready circulation is closely limited so long as the rock is in no way decomposed. But surface waters are able to dissolve calcite and to oxidize the sulphides, and in proportion as these are attacked the material becomes more porous and permeable. The tendency is to continually increase the readiness of circulation and thus to make existing water channels more and more permanent. As a result the configuration of the surface between the partly oxidized and the unoxidized material becomes one of extreme irregularity, and the products of enrichment are developed mainly in troughs or funnels between which there are ridges of essentially fresh material. These relations are observed in the Old Glory mine, the ores of which conform in a way, though not accurately, to the disseminated type. Here the pyritized and partly silicified rock presents a layered aspect, the layers having northwest strikes and steep southwest dips. Localization of circulation appears to have resulted from the presence of fractures that are more or less conformable with the preexisting structures. Through this localization the two known ore bodies have been developed in adjacent, nearly vertical channels that appear to converge toward the south. These ore bodies are compound masses, comprising different-sized irregular bowlders of nearly fresh rock set in a meshwork of decomposition products, and the secondary copper minerals are principally segregated in the decomposed material. Both ore channels are flanked by pyritic mate-



LONGITUDINAL SECTION THROUGH VETERAN WORKINGS AND BOSTON-ELY SHAFT; PLAN AND CROSS SECTIONS OF VETERAN ORE BODY.

rial that shows comparatively little oxidation. The narrowly wedge-shaped mass between them is wider than the eastern channel, which has a width of 20 feet, and narrower than the western channel, which is about 100 feet wide. On the 350-foot mine level the larger ore body is bounded on the west by a dike of pyritized porphyry, and in the ground west of the ore body several small masses of this rock were encountered by the workings on the two higher levels, though here the immediate wall of the channel is altered sedimentary rock. The ore of attractive grade appears to have a vertical range of less than 100 feet, and as nearly as can be ascertained the bottom of the ore stands about 30 feet above the position of standing water in 1910.

In these ores the secondary minerals are mainly malachite and brochantite, though there is some chalcocite and a little covellite. Coatings of the secondary suphides are present on chalcopyrite contained in a matrix that carries abundant calcite. No statement can be made in regard to the origin of the green copper minerals, whether they were formed by direct precipitation from percolating cupriferous solutions or as oxidation products from previously deposited chalcocite.

Assay plans of the Old Glory workings, furnished through the courtesy of the management of the Giroux Consolidated Co., indicate that although the distribution of copper is very irregular, a large amount of the rock carries over 5 per cent of this metal.

Alteration products like those observable in the Old Glory mine have been exposed on the 1,000-foot level of the Alpha mine, and from the nature of the surface débris it may be judged that similarly altered limestone is characteristic along the south side of the zone of general metamorphism for a distance of 3,600 feet toward the east, where heavy jasperoid appears. Throughout this section very little information can be acquired from a study of the surface, though the general impression is gained that the structures strike parallel with the axis of the Bunker-Morris porphyry mass and, like it, are inclined toward the south-southwest. This belt of country, which is from 600 to 1,200 feet wide, is virgin ground, except what is known from the Alpha workings and from the records of a few drill holes in the eastern section. Four of these records show the occurrence of copper minerals in the ferruginous capping, and one of them indicates the presence of 0.1 to 0.4 per cent of copper in unweathered material. As there are abundant showings of copper in the Alpha ground and in the Bunker-Morris body of porphyry, it may be fairly assumed that the metamorphosed limestones are generally copper-bearing, and it seems that this belt should contain ore bodies like those of the Old Glory mine and perhaps others more like those of the Alpha mine. From conditions in the Alpha workings it is evident that somewhere near the edge of the metamorphic belt in this vicinity there is a deep-seated outlet for ground water (as there is farther to the northwest in the Boston-Ely ground), and the suggestion is hazarded that along the west edge of this belt there may be several deep drains, so that in general from north to south the bottom of the oxidized capping will be found at lower and lower levels. (See Pl. VII and fig. 4, p. 144.)

COPPER-BEARING GARNET ROCK.

Though garnet is a widely distributed mineral in the altered limestones along the zone of general metamorphism, compact masses of rock that are largely composed of garnet or other silicate minerals are in general much smaller than the masses of pyritized porphyry, the larger masses of typical jasperoid, and those bodies of altered limestone that have been thoroughly impregnated with sulphide minerals but only partly and irregularly replaced by quartz and silicate minerals. As these deposits are relatively small, they do not conform strictly to the division of great-mass deposits, to which, however, most of them are allied in that their metallic minerals are in a general way sparsely distributed through the rock matrix.

Examination of material from prospects in different parts of the district indicates that rock in which garnet is the principal replacement mineral ordinarily carries somewhat more chalcopyrite than other phases of altered limestone. In a few places minor bodies of garnet rock contain from 5 to 6 per cent of this primary copper mineral, and therefore about 2 per cent of copper. Nothing has been discovered, however, which would warrant the statement that deposits of the sort offer any promise of future commercial importance. In general the heavy deposits are too irregular to be reliable, and they appear not to contain enough copper to be valuable as primary ores. Because the primary material is very dense and impermeable the deposits are weathered only to very shallow depths, and because the development of secondary copper minerals has been on a correspondingly small scale, the outlook for valuable bodies of enriched material is not encouraging.

COPPER MINERALS IN METAMORPHOSED SHALE.

Large bodies of heavily pyritized shale which occur in three localities in the district are here considered more for the purpose of rendering the systematic discussion of the metalliferous deposits complete than because of any economic promise which they appear to offer.

Where shales occur within the zone of intense metamorphism they are strongly baked and generally impregnated with pyrite, and outside of the areas in which the more uniform alteration has been imposed pyrite has been deposited in certain layers of the rock. In the eastern part of the district there has been little exploration within the areas of intense metamorphism, and in the few places where the weathered material has been penetrated nothing has been found to indicate either the presence of abundant primary chalcopyrite or the development of secondary copper minerals.

The greatest body of pyritized shales lies north of the Copper Flat-Liberty mass of porphyry and east of the Weary Flat intrusion, where, within an area exceeding 150 acres the shales are everywhere rather heavily charged with pyrite. North of the railroad several excavations and drill holes have shown that the shales, though generally pyritized, are not strongly baked, and so far as known noteworthy amounts of chalcopyrite have not been found excepting that a little material penetrated by drilling in the Puritan claim is reported to carry about 1 per cent of copper. From a study of the surface débris it is apparent that the degree of baking which the shales have suffered increases from north to south, and oxidized material from a shaft situated near the northeast corner of the Oro claim has zoisite and secondary mica developed in it. About 600 feet south of this shaft a drill hole (hole 19, Copper Flat series) 270 feet deep encountered pyritic material, probably representing altered shale, in all of which, according to report, copper was absent. The southern boundary of the shale is not actually known, and as represented on the map the area includes jasperoid bodies that are more likely to have been derived from limestone than from shale.

MINOR-MASS REPLACEMENT DEPOSITS.

CLASSIFICATION.

In contrast to deposits in which the primary metallic minerals are sparsely distributed through large masses of rock there are other replacement deposits that are characterized by a closer segregation of these minerals in bodies of comparatively small size. These minor mass or compact segregation deposits may be conveniently classified as irregular bodies and tabular bodies. The irregular deposits are described under two heads, according to specific mineral characteristics, and the tabular deposits are subdivided into pyritic replacement veins and bed deposits. Certain kaolinic copper ores that occur in the Alpha mine are described under a heading which do not conform to the scheme of classification by primary features.

Though it has seemed desirable to classify the metalliferous deposits on the basis of their primary characteristics, the result is less satisfactory in the general group here under consideration than could be wished, because it has been necessary to infer the primary features of almost all the deposits from exposures of greatly weathered material that have been made in mining explorations.

IRREGULAR REPLACEMENT BODIES CARRYING SULPHIDES AND MAGNETITE.

Though magnetite is a common associate of pyrite and chalcopyrite in masses of garnetized limestone, the proportion of this mineral is generally small, and only three localities are known where magnetite has been deposited in such amounts as to make it the most prominent constituent of the metamorphic material.

In Ruth Gulch, between the Brilliant and Ruth shafts there is an area 3 or 4 acres in extent within which there are a few outcrops of garnet rock and abundant magnetite. The relations of these two materials is nowhere exhibited, but it may be surmised that the magnetite occurs in bunches distributed through the garnet rock. Both materials contain limonite, obviously derived from pyrite, and copper stains, which indicate that the unweathered materials contain chalcopyrite. The northern edge of the area in which the garnet outcrops occur is about 200 feet from the edge of the Ruth mass of porphyry, but the intervening rocks are not exposed. Toward the east and southeast there are massive outcrops of rusty jasperoid, and in the Brilliant mine the limestone has been greatly silicified and heavily though irregularly impregnated with sulphides and magnetite.

The second body of magnetite rock occurs on the Josie claim on a low ridge west of the Oro mine pit. Here a shaft was sunk at a place where fragments of compact magnetite occur on the surface and near a small rusty outcrop of garnet rock. This shaft entered a body of magnetite containing irregularly distributed copper minerals, mainly carbonates, and a few tons of material mined prior to 1909 is said to have assayed more than 3 per cent copper. The size of this magnetite body is not known, and its geologic setting was not determinable because the locality is one in which rock exposures are almost entirely absent. It is probable, however, that the area is occupied by metamorphosed limestone, and dikes of porphyry may be present south of the magnetite outcrop.

The most prominent exposures of magnetite are those on the Pilot Knob claim in the western part of the district. Here surrounded by rocks that are in no way strongly metamorphosed there is a mass of material nearly 100 feet wide and about 400 feet long that is composed in large part of fine-grained blocky magnetite. From very imperfect exposures the magnetite appears to occur not as a solid body but as irregular masses between which there is rusty material. Green copper minerals occur at several points, and it seems safe to assume that unweathered portions of the ore mass carry both pyrite and chalcopyrite. The ore body occurs near a profound, easterly coursing fault that brings vertical limestone strata on the north against shales on the south.

There is no obvious genetic relation between the Pilot Knob magnetite body and the intrusive porphyry of the mass which outcrops under the Giroux mill only a short distance away. The character of the material from several excavations in this vicinity shows definitely that the porphyry is of the normal or unmetamorphosed type, and the shale which occurs between the porphyry area and the ore body is only slightly altered. From these relations the conclusion is drawn that the deposit was not formed by laterally moving emanations from the contiguous portion of the porphyry mass, but that the ore-forming solutions originated far below the present surface.

IRREGULAR REPLACEMENT BODIES COMPOSED MAINLY OF PYRITE.

So far as has come to the writer's notice, essentially solid pyrite in masses of noteworthy size has been found in only two localities in the Ely district. About 800 feet west of the Oro mine pit on the Emma Nevada claim such material was discovered at one place beneath a reef-like body of gossan. As the gossan reef may be traced for a distance of several hundred feet, this can hardly be other than a tabular body. The other occurrence, which is a larger and less regular body, is on the Reipe claim near the general store at Kimberly. Here the material from a shaft, which is said to be somewhat less than 100 feet deep, consists principally of spongy gossan but includes some crumbling pyrite. A diamond-drill hole was bored beneath this shaft from the 300-foot level of the Old Glory mine. Assays of material from the first 260 feet of this hole show a mean copper content of about 0.5 per cent; three returns give 1 per cent or slightly more, and the others range from 0.2 to 0.7 per cent. The middle section, about 530 feet, appears to contain no copper (corresponding with the occurrence of marble on the surface), but the outer 120 feet was reported to show from 0.2 to 0.8 per cent copper, and part of the material is said to have been massive sulphides.

Large bodies of spongy limonite, in the eastern part of the district, on the Joana and Aultman claims south of the lower part of Lane Valley, are regarded as having been derived from pyritic replacement deposits as a result of weathering. A small body of similar material is exposed on the Great Western claim on the north side of the valley east of Lane.

PYRITIC REPLACEMENT VEINS.

Under the head of pyritic replacement veins it is purposed to describe cross-breaking tabular replacement bodies that occur outside of the general zone of intense metamorphism in limestone country that has not been generally mineralized.

In several places deposits of this type have furnished rich carbonate and chalcocite ores from shallow workings. Because the secondary ores are of high grade it might be inferred that the primary deposits carry large proportions of chalcopyrite, but such material has not been found in the few places where explorations have been made beneath enriched material.

Though most of the replacement bodies are of veinlike or tabular form, others appear to be mere bunches. As a rule the veinstuff is highly siliceous and in many places it is composed of jasperoid, essentially like that which occurs in large masses within the areas of most intense metamorphism.

It is sufficiently obvious from a study of surface outcrops and exposures in shallow excavations that these veinlike bodies have been formed by the replacement of limestone through the action of solutions circulating along rather tight channels, and not to any important extent as fillings of open fissures.

In the western part of the district some of the jaspery veins are offshoots from the great mass of jasperoid that outcrops over an extensive area on the Veteran group of claims. Here the offshoots and numerous outliers trend mainly toward the northwest, or in the same general direction as the axis of the principal zone of porphyry intrusion, and the formation of the veinlike masses was probably contemporaneous with the general metamorphism that elsewhere resulted in the bulk replacement of great masses of limestone by pyritiferous jasperoid. In this vicinity most of the jaspery replacements appear to conform with the stratification of the country limestone, but besides these bed deposits there are several transverse veins. Ores, both of copper, and lead, reported to carry silver and gold, have been mined from shallow workings, but in no place where copper minerals are abundant have the primary sulphides been revealed.

In the central part of the district jaspery veins occur here and there along the flanks of the metamorphic zone. The outcrops are usually very ferruginous, but the occurrences of copper minerals that have been found appear to be insignificant.

In the eastern part of the district copper-bearing replacement veins occur in several localities. On the north side of Robinson Canyon just below Lane Valley there are four separate intrusions of porphyry and between these intrusions the massive Devonian limestones are irregularly bleached and marbleized and in some places next to the porphyry masses garnet and other silicate minerals have been developed in company with pyrite and a little chalcopyrite. Within this area of moderate alteration there is considerable fissuring, and along some of the breaks the rock has been strongly affected by replacement metamorphism. Because of weathering and the shallowness of workings the original character of the lodes is not directly observable, but the presence of strong limonite gossans permits the inference that unoxidized portions of the deposits must be highly pyritic. The gossans are siliceous in different degrees, so that in some places the exposed vein matter is spongy limonite and in others is dense rusty jasperoid.

East and northeast of the four porphyry masses that have been mentioned there are numerous rusty mineral showings. Many of the outcrops appear to represent mere bunches, but some of them occur in alignment and are doubtless local replacements adjacent to definite fissures. One of these recurrent veins that strikes north-northeast from the north end of the second porphyry mass may be traced for about 500 feet by outcrops 3 to 4 feet wide. Workings along this lead are unimportant, but copper stains are seen in a few places.

East of the rounded end of the hook-shaped termination of the westernmost porphyry mass is a series of irregular replacement bodies. One of these, a veinlike body from 1 to 6 feet wide, may be traced northeastward for a distance of 300 feet. Near the northeast end of this line of outcrops some carbonate ore has been mined from shallow workings.

About 500 feet southeast of the vein last mentioned, on the crest of a prominent ridge, there is a prominent gossan of limonite and rusty jasperoid. Here from shallow workings on the Florence claim much carbonate copper ore has been produced. From a study of the surface outcrops and the old excavations it appears that the original replacement body was deposited where two nearly vertical fractures with northeast strikes meet an east-west fracture that dips toward the north. The parallel fractures, about 90 feet apart, flank the ridge crest, and between them along the east-west break the principal segregation of vein matter took place. The eastward striking vein may be traced for a total distance of 250 feet. The other fissures do not appear south of the pit, but on the north they contain small amounts of jaspery filling.

In the section of country that lies north of the four porphyry bodies and south of the drainage divide, jaspery veins occur at several points. One of the oldest mineral claims in the district, the Brownstone, is situated about three-fourths of a mile northeast of Lane, on the first ridge east of the fault which bounds the Nevada limestone area on the west. Here shallow pits expose an irregular vein 2 to 6 feet wide for a distance of 70 feet. The outcrop trends nearly parallel with the fault in the neighboring gulch, and toward the north there are showings of jasper at several places along or adjacent to the extension of this line of outcrop throughout a distance of 1,800 feet.

Jaspery copper-bearing veins and bunches occur at several localities on both sides of the lower canyon west of Ely. Prominent showings have been made at a point about a quarter of a mile above the railroad tunnel and about 200 feet above the track on the north wall of the valley. Here a small body of heavy chalcocite ore was found beneath an outcrop of siliceous gossan that had a total area of only a few square feet.

North of Ely, a short distance above the first showing of rock in place, several rich bunches of ore were found beneath outcrops of rusty jasperoid. No continuous veins are visible, but these ore masses probably represent local replacement of limestone adjacent to eastward-trending fissures. A tunnel which was run into the mountain to explore the ground beneath these outcrops found nothing which can be definitely correlated with the surface showings, though in several places the limestone was charged with pyrite.

In the gulch east of the outcrops just mentioned there is a strong fault break which can be followed in a northerly direction nearly to the watershed, and which is probably continuous with a fault which has been recognized somewhat more than a mile beyond. On the Grand Deposit claim, just above the head of the talus deposit at the mouth of the gulch, there are old workings from which considerable copper ore has been mined. The depth of these workings is reported to be about 30 feet and the maximum width of the vein appears to have been about 20 feet. Replacement of the limestone appears to have occurred along a spur from the main fault. The vein diverges toward the southwest and the lode matter extends about 150 feet along the trend.

Along the fault fissure toward the north there are minor showings of jasperoid and of copper carbonates at several places, and at two points there are narrow dikes of rhyolite. The land rises steeply to the divide at the head of the gulch, where the position of the fault has not been recognized. Across this divide and a short distance west of a line in prolongation of the fault trace lie the North Star workings. Here an irregular mass of ferruginous and somewhat siliceous carbonate and chalcocitic ore was opened and mined out during the summer and fall of 1910. Several carloads of ore was shipped, and some of the better lots contained above 20 per cent copper, about 25 per cent iron, 1 or 2 per cent zinc, and traces of gold. All the ore was taken from workings less than 50 feet beneath the surface. The relations of the lode matter to the inclosing limestone are not well exhibited, but the writer believes that the more or less jaspery sulphide-bearing material forms an irregular replacement adjacent to an essentially upright fissure. The width of the mass appears to be from 10 to 20 feet, and its observable length, from east to west, is not more than 50 feet.

PYRITIC BED DEPOSITS.

In contrast with tabular replacement deposits formed along cross-breaking fractures are compact segregations, wherein the tabular form has resulted from replacement under the control of the original layering in stratified rocks. Though such deposits are commonly called blankets if they lie nearly horizontal, the term bed deposit is here preferred because of its more general applicability. In the Ely district primary deposits of this general type may be divided for convenience into those that contain only pyrite or pyrite and chalcopyrite and those in which galena also occurs. The deposits that contain galena are discussed on pages 128–129.

The pyritic bed deposits are best known from occurrences outside the zone of most intense metamorphism. In massive limestones, where they are much less common than in shales, they are generally highly siliceous and very much like the cross-breaking replacements with which they are commonly associated. Most of them carry very little chalcopyrite, but in a few places bunches of rich secondary copper sulphides occur, as a rule near bodies of jasperoid. In the shales outside the central metamorphic zone layers which are heavily impregnated with pyrite but which carry negligible amounts of chalcopyrite have been encountered in several places and are probably more common than explorations have shown. That chalcopyrite occurs locally is known from drill holes on the Monitor claim west of Copper Flat station, on the Puritan claim east of Reipetown, and on the Blue Jacket claim southeast of Veteran village.

Very striking examples of bed deposits are represented by tabular bodies of limonite that occur in a few places in the eastern part of the district along the partings between shale and the overlying limestone formations. These masses of limonite, which are siliceous in different degrees, are probably the gossans of pyrite deposits that were formed by the replacement of limestone. They have been so slightly explored that the extent of individual deposits is not known, but their thickness ranges from a few feet to 30 feet. Copper minerals were not observed in these deposits, although they are reported to carry small amounts of gold.

In the central part of the district north of Copper Flat there are outcrops of very ferruginous jasperoid that extend for several hundred feet along the parting between the Joana limestone and the overlying Chainman shale,[1] and in two places copper ores have been found. One of these two occurrences of copper ore, on the Monitor claim, is noted above. The other, on the Clipper claim, was a pocket of rich chalcocitic carbonate ore that lay practically at the surface. Explorations elsewhere along this replacement deposit show only jaspery limonite and nothing of promise was found in a deep shaft.

To what extent the great bodies of generally metamorphosed and pyritized limestone carry compact bed deposits is not known, because these rocks have been but slightly explored below their weathered portions, and even where they have been exposed in mine workings it is usually impossible to determine the original bedding structures. In the workings from the Brilliant shaft a thin layer of nearly solid pyrite and chalcopyrite was noted as definitely conformable with the bedding of the limestone by which it is inclosed, and in the same mine layers of sphalerite an inch or two in thickness were found. On the 1,100-foot level of the Emma shaft generally pyritized and silicified limestone carries numerous parallel layers of pyrite, and assays of material from these layers are reported to show a maximum of about 1 per cent of copper. Here again it is almost certain that the layering is parallel with the original bedding of the metamorphosed rock.

Where, in areas of metamorphosed limestone, mine workings have penetrated the weathered capping, alternations of harder and softer materials are common, as for instance of compact jasperoid and ferruginous earthy material, an arrangement which obviously indicates a layering of different sorts of alteration products in the primarily mineralized rocks and which in many places certainly indicates original stratification. Layering of this sort is a prominent feature in the upper workings of the Veteran and Old Glory mines and on the 1,000-foot level of the Alpha mine, in all of which, the writer believes, the different materials represent selective replacement of the beds of stratified rock bodies.

COPPER ORES ASSOCIATED WITH KAOLIN.

In certain copper ores developed in the Alpha mine, oxidic copper minerals occur as rather compact bodies in masses of kaolin. The ore minerals comprise metallic copper, cuprite,

[1] The Chainman-Aultman bed deposit, which is described on p. 172, is similarly situated.

malachite, and a black mineral which appears to be either an indefinite compound or a mixture of black copper oxide and hydrous iron oxide. As this list of minerals indicates, these ores occur where the rocks are strongly weathered, though in the Alpha mine they have been found principally at depths below 900 feet, are known to be abundant on the 1,200-foot level, and probably occur at even greater depths. In the Boston-Ely mine a small body of somewhat similar ore was found on the 1,100-foot level.

The Alpha workings explore the outer edge of the zone of intensely metamorphosed limestones, about 1,200 feet wide, that lies southwest of the Bunker-Morris mass of porphyry. Between these workings and the Old Glory shaft, 1,600 feet distant, lies the porphyry intrusion of Old Glory Hill. Toward the west the limestones are essentially unaltered.

In the Alpha shaft complete oxidation extends at least to a depth of 1,200 feet or to an elevation not higher than 5,900 feet, whereas from drill holes and mine workings within a radius of 1,600 feet toward the east, north, and north-northwest, equivalent weathering is known to have reached only comparatively shallow depths, corresponding with elevations between 6,900 and 7,100 feet. Only 1,000 feet to the northeast a drill hole in mineralized porphyry revealed the existence of unweathered sulphides at an elevation of about 7,000 feet. From these observations it appears that the Alpha shaft penetrates a rudely funnel-shaped mass of material that was formerly pyritic but which has been thoroughly oxidized under the action of seeping ground waters, which found a deep outlet near by, perhaps beneath the shallow gulch that lies just to the north.

As is indicated by sintery iron-stained débris on the surface, by an abundance of rusty cellular silica rock exposed in the mine workings, and by pyrite-bearing silicified limestone which occurs north and east of the ore ground on the 1,000-foot level, the great bulk of the metamorphosed limestone in the vicinity appears to have been pyritic jasperoid, but associated with these highly quartzose replacement products of limestone there was material from which the kaolin bodies have been derived. North of the shaft, on the 1,000-foot level, the kaolin occurs in rude layers from a few inches to nearly 30 feet thick, alternating with equivalent layers of leached and more or less ferruginous jasperoid, the whole complex showing in the north-trending drift for a distance of 230 feet. On higher levels the corresponding ground had not been prospected at the time the mine was examined, and the 1,200-foot level was then flooded. The white and brown clays are composed mainly of kaolinite, as is shown by the abundance of alumina and the absence of potassium. Most of the samples collected contain no sulphate, but a positive test for this radicle was obtained from one specimen of drab-colored clay.

The layering of kaolin and weathered jasperoid, which probably represents the original stratification, strikes generally from southeast to northwest and dips either vertically or steeply toward the southwest. The kaolin is undoubtedly a product of secondary alteration, attributable to the action of the same downward-moving solutions that caused the oxidation of the pyrite and the local concentration of copper minerals, but the nature of the primary materials that have been replaced can not be satisfactorily inferred. It is suggested that the kaolin masses represent either beds of shale which were intercalated in the limestone, or layers of strongly sericitized limestone. The first suggestion would make the alumina an original component of the sedimentary rock, whereas the second contemplates the introduction of alumina during primary mineralization. A third possibility is that the alumina was contributed mainly by sulphate solutions during the process of weathering.

It is unlikely that the kaolin bodies of the Alpha mine represent former beds of shale, mainly because elsewhere in the district there are masses of kaolin in situations where it is obvious that only limestone could have been involved in their formation.

Basis for the hypothesis that the kaolin has been formed from sericite is found in the fact that sericite is a constituent of metamorphosed limestone at several localities in the district. In one place a small mass of material composed of extremely fine grained quartz and sericite has been so altered along a water seam as to give rise to a gouge of white plastic clay that is quite free from grit. North of the ore ground on the 1,000-foot level of the Alpha mine pyritic alteration products of limestone occur, evidence of intense crushing is afforded by bluish plastic gouge, composed principally of quartz, calcite, and pyrite. The plastic quality of the material is due to the presence of a considerable proportion of sericite, which may be readily isolated by treatment with acid followed by elutriation. Tests show abundant potassium, and also the absence of sulphate, which if present would indicate alunite instead of sericite.

No argument is offered either for or against the suggestion that the kaolin bodies may owe their origin to the action of downward-moving aluminous solutions. This hypothesis, which was advanced by Douglas [1] in a discussion of the origin of the great masses of kaolin associated with the ores of the Copper Queen mine at Bisbee, Ariz., is not accepted by Ransome. Here the original country rock was limestone, and concerning the kaolin or clay Ransome [2] says:

> The analysis of mineralized limestone given shows less than 1 per cent of alumina, and the Escabrosa limestone on the whole contains very little argillaceous impurity. In spite of these facts, however, the occurrence of these clays is such as to strongly suggest that the alumina contained in them was originally a constituent of the limestones. Its concentration in the porous limonitic ledge matter has probably been effected by mechanical as well as chemical agencies.

With this presentation the kaolin problem must be left for elucidation to others who may have the opportunity to study the Alpha copper deposits when the difficulties have been overcome that thus far have beset their commercial development.

In the kaolin ground in the Alpha mine the copper minerals occur as bunches, chimneys, and more or less tabular shoots within the kaolin bodies. The richness of the ores is indicated by the fact that 210 tons of ore mined in 1907 from stopes above the 1,000-foot level contained 12.6 per cent copper. It is noteworthy that even on the 1,200-foot level the ore minerals do not include chalcocite, but much metallic copper is present, which, because it is a common alteration product of chalcocite, may indicate that the ores, which now consist mainly of oxides and carbonates, have passed through the chalcocite stage. Both because of the high grade of the ores and because the derived or secondary minerals occur in compact bodies, the deduction may be tentatively made that the distribution of the ore shoots corresponds with the distribution of limited bodies of primarily mineralized material that were heavier with pyrite or with pyrite and chalcopyrite than the bulk of the metamorphosed country rock.

The belt of metamorphosed limestones on the edge of which the Alpha mine is situated would seem worthy of careful exploration from the Boston-Ely shaft to the rhyolite areas that lie south of the Bunker Hill shaft. Some ore of the Alpha type has been found in the 1,100-foot level of the Boston-Ely exploration, and in higher levels several irregular bodies of kaolin were found. In the Veteran mine some minor occurrences of kaolin were also noted, and it may be fairly assumed that bodies of this material are present from place to place throughout this general belt. Everywhere the mineralized materials appear to be sharply bounded against essentially unaltered limestone; the flanking strata have been greatly disturbed so that they exhibit rather steep dips, and locally they have been broken; and in general conditions appear favorable for deep drainage, such as exist in the Boston-Ely and Alpha blocks of ground. Several deep ground-water outlets may exist east of Alpha locality, and such outlets, if present, have undoubtedly drained more or less funnel-shaped bodies of the mineralized rocks. Probably these drains would be more likely to lie beneath gulches than under ridges, though there is no apparent reason why ore masses might not occur in different parts of the funnels of weathered material, the greatest vertical range of ore bodies would be expected where oxidation has been the deepest. A drill hole situated 2,500 feet west of the Alpha shaft on the Richard claim is reported to have penetrated oxidized material to a depth of nearly 1,000 feet and to have revealed copper minerals. Other borings 1,200 feet farther east show the presence of copper, both in oxidized and unoxidized materials.

Northwest of the Alpha mine, on the 1,100-foot level of the Boston-Ely mine, a small body of oxidic copper ore was found.

In the central part of the district weathering in pyritic altered limestone appears in general to extend to depths of only 200 to 300 feet, though in workings from the Zack shaft completely

[1] Douglas, James, The Copper Queen mine, Ariz.: Am. Inst. Min. Eng. Trans., vol. 29, p. 535, 1900.

[2] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 158, 1904.

oxidized material was found below a depth of 500 feet. The presence of sericitized limestone in material from the Zack shaft, and of kaolinic copper ores in the Blair prospect, suggests that ores of this type may occur here and there in the weathered capping of the altered limestones south of the Copper Flat Liberty porphyry mines and in the similar rocks that occur adjacent to the Ruth intrusion. North of this intrusion, in the vicinity of the Phoenix silver-lead vein, the limestones are locally altered to material that resembles kaolin but effervesces freely with acid.[1]

In the eastern part of the district specimens of sericitized limestone were collected from the Hidden Treasure tunnel and from a shaft on the St. Patrick claim.

QUARTZ VEINS CARRYING PYRITE AND CHALCOPYRITE.

Although the porphyry masses within the principal zone of intrusion carry innumerable pyritic quartz veinlets and in places such veinlets form intricate reticulations through large masses of rock, separate veins occupying extensive fissures are uncommon, and most of those that have been discovered carry more galena than chalcopyrite. A narrow vein composed largely of quartz and containing chalcopyrite was cut in the Taylor workings half a mile north of the Giroux concentrator, and other small veins of the same sort are exposed in two prospect pits near by. Small veins of sulphide-bearing quartz were noted also in the eastern part of the district, but the only large body of typical vein quartz which has come to light occurs within the mass of porphyry in the Copper Flat mine. As exposed on the sides of the great pit in 1910 this quartz body had a length of 600 feet and an irregular width of 100 to 200 feet. Thin sections examined under the microscope show that the material contains a little orthoclase. Pyrite and chalcopyrite, the only primary sulphides noted, are generally distributed as they are in veinlets in the porphyry ore, and both minerals are commonly coated with chalcocite. The upper parts of the vein contained only oxidized copper minerals, principally malachite. Large amounts of this so-called "siliceous ore" were found to contain more than 3 per cent copper. It is mined separately and is used as a source of silica in converting matte into blister copper.

SILVER-GOLD DEPOSITS.

OCCURRENCE AND CHARACTER.

The occurrence of silver ores and silver-gold ores is nearly confined to localities bordering or outside of the zone of intense metamorphism. Almost everywhere the heavily pyritized rock bodies of this zone are rather sharply bounded against masses of limestone and shale that have not been affected by the same thorough metasomatism, but in which here and there occur compact bodies of sulphide-bearing material. These outlying deposits resemble the mineral deposits of the central zone in being principally replacements, though a few of them fill fissures; they differ in showing among themselves wide variations in their proportions of iron, copper, lead, and zinc, and in their precious-metal content.

Although there has been practically no mining and very little prospecting, except in weathered materials, the primary characters of the lodes can be made out, in a general way, from what is known of their oxidation products. Those lodes which contained galena are as a rule carriers of precious metals, whereas originally pyritic deposits without galena, whether copper-bearing or not, generally carry very little gold or silver.

REPLACEMENT DEPOSITS CARRYING PRECIOUS METALS.

The classification that has been adopted for replacement deposits containing silver and gold in commercial quantities follows closely that which has been given for the essentially pyritic and copper-bearing deposits of the same general class, the only difference being that the group of great-mass replacements is not represented.

DEPOSITS OF IRREGULAR FORM.

In the eastern part of the district the gossans of several irregular pyritic replacement deposits were mined in a small way during the decade 1870–1880 as flux for local copper and lead

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 347-349, 1906.

smelters. Excess iron was furnished by material from the Joana claim, which is reported to carry generally from $1 to $3 in gold. Pockets or bonanzas in this mass of gossan have furnished ores whose gold content is said to have ranged from $40 to $100 a ton.

Siliceous material appears to have been worked principally on the Union claim, north of Lane Valley, where a large pit has exposed an irregular body of cellular and crumbling yellow gossan, which, though greatly obscured by surface débris, appears to cover an oblong area about 100 feet wide and 400 feet long. A body of similar material was cut in the old tunnels on the Rob Roy claim, a short distance south of Lane. Though these siliceous materials are reported to have been particularly desired because of the gold which they contained, nothing definite was learned regarding their assay value. Both of the deposits may represent pyritic jaspery replacements of limestone.

VEINLIKE REPLACEMENT LODES.

Most of the transverse tabular replacement deposits of the district are merely more or less pyritic jasperoids, but there are a few, as already stated, that carry chalcopyrite, and others that contain mixed sulphides, including galena and sphalerite. The galena and sphalerite ores, which are rather characteristically carriers of gold and silver, are found in perhaps a dozen well-distributed localities in the limestone country. They are most prominently developed along the north flank of the central zone of metamorphism from Lane westward for a distance of 2 miles. Here and there it is observed that veins of this sort appear as feeders for bed deposits and locally they grade into veins of the filled-fissure type.

The lodes are from a few inches to 6 feet wide, rarely more. They are not continuous as a rule for more than 200 to 300 feet, though the stronger ones extend interruptedly for distances of 1,200 to 1,800 feet. The metallic minerals occur principally in irregular shoots, though the more jaspery parts of the lodes carry pyrite and usually minor amounts of other sulphides. Fluorite is a rather common gangue mineral.

BED DEPOSITS CARRYING PRECIOUS METALS.

Bed deposits that carry precious metals occur in the extreme western part of the district and in the eastern half of the mineralized belt.

West of Veteran Hill, where the massive jasperoid of the metamorphic zone gives place to less-altered limestones, there are several replacement bodies, some of them following cross-breaking fractures and others, which are the stronger and the more numerous, conforming to the stratification of the Ely limestone, the beds of which here strike northwest and dip toward the southwest. The lodes of this locality are all similar, in that they are essentially jaspery replacements with sulphides locally abundant, and with fluorite as a rather common constituent. The principal bed deposits occur on the Emma and Matilda claims. These lodes, though more or less discontinuous, are traceable for 500 and 300 feet respectively, and they range from 1 foot to 6 feet in width.

That parts of the Matilda lode may have been deposited in open spaces is suggested by the local occurrence of a 2-inch layer of fluorite along the footwall.

In the east half of the district there are several replacement blankets or bed deposits of silver and silver-gold ores. Some of these are well removed from the central metamorphic zone, but most of them border the intensely altered rocks.

On the west side of the upper end of Robinson Canyon, southeast of Keystone Hill, there are mine workings from which oxidized manganiferous silver-lead ores were taken many years ago. The richest silver ores that the district has afforded are said to have come from this locality. The Ely limestone is here made up of massive beds, and the ore bodies occur locally along well-defined partings between these beds. All the workings lie within 400 feet of the south boundary of a small porphyry intrusion that outcrops on the east side of Keystone Hill, but the limestones show no general metamorphism. These lodes are exceptional in that they contain no jasperoid.

Other outlying bed deposits occur three-quarters of a mile south of Lane in the Rabbit mine and the same distance northwest of Ely on the Sentinel claim.

In several places the veins occurring along the north side of the principal zone of metamorphism west of Lane have acted as feeders for bed deposits, and within the same general belt there are similar deposits which have no ascertainable connection with transverse lodes. These deposits are in the Ely limestone. Like the veins with which they are mainly associated, they are locally composed of dense pyritic jasperoid, but elsewhere they carry fluorite and abundant metallic sulphides, including galena, and in general the sulphides are accompanied by precious metals. Examples of bed deposits associated with upright veins occur in the Phoenix, Ontario, and Elijah mines.

The most extensive precious-metal deposits developed in the district are those of the Chainman group of mines. Such studies as it was possible to make in abandoned workings, taken in connection with what is known of the general geologic features of the locality, show that these are replacement deposits conformable to the stratification of the massive Joana limestone and the overlying Chainman shale. In the extensive Chainman-Aultman workings two ore horizons were developed, one at the top of the limestone, and the other perhaps 20 or 30 feet higher, in the shale. In this mine the ore stopes in the two deposits appear to have been about equally extensive. Locally they overlap, but most of the mining in the upper bed was south of the most productive part of the lower deposit. The ore mined is said to have been from 8 to 10 feet thick, though in the Revenue shaft the upper deposit is a siliceous stratum at least 20 feet thick. A drift, opened in the lower part of this stratum and extending about 250 feet west from the Revenue shaft, approaches within 200 feet of the southern Chainman stopes in the same bed, which thus appears to have the same general character over an area measuring at least 350 feet north and south and 500 feet east and west.

A study of the Chainman mine map indicates that in the western workings the top of the Joana limestone was explored from north to south for nearly 500 feet, though in the eastern part of the mine, where the deposit at this horizon furnished a body of high-grade ore, the stopes are nowhere more than 150 feet wide. From west to east there are continuous workings for a distance of 700 feet.

The productive workings of the Chainman-Aultman mine are all above the level of standing water, and the ores mined were almost entirely oxidized. The better ores consist of spongy siliceous material that is gray or yellow from the presence of lead carbonate or of lead-iron sulphate minerals.

FILLED FISSURE VEINS CARRYING PRECIOUS METALS.

In the eastern part of the district the Robust, Isaacs, and Elijah, in the central part the Hayes and Badger, and in the western part the Matilda lodes are probably in part replacement deposits and in part deposits formed as a result of the filling of open fissures. Because conditions were unfavorable for detailed studies of any of these deposits, this suggestion is made more on the basis of general impressions than on adequate evidence.

The gold-bearing ores won from the Robust vein come entirely from the oxidized portion of the lode. The vein stands nearly vertical and breaks across the stratification of the limestone country. Jasperoid occurring along the outcrop can hardly have been formed otherwise than by replacement of the limestone, but, as disclosed in the underground workings, sections of the vein appear to have carried little or no silica, and because the walls of the lode are sharply defined there is room for the suggestion that locally the original vein minerals were deposits in open spaces.

The Hayes workings were not accessible in 1910, but some of the material from this cross-breaking auriferous lode carries considerable amounts of white quartz, such as is ordinarily characteristic of veins that are known to have been formed in open fissures.

The Badger vein has been worked for oxidized silver-lead ore. As in the Robust vein there is some jasperoid along its outcrop but a large part of the material mined appears to have been essentially nonsiliceous, and the presence of well-defined walls again suggests that the deposit is in part of the filled-fissure type.

From a study of artificial exposures along its outcrop the Matilda lode is known to occur along the upper surface of an inclined sill of porphyry, which follows the bedding of the invaded limestone. The greater part of the lode is believed to have been formed as the result of metasomatic replacement of the limestone, but a layer of fluorite about 2 inches thick, which was found in one place between the oxidized ore and the porphyry sill, might be interpreted as a deposit formed in an open crevice.

THE MINES.

BOSTON-ELY GROUP.

LOCATION AND HISTORY.

The property of the Boston-Ely Mining Co. is situated in the western part of the district a short distance beyond the divide between Robinson Canyon and White River and about 9 miles from Ely. Fourteen claims or fractions, aggregating perhaps 280 acres, are owned and two others are controlled by this company. Title to the Matilda and Matilda Extension claims was held by the Ely-Western Copper Co. in 1910.

Prior to the interest in copper awakened by the development of low-grade deposits in the district small amounts of silver-gold ore had been mined from shallow workings on the Emma and Matilda claims, but no extensive explorations had been made when the present company was formed, about 1905. During 1906 some prospecting was done by means of churn drills and a shaft was started with a view to deep exploration.

LOCAL GEOLOGY.

Massive limestones belonging to the Ely formation constitute the main country rock of the Boston-Ely ground. (See Pl. VI.) East of a line running north and south through the Emma shaft the limestone beds dip slightly in different directions, but throughout the western part of the group strikes are toward the northwest and dips everywhere are to the southwest at angles of 35° to 60°. Over the greater part of the area the limestones are unaltered, but in the south-central part they are bleached and generally crystalline, and locally garnet is present in them. These metamorphosed phases of the limestone form a border from 600 to 900 feet wide on the west and north sides of the extensive area of jasperoid that occurs on the adjacent Veteran ground toward the southeast. On the surface the line between jasperoid and marble, which runs east and west, is located south of the common side line of the Emma and Elk claims, but in the Emma workings this parting dips toward the northwest and on the 1,200-foot level it lies about 300 feet north of the shaft.

The main jasperoid area presents smooth boundaries along the north and west sides, but toward the northwest there are several wedges that extend out along the bedding of the limestone, so that here the border is very ragged.

Two narrow bodies of porphyry, one on the Emma and the other on the Matilda claim, are injections that follow the stratification of the limestone.

UNDERGROUND DEVELOPMENTS.

Except for 300 to 400 feet of adit workings on the Matilda lode the only development of the Boston-Ely ground has been by workings from the Emma shaft, which is situated on high ground (elevation of shaft collar, 7,336 feet) near the northeast corner of the property. From this shaft, which is 1,260 feet deep, there are five levels: The 600-foot level, which has drifts toward the north and west that aggregate about 80 feet; the 700-foot level, which comprises about 500 feet of workings toward the south; the 800-foot level, which has 250 feet of workings to the south; the 1,125-foot level, which has tunnels 200 feet to the north and 1,350 feet to the southwest;[1] and the 1,245-foot level, which has several hundred feet of workings.

[1] Min. and Eng. World, vol. 40, p. 298, 1914.

VEINS AND JASPEROID BODIES.

Minor bodies of rusty jasperoid or of siliceous limonite occur in several places well outside of the central wedge-shaped area, where the limestones are generally bleached and marbleized, but the principal outcrops of vein materials are in or near this area on the Emma, Emma No. 2, and Matilda claims.

Veinlike bodies of jasperoid occur along fractures that break across the stratification and also along partings parallel with the original bedding. In both occurrences the lode stuff appears to have been formed mainly by replacement of the limestone country, but locally some of the veins probably include material that was deposited in open spaces. The cross veins are not numerous, and those that have been prospected show very slight persistence along the strike. On the Sevastapol claim shafts 35 and 70 feet deep have been sunk on two parallel narrow veins that strike N. 60° E. and dip steeply toward the northwest. Both shafts penetrated jaspery lode material carrying galena. The only really strong cross veins are in the vicinity of the Emma shaft, where there are several ledges of rusty jasperoid, and one of them, which is traceable for about 600 feet, has a width of 4 to 8 feet.

The silver and silver-gold ores that have been mined have come from shallow workings on the Emma and Matilda veins, which are bed deposits that strike northwest and dip southwest. The outcrops of these deposits lie along the same general line, but they hardly occur at precisely the same horizon in the Ely limestone.

The Emma lode appears to be an offshoot from the great mass of jasperoid on Veteran Hill. At the surface it runs out from this mass as a wedge-shaped ferruginous jasperoid body about 30 feet wide at the base, narrows to 10 feet about 100 feet away from the junction, and is continuous with about this width for an additional 200 feet. Beyond this first apparent termination the lode is traceable for 300 feet by means of recurring jasperoid outcrops and old workings from which oxidized ores were mined many years ago. The ore shoots, which are from 1 to 6 feet thick, appear to have been separated along the strike of the lode by masses of jasperoid. Ore found during assessment work in 1895 is reported [1] to have assayed silver 43 ounces and gold 0.25 ounce to the ton, and lead 60 per cent.

The distance between the Emma and Matilda workings is about 1,000 feet, and though there are two narrow outcrops of jasper and fluorite in the intervening ground the most prominent of these can be followed for only 50 feet and neither can be definitely correlated with either of the principal lodes. The Matilda workings have exposed a thin sill of intrusive porphyry that lies parallel with the stratification of the limestone and serves as the footwall of the lode. This lode differs from the Emma lode in that heavy bodies of jasperoid are not present. Though the original sulphides were evidently deposited in the main through replacement of the limestone, the lode was possibly in part formed in an open fissure. A suggestion of this is seen in the local occurrence of 2 inches of fluorite next to the footwall porphyry.

The lode has been opened in several places along the outcrop for a distance of nearly 300 feet, and the ore was from 1 to 3 feet thick. The porphyry sill, which is about 6 feet thick, is present throughout the 300-foot section where the lode is prominent, and though the intrusion is probably not continuous at the surface there are outcrops of the same rock 150 feet toward the northwest and 200 feet toward the southeast. The ore is a spongy ferruginous gossan that carries copper, lead, silver, and gold. A small lot shipped in 1910 is said to have returned about $80 to the ton, principally in gold.

The Emma shaft penetrates 850 feet of white marble and below this 200 feet of limonitic jasperoid before it reaches unoxidized pyritic jasperoid. Between the depth of 1,050 feet and the 1,125-foot level some of the jasperoid is decomposed, but at the lower of these levels the shaft is in pyritic material that is entirely unoxidized.

There is little room for doubt that the jasperoid body here disclosed represents an underground continuation of the Veteran Hill mass. On the 700-foot level, about 230 feet southeast of the shaft, marble gives place along a sharp surface to rusty jasperoid that has been exposed

[1] Min. and Sci. Press, vol. 71, p. 286, 1895.

to a width of about 80 feet. A similar parting was found on the 800-foot level about 100 feet southeast of the shaft, in the shaft at 850 feet, and on the 1,125-foot level nearly 200 feet north. (See Pl. VII.) On the 700-foot level an oxidized but originally pyritic jaspery vein that was encountered about 50 feet west of the shaft was followed for 200 feet to a point where it is seen to be an offshoot from the main jasperoid body. As exposed between walls of limestone this vein is from 2 to 10 feet wide, its strike is about N. 20° W., and its dip is steep toward the east. Locally along the walls there is a strong gouge of white clay. Gold and silver are reported in the vein material to the value of about $1 to the ton.

On the 1,125-foot level unoxidized and partly weathered pyritic jasperoid or silicified limestone occurs along the north tunnel for a distance of about 80 feet and then limonitic jasperoid for 100 feet. At a point 180 feet north of the shaft a body of copper ore was discovered. Between the rusty jasperoid and a hanging wall of massive white marble there lay a mass of loose pulverulent material that contained green copper carbonate and black oxide distributed irregularly through it. This ore resembles some of the Alpha ore. When dry it is spongy and crumbling, but when wet it becomes very plastic, a property due to the presence of kaolin. Though this ore body had a thickness of over 20 feet where it was cut by the tunnel, toward the northeast and southwest, parallel with the strike of the hanging wall of marble, it gives place to ordinary rusty jasperoid within short distances, and its bottom was reached only a short distance below the level.

In June, 1910, an inclined winze had been sunk from the 1,125-foot level, and at a depth of about 1,225 feet about 90 feet of horizontal workings had been opened in unoxidized pyritic and siliceous limestone. On this sublevel the pyrite-bearing rock was again found to be sharply walled by white marble at a point 380 feet north of the shaft.

Early in 1911 the shaft was sunk to 1,260 feet, near which depth water was found.[1] A level was opened at 1,245 feet, and as a result of extensive explorations, carried on during 1911 and 1912, several copper-bearing deposits are said to have been discovered.[2] In July, 1912, it was reported [3] that these workings had cut the Emma vein. When pumping was discontinued at the Giroux shaft in March, 1913, the Boston-Ely pumps, which were raising 20,000 gallons a day, were unable to handle the inflow of water, and as a consequence the 1,245-foot level was flooded.[4]

Since 1913 explorations on the 1,125-foot level have been made toward the southwest, and in January, 1914, a point 1,350 feet from the shaft had been reached. At 1,258 feet a seam of chalcopyrite that carried 9 per cent copper was cut.[5]

VETERAN GROUP.

LOCATION.

The Veteran property, which comprises 14 claims and fractions, is situated in the western part of the district between the Boston-Ely group on the north and the Giroux group on the south and east. The Veteran shaft on the Blair claim southeast of Veteran village is the western terminus of the mines branch of the Nevada Northern Railway. (See Pl. V, *B*.)

HISTORY.

The Veteran group of claims was brought under the ownership of the Veteran-Ely Copper Co. in 1905, and in that year the property was under development by means of the Paul tunnel, the mouth of which is situated a short distance southwest of the center of the Blair claim.

By means of these tunnel workings a large area of mineralized ground was explored without discovering anything of immediate promise, and in 1906 the property was acquired by the Cumberland-Ely Copper Co. By means of a shaft the highly ferruginous capping was penetrated, and beneath it a body of disseminated copper ore was discovered in October, 1906. During 1907 the ore body was blocked out, a working shaft was completed, and in May, 1908,

[1] Ely Daily Expositor, Jan. 23, 1911.

[2] Min. and Sci. Press, vol. 103, p. 151, 1911. Min. and Eng. World, vol. 35, p. 551, 1911.

[3] Min. and Sci. Press, vol. 105, p. 97, 1912.

[4] Weed, W. H., The Copper Handbook, vol. 11, p. 140, 1914.

[5] Min. and Eng. World, p. 298, Feb. 7, 1914.

ore shipments were begun. In 1909 production was in full swing, but on July 1 a miners' strike began and the mine remained idle for more than two years. In the meantime the interests of the Cumberland-Ely Co. had been purchased by the Nevada Consolidated Co., under the auspices of which mining operations were resumed in November, 1911. Before July 1, 1909, about 380,000 tons of concentrating ore, which had a mean copper content of 62 pounds to the ton, and 21,022 tons of direct smelting ore had been mined. The published reports of the Nevada Consolidated Copper Co. show an output of 5,584 tons of ore that carried 3.05 per cent copper in 1911, and 253,365 tons that carried 2.605 per cent in 1912. At the close of 1913 the total output of the mine had amounted to about 900,000 tons of ore, from which about 33,000,000 pounds of copper were recovered.

LOCAL GEOLOGY.

The Veteran group of claims covers the northwest end of the central zone of intense metamorphism, and includes areas adjacent to this zone where the limestones are either unaltered or are metamorphosed only to the extent of being bleached and rendered crystalline. The sedimentary formations involved are the Chainman shale and the Ely limestone. (See Pl. VI.) On the Blue Jacket and neighboring claims to the west and in the southern part of the Hidden Treasure the general strike of the stratification is nearly parallel with the Blue Jacket side lines (about N. 20° W.), and dips are either vertical or steep toward the west, but farther toward the north the strikes lie in the northeast quadrant and the dips though still westerly are less steep. The shales are not baked or otherwise pervadingly altered, but locally they are charged with pyrite.

In the southern part of the Veteran claim and north of the railroad on the Surprise claim there are rusty showings of decomposed garnet-pyrite rock, which doubtless represents intense alteration of the same limestone beds that near by have been changed to jasperoid. Between the central jasperoid area and the band of shale on the east Ely limestone beds have been rather generally marbleized, and in places bunches of tremolite or of garnet are noted. Where garnet occurs small amounts of pyrite and chalcopyrite are generally present.

North of the jasperoid area, within a zone about 500 feet wide, the limestones contain here and there bunches of yellow or green garnet and are generally marbleized, and within an irregular area nearly 1,000 feet in width they are notably bleached.

Inasmuch as the pyritic jasperoid to the south is everywhere deeply weathered it is noteworthy that in several localities on the Manhattan claim garnet-bearing limestone carries pyrite and chalcopyrite practically at the surface.

Where the north side line of the Empire claim crosses the prior Greek Chief location there are some irregular veinlike bunches of jasperoid, the only outcrops of this material in the portion of the marble zone that lies east of the Emma claim.

On the western part of the Elk claim, and on the Emma claim, which lies to the north, the limestones are generally bleached, and within 400 to 500 feet of the main jasperoid area the outcrops are more or less crystalline. Though the stratification of the limestone is nowhere directly determinable, the presence of a narrow intrusion of porphyry and of many essentially tabular bodies of jasperoid, all of which trend toward the northwest, indicates that the original bedding strikes in this direction, and observations both to the north and to the west indicate that dips are toward the southwest. Within the portion of the Elk claim that lies west of the main jasperoid area there are a larger number of shallow exploration pits and shafts than in any other equivalent area within the district. Copper minerals occur adjacent to several of the jasperoid bodies, ferruginous gossans have been disclosed in a few places, and lode stuff which carries copper minerals, fluorite, and white quartz was noted in materials from workings situated in the northwestern part of the claim.

On the Calker claim the band of crystalline limestone narrows to about 400 feet. Its outer boundary, which is here rather sharply defined, trends somewhat east of south as far as the Easter claim of the Giroux group, where it turns toward the east and becomes much less definite.

Between the main jasperoid area and the boundary of the bleached zone there are several jasperoid outliers, on the Calker, Dakota, and Easter claims, and there are others beyond the place where this indefinite boundary has been drawn on the Mother Lode and Calker No. 2 claims.

The most striking geologic feature of the Veteran group is the great body of jasperoid that outcrops in the central section of the group. This mass of silicified and pyritized limestone, which is for the most part sharply bounded against white crystalline limestone and occupies a compact area of perhaps 70 acres, forms a jacket about a comparatively small intrusion of porphyry that outcrops on the Blair, Veteran, and Veteran No. 2 claims. At the surface, and perhaps everywhere to depths exceeding 200 feet and locally to a depth of 1,200 feet, the original pyrite of the jasperoid has been fully oxidized. The weathered rock consists either of a highly ferruginous mixture of quartz and limonite, or locally of a cellular quartz aggregate, the cavities of which formerly contained pyrite. At the surface copper minerals are rare, though small amounts of chrysocolla and malachite were noted in two or three places in shallow excavations. In a few places in mine workings unoxidized pyritic jasperoid has been found, and as a rule this material carries from 1 to 2 per cent of chalcopyrite.

The Veteran mass of porphyry is so poorly exposed that no satisfactory delimitation of its areal distribution is possible. As represented on the maps (Pls. II, in pocket, and VI) the area of outcrop is probably somewhat exaggerated, and from what may be seen in the accessible workings on the tunnel level it seems that the porphyry northeast of the ore body occurs not as a compact mass but as a series of irregular though rudely tabular intrusions that stand nearly vertical and strike about N. 30° W. In the Veteran mine porphyry occurs several hundred feet beyond the southwest boundary of the general area of porphyry outcrops on the surface. Though structural relations are very obscure it is probable that this underground mass is a flat-lying sheet connected with the upright intrusions.

As is true of other masses of porphyry along the principal zone of intrusion the porphyry of the Veteran mine has been thoroughly metamorphosed, so that the extensive and profound alteration of the sedimentary rocks in the vicinity must be regarded as produced not by this small intrusion but by heated solutions that came from the deep-seated source from which the igneous rock had been derived.

Though little is known concerning the structural features that have controlled the penetration of surface waters, the accompanying sketch (Pl. VII), which represents a southeast to northwest section through the Veteran ore body and the Emma shaft, is of interest in this connection. The top and bottom of the Veteran ore blanket both decline gently toward the northwest, and though the ore body terminates where the capping of limonitic jasperoid is 440 feet thick, similar oxidized material occurs in the Emma shaft between the depths of 865 and about 1,100 feet.

UNDERGROUND DEVELOPMENTS.

Systematic exploration of the Veteran ground began about 1905, the first work being an adit level on which eventually about 2,600 feet of tunneling was done, the materials exposed being almost everywhere fully oxidized. After the property had been acquired by the Cumberland-Ely Copper Co., ore was discovered below the adit level, a development shaft was opened to the surface, and, for the purpose of outlining the ore body and in provision for mining, nearly 2 miles of drifting and crosscutting had been done before the end of 1908. A four-compartment shaft, about 420 feet deep, was opened northeast of the ore body, and a third shaft was opened to provide for ventilation and to serve as an additional exit in case of accident.

The main or tram level is at a depth of 380 feet below the mouth of the working shaft. Here four drifts were run parallel with the longer southeast to northwest axis of the ore body, and crosscuts were made at irregular intervals. The total preliminary work within the productive area amounted to more than 8,000 feet. Although in the northwestern and southeastern sections of the mine there is some ore beneath it, the main level was planned to follow as closely as possible the bottom of the ore blanket. Supplementary development was carried on principally by means of sublevels, from 20 to 80 feet above the tram level, access being provided by numerous raises. The workings mentioned are confined to an area about 1,100 feet long and from 200 to 500 feet wide, but since 1910, when the mine was examined, the workings in ore have been considerably extended, mainly toward the northwest, and at a level below the tram level.

Outside of the proved ore ground, in 1910 the only explorations consisted of a tunnel 250 feet long to a raise connecting the tram level with the adit level, which was situated about 100 feet northeast of the southeast end of the ore body; two tunnels 300 feet long in extension of two crosscuts beyond the edge of the ore body toward the southwest, and a drift that extended 600 feet beyond the northwest end of the ore body in the same general direction as its axis.

Before the closing of the mine, on July 1, 1909, ore extraction was in progress in four sections of the mine, the principal work having been done in the southeastern section, which is farthest removed from the hoisting shaft. In mining the modification of caving that is known as top slicing has been employed.

FORM AND OCCURRENCE OF THE ORE BODY.

The Veteran ore body as developed was a nearly horizontal though undulating blanket, which had an area of perhaps 10 acres, and a mean thickness of approximately 50 feet. As seen in 1910 its length from southeast to northwest was about 1,100 feet, its width from 200 to 500 feet, and its thickness from 20 to 110 feet. (See Pl. VII.) Like the porphyry ore bodies of the district this blanket occurred beneath a capping of fully oxidized material and above pyritic material that carries much less copper than the ore. From these relations and from the nature of the ore it was obviously developed as the result of chalcocite enrichment.

A generalized longitudinal section through the ore body and cross sections taken from the records of the Cumberland-Ely Copper Co. are given in Plate VII. These sections exhibit the undulations of the ore blanket, and the longitudinal section shows that it declines gently from southeast to northwest. Most of the ore appears to have been formed in porphyry, but a little of it was composed of enriched pyritic jasperoid.

Though structural relations could not be satisfactorily determined, a study of the mine gives the impression that the general form of the porphyry mass is that of a sheetlike intrusion, that the general attitude of the sheet is nearly horizontal, and that it connects with the porphyry stocks that outcrop northeast of the ore ground.

Observations made by a member of the engineering corps of the Cumberland-Ely Co. in 1908 indicate the presence of metamorphosed limestone everywhere beneath the ore body, but opportunity to check these observations was found only in the southeastern part of the mine. Here jasperoid was present in several places beneath the body of porphyry ore, and the parting between the two rocks was seen to rise toward the northeast. That the porphyry mass in the central part of the ore ground has the form of a sill is indicated by the fact that in several places where stoping had been done in 1910 the overburden was weathered jasperoid.

On the main level the ore body was bounded on the southwest by pyritized porphyry, except in the southeastern part of the mine, where heavily pyritized jasperoid and garnet rock was found. Two 300-foot crosscuts extend southwestward from the edge of the ore, but these tunnels were closed in 1910, so that the limits of the porphyry mass in this direction were not observed. Though no definite statement can be made regarding its shape this body seems clearly to have been a part of the sheet in which the porphyry ore occurs.

The parting between the ore and the unenriched but pyritized rock that lies to the southwest was very sharp, and here a strong fault strikes parallel with the principal axis of the ore body and dips about 30° NE. A heavy gouge of chloritic material which follows this break has prevented the passage of downward-moving waters, except very locally, so that though the material above has been greatly enriched, the rock below the fault does not carry chalcocite. The ore bottom rises toward the southwest, conformably with this well-defined fault surface, and the ore wedges out between the fault and the bottom surface of the oxidized capping.

In the northwestern part of the mine the ore body was bounded on the northeast by pyritized porphyry. The limits of ore against unenriched sulphide-bearing rock in several places occurred along highly inclined slips or gougy seams, the general trend of the ore edge being again essentially parallel with the axis of the ore body.

On the main level, southeast of a point near the middle of the northeastern boundary of the ore body, the limiting rock is pyritic jasperoid, and as already stated the same material occurs under porphyry ore near the southwest end of the ore body. The same rock is exposed in a tunnel that connects the tram level with a raise that is situated about 100 feet north of the edge of the ore, but above the main level this raise passes out of the jasperoid into a body of porphyry which is well exposed on the adit level and between this level and the surface.

Above the southeast end of the ore blanket the depth of the oxidized capping is about 200 feet, but because of a considerable topographic rise and a slight decline of the ore top toward the northwest the depth of the overburden at this end is fully 450 feet. Beyond the ore body a drift that extends 600 feet to the northwest encountered nothing but limonitic jasperoid.

Great differences are noted in the physical character of the weathered jasperoid and in the amount of limonite which it carries. Much of it is very dense and massive, but in places the rock has been thoroughly disintegrated, forming loose angular gravel or sand. As a rule the massive phases are highly ferruginous, though in certain heavy ledges the rock is so low in iron that it has been used as converter flux. The sandy material is generally not very ferruginous and some of it is almost free from iron stains. Even where the weathered jasperoid now carries little or no iron there are cavities in the material that evidently contained pyrite originally.

Material which has a very different appearance from weathered jasperoid occurs at the surface above the east corner of the ore body, where it has been exposed by caving above the mine workings. It is ferruginous material, not at all sandy and hardly claylike, though soft and of homogeneous earthy texture. This material is believed to have originated through the decay of altered limestone that was less siliceous than the jasperoid and which probably carried pyrite and such minerals as tremolite, diopside, and garnet. The chemical analysis of a sample of the earthy capping given on page 75 shows the presence of 0.19 per cent of copper.

RELATIONS OF THE ORE BODY AND PRESENT WATER TABLE.

In the southeasterly workings of the Veteran mine there was considerable seepage, and water accumulation in some of the drifts, but no water was encountered in the northwesterly two-thirds of the mine, even in winzes 20 feet or more below the working level, so that there appears to be a natural drainage from southeast to northwest and in a general way parallel with the axis of the ore body. Corresponding with the direction toward which the water surface declines, the oxidized capping descends steeply at the northwest end of the ore body, and about 1,100 feet farther toward the northwest completely oxidized capping occurs on the 1,100-foot level from the Boston-Ely shaft at an elevation about 700 feet lower than the Veteran tram-working level. With reference to topography the direction in which the bottom of the fully weathered mineral declines is the direction in which the surface rises.

GIROUX GROUP.

LOCATION.

The property segregated by the Giroux Consolidated Mines Co., here called the Giroux group, consists of 109 claims and fractions aggregating nearly 2,000 acres. The group includes an area about 1,600 feet long and from 4,000 to 9,000 feet wide, situated between the Veteran group on the northwest and the Copper Flat and Ely-Central groups on the east. It lies partly within the broad basin that comprises Weary Flat and covers also the ridge between the Robinson and White River basins, together with the upper south and west facing slopes beyond this divide.

Within the area on the north are the Taylor and Dewey shafts; in the west third the Pilot Knob, Old Glory, and Alpha shafts, and the Bunker-Morris mines; and in the eastern part the Oro open mine and the Tonopah and Westphalia ore bodies.

HISTORY.

The systematic development of the Giroux property was begun in 1900. In May of that year J. A. Snedaker and E. L. Giroux examined several groups of claims situated in the western part of the district and arranged for prospecting work to be done on the Pilot Knob and adjacent claims. In May, 1901, Mr. Joseph L. Giroux visited the district in company with Mr. Snedaker, and during the following summer a group of 33 contiguous claims came under the control of these engineers and their associates. In 1901 or 1902 the Pilot Knob Copper Co. was formed, and before the close of 1902 eight shafts from 85 to 330 feet deep had been sunk, nearly 3,000 feet of lateral work had been done, and copper deposits had been discovered in the Taylor, Pilot Knob, Old Glory, and Brooks workings.

The Giroux Consolidated Mines Co. was organized in 1903, and the Pilot Knob group passed into its possession, together with the Morris group of claims. At this time the total area of the group was about 870 acres, but during the next six years several parcels of land were bought and in 1908 the area amounted to 1,050 acres.

In the later part of 1908 the majority of the shares of the Giroux Co. were acquired by the Cole-Ryan interests. The new management made extensive purchases of contiguous lands situated west of the original group in 1909–10, and in 1910, through the purchase of a majority of the Butte & Ely Copper Co. shares, secured control of 210 acres lying between the Giroux and Copper Flat groups.

In 1913 the Consolidated Copper Mines Co. was organized and in May of that year this company acquired a substantial majority of the outstanding shares of the Giroux Consolidated Mines Co. and took over its affairs.

Previous to 1905 explorations under the presidency of Mr. Giroux had revealed disseminated chalcocite ores in the Bunker, Brooks, and Morris mines, and ores of higher grade in the Taylor and Old Glory mines, and on the basis of these developments the decision was made to install concentrating and smelting works. A 250-ton blast furnace, completed in May, 1907, was destroyed by fire in December, 1908, before it had been put into use. The concentrator, which had a rated capacity of 500 tons a day, was put into experimental operation in October, 1907. (See Pl. V, *A*, p. 96.) The ore treated came principally from the Morris porphyry mine.

Early in 1906 the discovery of oxidized copper ores was announced on the 770-foot level of the Alpha mine, and during the following 18 months explorations were extended to the 1,000-foot level. In August, 1907, 210 cars of ore that carried between 12 and 14 per cent copper were mined from the 1,000-foot level and shipped to the Garfield smelter at Salt Lake City. On December 4, 1907, the Alpha shaft gave way above the 600-foot level and several miners were imprisoned on the 1,000-foot level during a period of 46 days. In May, 1908, the shaft repairs were completed and sinking was continued to a depth of 1,200 feet, where oxidized ores like those on the 1,000-foot level were found in November or December, 1908.

The Giroux shaft, which was planned as a working shaft, was begun in 1909 and opened to a depth of 1,440 feet in 1911. Connections with the Alpha workings had been made on three levels, the Alpha 100-foot and 1,200-foot workings had been retimbered, and some new work had been done in the ore ground on these levels. On the 1,400-foot level a tunnel had also been opened for a distance of 420 feet in the direction of the Alpha shaft, when on August 23, 1911, the main shaft took fire at the 1,000-foot level. As a result of this disaster several lives were lost, and the workings were flooded. Though the mine was unwatered in February, 1912, little or no work was done in the way of further development, and on October 2, on account of a strike of the mine workers, the pumps were stopped and water again took possession of the workings below the 1,000-foot level.

During the year 1913 the mine appears to have been again active, as the shipment of 230 tons of ore that contained an average of 8.77 per cent copper is reported.[1]

The Butte & Ely Copper Co. was organized in 1905. Three shafts were sunk, and on the Beehive and Westphalia claims some porphyry ore had been developed when the active opera-

[1] Weed, W. H., The Copper Handbook, vol. 11 p. 390 1914.

tions of the parent company were suspended in 1907. Subsequent to 1909 explorations by the Giroux management were made by churn drilling, and porphyry ore that was developed on the Westphalia claim has been stripped by the Nevada Consolidated Co. in connection with its own operations on the adjoining Liberty claim.

The bodies of porphyry ore in the Bunker-Morris group of mines had been explored by more than a mile of workings previous to 1909, and at that time the estimate of the known minable porphyry ore was 4,000,000 tons of 2.25 per cent grade. Between 1909 and the end of 1911 explorations in the porphyry areas were carried on mainly by means of churn drills.

In the annual report of the company for the year 1911 the aggregate porphyry ore tonnages then developed in four localities were estimated at nearly 10,000,000 tons of 2 per cent and more than 6,000,000 tons of 1.65 per cent ore. Later estimates are referred to on page 114.

In 1911 a contract was made with the Steptoe Valley Mining & Smelting Co. for the treatment of concentrating ores in quantities as large as 1,200 tons a day, and between May 1 and the close of the year 1912 shipments from the Bunker-Morris mine amounted to 140,877 tons of 2.15 per cent ore. This mine continued to furnish its quota of 1,000 tons per day until September 1, 1913, when all mining underground was suspended.

During 1913 a previously unknown ore body was discovered east of the Morris shaft, and stripping was reported in progress in November [1] of that year.

Perhaps the most striking incident in the history of the Giroux property was the discovery of the body of disseminated copper ore in the Oro claim. The Nevada Consolidated Co. had secured right of way through this claim, and in excavating for an approach to the Liberty pit the ore was encountered. The first shipment of about 1,100 tons of ore was made on August 19, 1913, and a steady production appears to have been maintained to the close of the year.

Between May 1, 1912, and December 31, 1913, the production of copper from Giroux ores amounted to somewhat more than 9,000,000 pounds.

LOCAL GEOLOGY.

The Giroux group of claims covers approximately one-fifth of the central zone of intensely metamorphosed rocks that traverses the Ely district; north and northeast of this zone an area of about 350 acres within which the rocks are moderately metamorphosed; and, to the west and southwest an extensive area that is occupied by entirely unaltered rocks. Six of the eight sedimentary formations of the district occur within the area; rhyolite is found in several places; beds of volcanic ash cover several claims situated in the extreme western part of the group; and there are five large and several small bodies of intrusive porphyry.

Aside from the rhyolite, which occurs on the De Soto, Clairy, United Verde, and Express claims, and about 120 acres of volcanic ash beds on the Military subgroup west of the area shown on the map (Pl. VI, p. 112), the western and southwestern parts of the Giroux group are underlain by limestones which belong to the Arcturus and Ely formations. The strata of these formations appear to be entirely unmetamorphosed, though there are beds in the Arcturus which break down into earthy material that shows hues of yellow, orange, and red. The iron to which these colors are due is regarded as an original constituent of the sedimentary rocks rather than as a substance introduced through metamorphic processes.

In this outlying district the course of the parting between the Arcturus and Ely formations and the trends of the limestone beds are toward the northwest, and dips are principally toward the southwest. There are, however, marked variations in strike and dip from place to place, and the formations are broken by several faults.

Within the central metamorphic zone the Ely limestone has been greatly silicified and pyritized, and the porphyry of several intrusive masses has been generally sericitized and charged with pyrite and chalcopyrite. At the surface the outcrops and loose débris are everywhere heavily stained with iron, and by means of these materials the distribution of the pyritic metamorphosed rocks can be determined.

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[1] Min. and Sci. Press, Nov. 8, 1913.

Toward the west, on the Veteran group and on the Easter and Alpha claims of the Giroux group, there is a border of marbleized limestone outside of the jasperoid area, but from the Alpha shaft as far east as the Sidney claim the limestones exposed near the jasperoid edge are nowhere strongly altered. That the boundary between the unaltered and silicified portions of the limestone is extremely abrupt is apparent not only from a study of the surface but also from exposures in the Alpha workings, where sharp-walled jasperoid masses dovetail into essentially unmetamorphosed limestone.

Across Holder No. 2, Colusa, April Fool, Champion, and Watson claims the metamorphic zone has a false boundary against rhyolite, but the true boundary appears south of the wedge-shaped area of the rock on the Westphalia, Herstelle, Fraction, and Liberty claims. Here there are several outlying ledges of jasperoid, and the Ely limestone, though not greatly altered, is locally somewhat bleached.

The width of the zone of intensely altered rocks ranges from 1,200 to more than 3,000 feet. Across the Alpha, West, Old Glory, and Jessie claims the occurrence of rusty débris and outcrops of massive iron-stained jasperoid shows that the area within which the rocks were thoroughly impregnated with pyrite is about 2,400 feet wide. On the Jessie claim, between the jasperoid and the shales that outcrop on the Blue Jacket and Texas claims, there is a band of coarsely crystalline limestone which in places carries bunches of garnet-pyrite rock. Though the surface is badly obscured by loose débris, it seems that there is a sharp parting between the jasperoid and the marble, just as there is on the east and north sides of the Veteran jasperoid area. The Jessie tunnel shows highly ferruginous and siliceous oxidized material all the way in from its mouth, but the north boundary of this iron-bearing material is near by, for marble is exposed along the Alpha Railway line 100 feet to the east. Along the Nevada Northern tracks near the smelter ruins weathered garnet rock is exposed, and out on the flat, where the mantle of outwash material is almost continuous, a single small outcrop of garnet-calcite rock was noted on the southeastern part of the Riepe claim.

Morris No. 2 shaft is sunk in marbleized limestone in which bunches of tremolite occur, but on the main mine level, at a depth of 165 feet, the rock between this marble and the body of porphyry ore to the west is to a considerable extent silicified and charged with pyrite.

South of the Bunker-Morris intrusion of porphyry it is clear that the original limestones have been thoroughly metamorphosed and pyritized within the area indicated on the map. Details can not be made out from surface exposures, but it is probable that materials showing different types and degrees of alteration are intermixed very much as in the Alpha block of ground.

On the Humbug, Kaboony, and Beehive claims, where the metamorphic zone is hardly more than 1,200 feet wide, there are many outcrops of rusty jasperoid, and this material appears to occur in bodies that are much more massive than anything that is indicated by outcrops between the White Chief claim and the western half of the West claim.

East of Butte-Ely Gulch exposures are so few that there is much doubt in regard to the boundaries between the jasperoid and porphyry on the Dexter, April Fool, Fraction, Watson, Emma Nevada, Josie, and Oro claims. Pyritic shales have been exposed in several prospects north of the railroad and south of the tract in the northern parts of the Washington and Emma Nevada claims, but garnet-magnetite rock occurs on the Josie claim just north of the shaft, and massive pyritic jasperoid was penetrated in drill holes 64 and 74 on Watson No. 2 claim; so that if, as is probable, jasperoid has been derived only from limestone, the line between the shale and the metamorphosed Ely limestone may lie north of hole 74 and trend nearly east across the Josie claim. Baked shale, formerly pyritic though now weathered, was noted in a shaft near the northeast corner of the Oro claim.

On the Watson and April Fool claims there are exposures of essentially unmetamorphosed limestone.

Below the depths to which the effects of weathering have extended the porphyry masses which occur within the zone of intense metamorphism are almost uniformly charged with disseminated pyrite and chalcopyrite. This is known from drill-hole explorations, from material encountered in mine workings, and from the nature of weathered and oxidized materials, which appear at the surface. The general outlines of the larger bodies have been fairly well determined, except on the Josie, Oro, and Wedge claims, but there are outcrops which represent minor bodies that can not be traced by any study of the surface.

The structural relations of the Old Glory intrusion are not known, but both in the Alpha and Old Glory mines there is in general a nearly vertical layering of the metamorphosed limestones, and it may be fairly presumed that the walls of this porphyry body are approximately upright. The Bunker-Morris intrusive mass is elongated parallel with the local trend of the intrusive zone, and its east wall is a footwall which dips at an angle of about 60° toward the south-southwest. Presumably the west wall dips in the same direction, and as the beds of Ely limestone beyond the area of metamorphism strike northwest and dip southwest the character of this intrusion is probably that of an intercalated sill. In the Bunker-Morris mine this porphyry mass is broken by several intrusive bodies of rhyolite, and just east of the Bunker Hill shaft the porphyry body is entirely cut off by one of these rhyolite masses. The small body of porphyry on the Humbug claim is not well exposed, but from weathered material exposed in a single pit it seems that the rock of this locality is not metamorphosed like that of the Bunker mine near by.

The porphyry that outcrops on the Tonopah, April Fool, and Beehive claims is an offshoot or appendage of the intrusion on Weary Flat, but whether this portion of the intrusion is cross-breaking or has a sill-like or laccolithic form is not known.

The mapping of porphyry on the Josie, Oro, and Wedge claims could not be done in detail for lack of adequate exposures in 1910, and at that time the presence of the porphyry ore discovered on the Oro claim in 1913 was not suspected. The porphyry that occurs on the Emma Nevada, Josie, and Oro claims belongs to the Copper Flat-Liberty intrusion, but it is now partly separated from this large body by a mass of rhyolite.

Along the northerly side of the zone of intense metamorphism there is almost everywhere a sharp gradation from rocks that are thoroughly pyritized in the mass to those which, though they are notably altered, have not been chemically transformed to anything like the same degree.

The Nevada limestone occurs on the Good Enough, Sacramento, and Gold Bug claims. Where unaltered the beds of this formation consist of dense, nearly black limestone, but here the rock is white and rather coarsely crystalline, and these characters persist for nearly half a mile toward the north from the boundary of the porphyry mass of Weary Flat. Though thus notably altered, in general the metamorphism is not of the kind that has involved addition of substance, and only in a few places along the immediate porphyry contacts have small bodies of jasperoid and garnet rock containing pyrite and chalcopyrite been developed.

The Pilot shale, though very poorly exposed on the Taylor, Dewey, Pilot Knob, and Schley claims, appears in general to have been only slightly metamorphosed, though near its contact with the porphyry on the Taylor and Dewey claims it has been somewhat baked and pyritized. Here the stratification strikes somewhat west of north and dips southwest. On the Schley claim the boundary of the shale against the Nevada limestone was not actually observed. The fault that has been indicated on the map is a hypothetical feature introduced to explain the abnormal presence of shale north of the concentrator house on the Pilot Knob claim.

Immediately west of the Pilot shale area on the Union, Dewey, Texas, and Pilot Knob claims occurs the Joana limestone. Here the beds stand in a nearly vertical position, so that the width on the outcrop of nearly 400 feet represents the thickness of the formation. Both on the north and on the south this ledge of massive limestone terminates endwise against shale, relations that can only be explained as the result of faulting. The more northerly of the two faults may be traced toward the northeast from the place where it crosses the end of the limestone ridge, but the actual position of the other fault can not be determined either east or west of the ridge, and it has been represented on the map in an entirely arbitrary way.

In this area the limestone has been moderately bleached and marbleized throughout, and in addition to this general alteration a large replacement body of mixed magnetite and sulphides occurs at the southern end of the area.

On the Union claim and in the northern part of the Texas the beds of Chainman shale are supposed to strike parallel with the parting between this formation and the Joana limestone, and like the limestone strata to stand nearly vertical. Where the shales have been exposed in a railway cutting about 20 feet deep on the Blue Jacket claim the strike is northwest and the dip about 85° SW. Here the weathered rock was evidently well charged with pyrite, though it is not greatly indurated. About 400 feet to the northwest of the locality just mentioned drill hole 114 of the Giroux series revealed shale heavily impregnated with pyrite and also carrying chalcopyrite. Water was found at 80 feet. Between 65 feet and 210 feet the rock carried from 0.2 to 2.5 per cent copper, and between 115 feet and 150 feet from 1.2 to 2.5 per cent of copper. Hole 113, situated 200 feet south of hole 114, was carried down to a depth of 260 feet, 115 feet in "limestone" and 145 feet in "pyritic limestone," assays of which showed from 0.1 to 0.3 per cent copper. In this locality the shales are strongly tilted and the copper-bearing rock penetrated in hole 115 is probably a body conformable with the stratification.

The southwest boundary of the shale area across the Jessie and Reipe claims, though not actually exposed, is thought to be nearly correct as shown, but a point not explained is that no jog appears to represent the Pilot Knob fault. Across the Victor and Brooks claims the continuation of the line has been drawn at random, because no outcrops could be found to indicate its position.

On the Pocahontas, Lexington, Iowa, and Victor claims shale débris constitutes the soil, and in general the rock appears to be but slightly metamorphosed. Cuttings from drill hole 22, situated near the north side of the Victor, show soft drab-colored shale that carries very little pyrite, but materials from two shafts on the Lexington claim are heavy with this sulphide. These shafts are situated near the porphyry contact, and in them water stands within 30 feet of the surface.

On the Humbug claim essentially unmetamorphosed shale is exposed along the railroad both west and east of the place where the track cuts into the main porphyry area, but material from a tunnel in the eastern part of the claim is of such a character as to show that here the rock, previous to being weathered, was rather heavily impregnated with pyrite.

East of the Weary Flat porphyry intrusion the shale is pyritized wherever artificial exposures have been made, and here the impression is gained that the intensity of metamorphism increases from north to south.

The porphyry mass that outcrops on the Good Enough and adjacent claims has been injected along the parting between the Nevada and Pilot formations, and the general structural features observable in the neighborhood indicate that the intrusion probably stands nearly upright. Here the igneous rock has not been metamorphosed, though it forms the matrix for a few irregular quartz veins. The shales near the contact are notably baked and pyritized, and garnet-pyrite rock occurs in the limestone just west of the place where the contact crosses the east side line of the Good Enough claim.

The Weary Flat mass of porphyry is regarded as being a generally cross-breaking body. It lies partly within and partly outside of the zone of intense metamorphism. In Butte-Ely Gulch and along the east border of the area the rock is as thoroughly metamorphosed as that of any of the porphyry masses in the district, and where the igneous rock is sericitized and pyritized the inclosing sediments are likewise intensely metamorphosed. Elsewhere the porphyry is either quite unaltered or is altered only to the extent of having pyrite seams developed along joint surfaces, and the inclosing rocks have been for the most part only moderately metamorphosed. Thus along the north side of the porphyry mass siliceous replacement deposits occur only within a few feet of the actual contact, though the limestone has been extensively bleached and marbleized.

TAYLOR SHAFT.

The Taylor shaft is situated in the southern part of the Taylor claim, just beyond the northerly end of the porphyry area of the Goodenough and adjacent claims. The workings, which comprise a shaft said to be 300 feet deep and about 400 feet of laterals, were not accessible in 1909 or 1910. Material on the dump consisted mainly of pyritized shale containing epidote and other silicate minerals of metamorphic derivation, but with this material there was associated a considerable amount of veinstuff composed of white quartz that carried irregularly distributed pyrite and chalcopyrite. The manner in which this vein material occurs is not known, but south of the shaft there are two shallow prospects in which similar material occurs as irregular narrow veins following the bedding of the altered shale, and there is one opening in which the rock matrix is porphyry.

In the report of the Giroux Consolidated Mines Co. for the year ending December 31, 1912, the statement is made that during the year there was shipped from the Taylor dump 179.6 tons of ore that carried 0.10 ounce gold and 0.93 ounce silver to the ton, and 4.7 per cent copper.

OLD GLORY MINE.

The Old Glory shaft, formerly called the Giroux, is situated on the east slope of Old Glory Hill. (See Pl. V, *A*, p. 96.)

The exploration of this ground was begun in 1900 and continued until 1906 or 1907. In 1910 the developed ore was estimated by the management of the Giroux Consolidated Mines Co. at 120,000 tons, and the average copper content at 3.5 per cent.

The shaft is 450 feet deep, and the five levels of lateral workings amount to about 6,600 feet.

The copper ores that have been developed in the Old Glory workings are secondary ores that occur in partly oxidized bodies of silicified or jaspery pyritic limestone. The ore bodies are compound masses that comprise rubble-like cores of nearly fresh pyritic rock set in an interweaving meshwork of decomposition products, and it is in the weathered material that the secondary copper minerals are principally segregated. The most abundant copper minerals are malachite and brochantite, but some chalcocite occurs, and this secondary sulphide has been deposited, to a minor extent at least, in the presence of calcite.

The mine is situated in the zone of intense metamorphism, east of the Old Glory intrusion of porphyry and just northwest of the surface termination of the Bunker-Morris intrusion. The limestones of the locality have been greatly silicified and are in part changed to jasperoid and in part charged with silicate minerals. Such materials may be seen in several places in the mine, and obviously the more or less weathered materials elsewhere exposed have been derived from similarly altered limestones. Where weathered, all of the metamorphic rock carries pyrite in grains and bunches, and from place to place there are reticulating seams of the same material. Magnetite, pyrrhotite, and chalcopyrite are constant associates of the disseminated pyrite and the average copper content of the primarily mineralized rock is probably not far one way or another from 0.5 per cent, or about the same as the primary copper in the bodies of pyrite porphyry that occur in the vicinity.

The east slope of Old Glory Hill is mantled by a brown ferruginous residuum that has been derived through the weathering of the pyritized metamorphic limestones. A general sample of this material taken from the adit level was subjected to chemical analysis with the result given on page 75.

Copper minerals were first discovered in the oxidized capping about 360 feet from the mouth of the 830-foot adit, where the development shaft was afterwards put down. In this shaft the fully oxidized capping gives place to material that carries some pyrite at a depth of about 250 feet, or about 125 feet below the adit level. Apparently there is some ore between the adit level and the depth of 250 feet, but the principal body occurs between the depths of 250 and 350 feet.

Throughout the Old Glory workings the pyritized and irregularly silicified rock presents a layered aspect, the strikes being generally northwest and the dips steeply southwest. Localization of circulation appears to have resulted from the development of fractures more or less conformable with the preexisting structures and comparable effects of weathering are to be observed at different depths in different sections of the ground. (See fig. 4.) On the 270-foot mine level all sorts of material from fresh to fully oxidized are present. On this level there was developed a body of enriched material about 100 feet wide, parts of which contained green copper minerals in an essentially uniform brown matrix and other parts which carried the same minerals associated with oxidized material occurring between irregular bowlders or cores of pyritic rock. In one place a crosscut shows nearly 100 feet of fully oxidized material that contains no visible copper minerals, but just under this barren material on the 300-foot level green minerals are abundant in company with gypsum, and there are remnants of pyrite.

The workings on the 300-foot level are more extensive than those above and below, and here, in a position corresponding to that of the similar material on the 270-foot level, partly oxidized and strongly enriched material was developed for a distance of 500 feet within a zone apparently about 60 feet wide. On this level, in a crosscut toward the east from a point 120 feet south of the shaft, a second ore zone about 20 feet wide was found. The two ore bodies appear to converge toward the south, but in this crosscut they are separated by 30 feet of siliceous pyrite-bearing rock, which, though it has been attacked by oxidizing waters, is much less weathered than the material in the ore channel.

On the 270-foot and 300-foot levels the main ore body has a very definite, nearly vertical wall on the east side, and on the 350-foot level the same feature separates materials that are weathered to different degrees. The rock in the ore channel on the 350-foot level shows a less advanced stage of decomposition than the corresponding material above, and it has not been more than slightly enriched. The bottom of the ore appears to lie about 30 feet above the level of standing water, which in 1910 was about 10 feet below the 350-foot level.

The main ore channel has been explored along its trend for a distance of about 350 feet on the 270-foot level and for nearly 500 feet on the 300-foot level. The smaller ore body on the 300-foot level was explored for about 150 feet along its strike.

On the 270-foot level, in a long crosscut toward the west, the material next beyond the ore body is heavily pyritized and silicified limestone that is but slightly weathered. About 350 feet from the edge of the ore there is a 10-foot dike of porphyry and beyond this oxidized jasperoid for 230 feet to the face of the tunnel. Forty feet below this level a body of 2.5 per cent copper ore 20 feet thick was reported in drill hole 122.

On the 300-foot mine level, where the main ore channel was explored for 380 feet northwest of the shaft, workings toward the west revealed entirely unweathered pyritic rock, but from the record of drill hole 122 it is evident that fully oxidized material would be found only a short distance beyond the end of the tunnel.

On the 350-foot level the slightly oxidized material beneath the ore body may be seen in two crosscuts about 140 feet apart to be bounded on the west by pyritic porphyry, and beyond this, in both tunnels, there is first silicified limestone and then more porphyry.

In 1910 the 450-foot level was flooded, and therefore not accessible.

ALPHA MINE.[1]

The Alpha mine is situated about 7 miles west of Ely on the west side of the divide between Robinson Canyon and White River. The mine is served by a standard-gage track which connects with the mines branch of the Nevada Northern Railway.

The output of the mine has been about 520 tons of ore that carried from 8 to 13 per cent of copper.

The mine has been developed by means of two shafts, the Alpha three-compartment shaft, situated on the Alpha claim, and the Giroux five-compartment shaft, situated on the Sam Long claim about 765 feet toward the southwest and outside of the mineralized area. The Alpha shaft was completed to a depth of 1,200 feet in 1908, and from it about 2,700 feet of

[1] In this description free use has been made of the annual reports of the Giroux Consolidated Mines Co. for the years 1910-1912.

lateral work had been done, mainly on the 770-foot and 1,000-foot levels, when in 1909 the construction of the Giroux shaft was undertaken. In carrying out this project the 770-foot and 1,000-foot levels of the old mine were extended to the position of the new shaft, where a two-compartment raise was carried up to the surface. After being equipped with a hoist this raise was enlarged and the shaft was sunk to a depth of 1,460 feet. In 1911 connection was made with the Alpha workings on the 1,200-foot level, and on the 1,400-foot level a tunnel was extended 420 feet toward the Alpha shaft.

At the close of 1911 the extent of the lateral workings in the mineralized ground was approximately as follows: 500-foot level, 420 feet; 615-foot level, 400 feet; 770-foot level, 1,100 feet; 1,000-foot level, 1,770 feet; 1,200-foot level, 1,070 feet.

The Alpha mine is situated on the outer edge of the central zone of intense metamorphism The most striking features of the locality are the sharp passage from intensely silicified and pyritized limestones to rocks that are essentially unaltered, the low water level, and the correspondingly great depth to which the pyritic materials have been fully weathered. Within

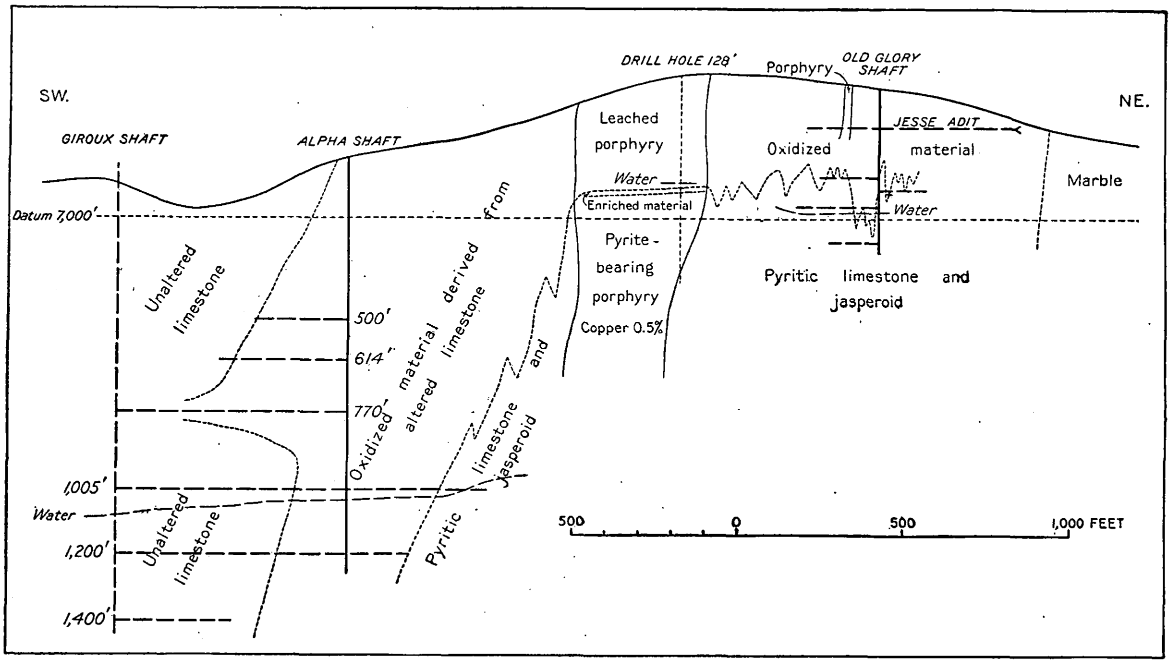


FIGURE 4.—Generalized section from northeast to southwest through Old Glory and Alpha shafts. Mine workings projected on plane of section.

the metamorphic zone the limestone alteration products consist largely of strongly silicified limestone, but the materials associated with this jasperoid, on being weathered, give rise to bodies of kaolin.

In the Alpha shaft complete oxidation extends to a depth of at least 1,200 feet, or down to an elevation below 6,000 feet, whereas to the east, north, and northwest, within a radius of 1,600 feet, equivalent weathering is known from drill holes and from mine workings to have reached only to depths corresponding with elevations between 6,900 and 7,100 feet. Drill hole 128, situated about 1,000 feet northeast of the Alpha shaft, revealed unweathered sulphides in porphyry at an elevation of about 7,000 feet. From these relations it appears that the Alpha shaft penetrates a rudely funnel-shaped mass of formerly pyritic material, which has been thoroughly oxidized under the action of surface waters. (See fig. 4.)

The mine is naturally drained to a point about 20 feet below the 1,000-foot level at the Alpha shaft, or down to an elevation of about 6,160 feet, but the occurrence of fully weathered material on the 1,200-foot level must be taken as evidence that formerly the position of ground water must have been much lower than at present.

The material penetrated by the Alpha shaft was in part loose angular gravel and in part compact siliceous limonite. The limonite appears to occur in rather definitely bounded bodies. On the 500-foot level such a body that was found about 200 feet south of the shaft appears to be about 100 feet wide. The same body was undoubtedly cut on the 615-foot level 240 feet from the shaft, the dip of the footwall being thus toward the south at an angle of perhaps 75°. Though barren on the 615-foot level, this material is reported to carry small amounts of copper on the 500-foot level.

A second limonite body, found below the 615-foot level, was explored by the 770-foot and 1,000-foot levels. Near the shaft on the upper of these levels the siliceous limonite or gossan is reported to contain less than 0.3 per cent copper, but the presence of copper carbonate was noted about 350 feet toward the southwest, where the drift approaches a footwall of unaltered limestone on the northwest side of the limonite mass. From this point toward the southwest the drift follows the parting between the limonite and the limestone for about 270 feet, and throughout this distance most of the material near the wall carries copper minerals, assay records showing from 0.5 to more than 9 per cent copper.

The footwall mentioned cuts into the northwest side of the drift, and about 80 feet southwest of this point the limonite body is bounded by a sharp wall that strikes about N. 70° W. and dips 45° NE. Between this limiting wall and the Giroux shaft the limestone beds strike to the northwest and dip about 65° NE.

A narrow vein of mixed limonite and copper minerals, which was found in the Giroux shaft about 120 feet above the 770-foot level, dips toward the northeast.

During the year 1911 nearly 700 feet of drifts were opened on the 770-foot level, but no ore bodies were discovered.

Between the 770-foot and the 1,000-foot levels the Alpha shaft is in the siliceous limonite, and toward the southwest the drift connecting with the Giroux shaft shows the same material for about 110 feet; beyond this point the rock is essentially unaltered limestone. Stratification is recognizable at several places and the strike is toward the northwest. Fifty feet southwest of the edge of the limonite body the limestone beds stand nearly upright, but 100 feet beyond, and again near the Giroux shaft, the dips are 35° to 45° toward the northeast.

North of the Alpha shaft the 1,000-foot level comprised in 1910 a crosscut 430 feet long, trending somewhat east of north, and laterals east and west from stations 70 feet and 260 feet, respectively, north of the shaft.

The first 40 feet of the crosscut passes through siliceous limonite, then comes 225 feet of alternating kaolin and cellular, more or less ferruginous jasperoid, and finally 165 feet of essentially unweathered silicified and pyritized limestone. On this level, then, the apparent width of the oxidized ground is about 370 feet.

Lateral workings toward the east encountered unweathered siliceous rock only a short distance from the crosscut, but toward the west oxidation has been complete as far as the workings extend.

Along the main gangway the alternating layers of kaolin and of weathered jasperoid range from a few inches to more than 25 feet in width. These layers strike northwest and dip steeply southwest. Part of the kaolin is white and part of it brown. In a few places it shows green copper stains, and the copper minerals of the ore shoots that were discovered on this level in 1907 are embedded in kaolin. One of these shoots occurs near the north side of the oxidized ground. It is about 10 feet wide in the drift and appears to conform with the southeast to northwest layering of the oxidized country. The only ore body that had been developed in 1910 was one that occurred about 30 feet from the north wall of the heavy limonite mass, or 70 feet from the shaft. This shoot had been followed in a nearly easterly course for a distance of 70 feet and its maximum width was perhaps 8 feet. A raise and sublevel showed ore 56 feet above the 1,000-foot level, and a winze situated 50 feet west of the main crosscut is reported to have passed through ore to a depth of 110 feet. On this level the most abundant ore mineral is a black hydrous oxide that carries both copper and iron, but cuprite and malachite also occur.

During the year 1911 additional work amounting to 571 feet was done on the 1,000-foot level, and ore bodies not previously known were revealed.

In 1910, when the mine was visited, connection between the Giroux and Alpha shafts had not been established below the 1,000-foot level, and the original 1,200-foot level workings, amounting to 160 feet, were flooded. This level was opened from the Giroux shaft in 1911, and 467 feet of exploratory work was done within the ore ground. The ores found are reported to carry red and black oxides, malachite, and metallic copper.

Though definite predictions can not be made, it is thought that the oxidic copper minerals which occur in association with bodies of kaolin on the 1,000-foot and 1,200-foot levels will give place to chalcocite at greater depths, and it would seem that ore bodies should occur beneath the large bodies of limonite that have been opened on the 770-foot and 1,000-foot levels.

PORPHYRY ORE BODIES OF THE GIROUX GROUP.

OCCURRENCE.

On the Giroux group of claims there are five bodies of pyritized porphyry in which blankets of material carrying secondary chalcocite occur. Three of these masses of metamorphosed igneous rock lie entirely within the property, whereas the other two are parts of the great body of copper-bearing porphyry that occurs on the Copper Flat group of claims.

OLD GLORY HILL.

The most westerly body of pyritized porphyry outcrops over an irregular area of about 15 acres, covering the summit and southwest slopes of Old Glory Hill. Though the general outlines of this porphyry body are indicated on the geologic map the mapping is not regarded as accurate in detail.

During 1910 the ground was explored by means of churn drills, 38 holes being put down to an average depth of 322 feet. Several of these holes were situated outside the porphyry area, and as most of them were drilled after the writer had left the field full data concerning the results of this prospecting are not at hand. From the records of nine holes, the locations of which are shown on Plate VI, it appears that there is an essentially continuous blanket of enriched material with its top between the elevations of 7,050 and 7,100 feet, or from 370 to 420 feet lower than the crest of the hill. Though the thickness of the blanket was 165 feet in hole No. 109, in only one of the other eight holes was the thickness as great as 50 feet.

As a result of the whole series of borings this section of the property was credited in the annual report of the company for the year 1910 with 650,000 tons of porphyry ore, whose mean copper content exceeded 1.6 per cent.

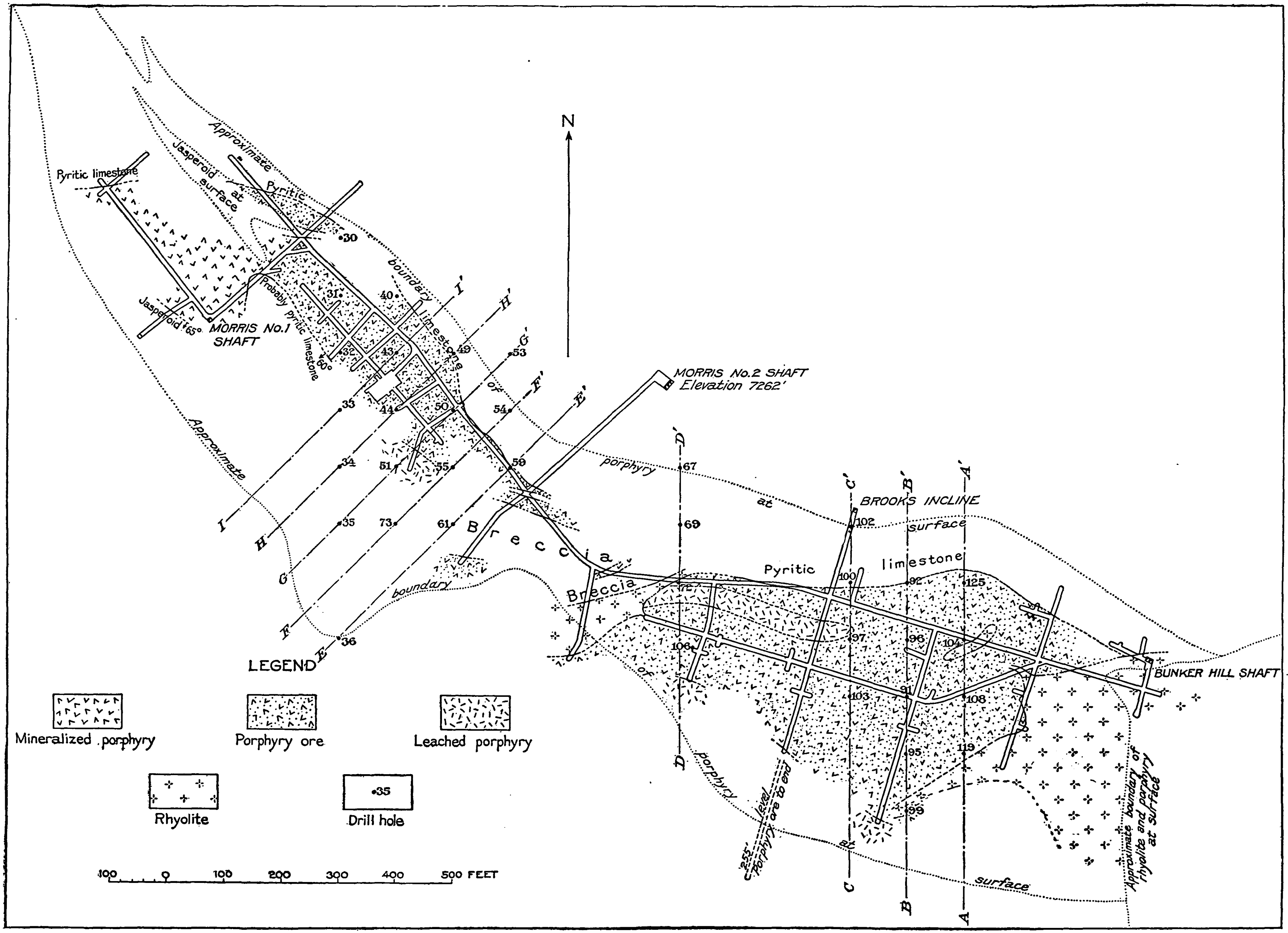
BUNKER-MORRIS MINE.

The most fully explored occurrences of porphyry ore on the Giroux property are those of the Bunker Hill, Brooks, Flying Dutchman, and Morris claims. Here in the connected workings known as the Bunker Hill and Morris mines two ore bodies were developed previous to 1909. In 1909 and 1910 this ground was explored by means of churn drills and in the annual report of the Giroux Consolidated Mines Co. for 1911 the developed ore was estimated at 4,010,000 tons of ore having a mean copper content of 2.14 per cent. An estimate[1] made by Henry Krumb for the Consolidated Copper Mines Co. of the reserves in 1913 indicates 7,000,000 tons of 2 per cent ore. In these estimates the sulphide ore and also the carbonate ore, which occurs in the capping, are included. During the period between May 1, 1912, and September 1, 1913, the mine shipped about 250,000 tons of ore.

The Bunker-Morris ore bodies prior to 1909 were developed by means of three shafts situated on the Morris, Brooks, and Bunker Hill claims. Morris No. 2 shaft, situated on the Brooks claim, was constructed in 1909, and in 1912 three new openings to the surface were made.

In 1910, when the mine was visited, the workings of the main level had explored the porphyry intrusion for a distance of about 2,100 feet along its course. (See Pl. VIII.) The two

[1] The Copper Handbook, vol. 11, p. 389, 1914.



PLAN OF 165-FOOT LEVEL OF BUNKER-MORRIS MINE, SHOWING DISTRIBUTION OF PORPHYRY ORE.

ore bodies were found in the section between the Bunker Hill shaft and a crosscut toward the northeast from Morris No. 1 shaft. Their combined length, including 300 feet of essentially barren ground between them, is about 1,650 feet, the Bunker Hill body being about 700 feet and the Morris body about 650 feet long.

The Bunker ore body lies partly on the Bunker Hill claim and partly on the Brooks claim. It is terminated at both ends by masses of rhyolite that were intruded into the mineralized porphyry previous to its conversion into ore through the deposition of the secondary chalcocite, which is the mineral that carries most of the copper. The rhyolite that cuts off the ore on the east is seen at the surface as a body of considerable extent, but no outcrops were found to represent the intrusion on the west, which, from exposures in the mine, appears to be a wedge-shaped body that has a maximum width of about 80 feet and whose trend is about N. 30° E.

On the 165-foot level of the mine the gangway that connects the Bunker and the Morris workings passes through the rhyolite dike about 385 feet west of the Brooks incline. Beyond this dike there is brecciated pyritic rock, which is thought to be pyritized porphyry that has been crushed along a fault zone. Some of this material carries as much copper as the porphyry ore, but the distribution of the copper minerals in it appears to be very irregular. Near the Morris ore body the breccia comprises fragments of rhyolite and the pyritic material shows the effects of incipient oxidation. This partly oxidized breccia is exposed both in the main drift and to the southwest in a crosscut opposite the haulway leading to Morris No. 2 shaft. In this crosscut the width of the brecciated material is about 100 feet.

The Morris ore body lies partly on the Flying Dutchman claim and partly on the Morris claim. It is terminated toward the southeast by the breccia mentioned above. Toward the northwest the ore grades into porphyry, which was never as thoroughly charged with pyrite as the rock that has been converted into ore.

The cross sections of the ore bodies shown on Plate IX have been constructed from data afforded by records of drill holes, free use of which was accorded by the management of the Giroux Consolidated Mines Co. Though lacking in completeness, in that the southerly side of the porphyry zone had not been systematically drilled, these records are adequate to bring out several interesting points regarding the forms and attitudes of ore bodies and to show the relations between topography and depth of oxidation.

From the observed positions of the porphyry edge at the surface and in three places on the 165-foot mine level the northeast wall of the intrusive mass in which the ore bodies occur is known to be a footwall, and its inclination appears to be about 60° SSW. That the opposite or southwest wall of the porphyry mass dips in the same direction is inferred from the fact that on the assay chart of the 255-foot level the occurrence of porphyry ore is shown in a crosscut from the bottom of the Brooks incline out to a point that lies fully 100 feet south-southwest of the place where the porphyry edge appears at the surface.

The bottom of the enriched material is generally well defined by a sudden decrease in the amount of copper indicated by assays of the drill cuttings. In sections C and D across the Bunker ground the relative depths of the ore bottom in holes successively farther south suggest that this bottom coincides with the footwall of the porphyry intrusion. This suggestion is upheld by the driller's reports, which indicate the presence of limestone immediately under the ore in holes 100, 97, 103, 69, 72, and 106 of sections C and D, in holes 96 and 92 of section B, and in hole 125 of section A. These observations may not be accepted, however, without reservation, because the basis upon which the limestone was determined is not known. If the test of effervescence in the presence of hydrochloric acid was dependend upon the results are not unequivocal, because calcite is characteristically present in specimens of mineralized porphyry in which there has been no chalcocite enrichment. The greatest depth at which the ore bottom has been encountered by drilling is in hole 185, referred to in the annual report of the Giroux Co. for 1912, which is situated in Morris Pass. In this place ore that carried 1.65 per cent copper was reported to give place to material that carried about 0.5 per cent copper at a depth of about 680 feet, corresponding approximately with an elevation of 6,580 feet, as referred to datum of 7,262 feet at Morris No. 2 shaft. Here again it seems very likely that the ore bottom may coincide with the footwall of the porphyry intrusion. This hole is situated near hole 34, and section *H–H′* in Plate IX shows that a point at a depth of 680 feet would lie very near the downward projection of the line joining the porphyry edge at the surface and the ore bottom in holes 49 and 44.

Along the northeasterly side of the ore ground the oxidized capping gives place to sulphides at the relatively shallow depths of 45 to 110 feet. Here the elevations of the bottom surface of the fully oxidized capping, referred to datum of 7,262 feet at Morris No. 2 shaft, range between 7,155 and 7,230 feet in holes 125, 92, 100, and 69; and from 7,160 to 7,200 feet in holes 59, 54, 50, 49, and 43. From this northeastern edge the surface between the oxidized material and the sulphide-bearing rock declines in general toward the southwest wall of the porphyry mass, though locally the direction of the slope is reversed, as is indicated by sections *A–A′* and *C–C′* in Plate IX.

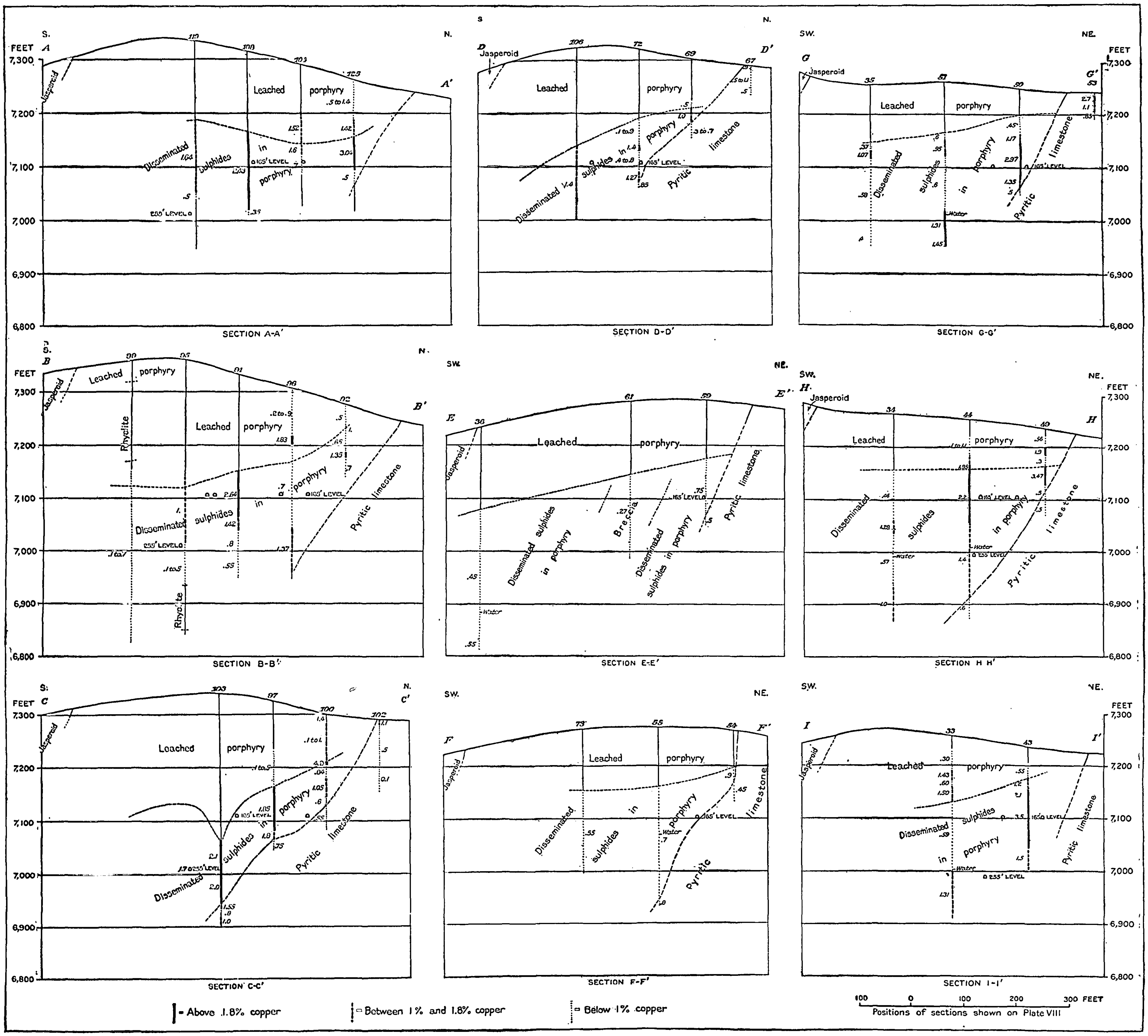
In several places the weathered material above the sulphide-bearing rock carries oxidic copper mineral in commercial amounts. In holes 103, 104, and 125 of the Bunker series from 50 to 60 feet of carbonate ore that carried from 1.5 to 2 per cent copper occurred immediately above the chalcocite ore. On the Morris ground from 15 to 45 feet of carbonate ore was found in holes 31, 32, 33, and 49 at depths between 15 and 120 feet. At hole 40 of the Morris series carbonates were discovered practically at the surface, and 40 feet of rock that carried above 2.5 per cent copper is reported. The sulphides below this carbonate ore are more than ordinarily rich, the drill record showing the following thicknesses of ore and percentages of copper: 4.5 feet of 7.6 per cent; 10 feet of 3.4 per cent; 15 feet of 2.7 per cent; 15 feet of 1.6 per cent; 20 feet of 0.8 per cent; and 30 feet of 0.7 per cent.

The recorded thicknesses of the enriched sulphides in the Bunker ground range from 65 to 260 feet, and those in the Morris ground from 30 to 260 feet. In both mines the better grades of ore occur in the footwall half of the porphyry mass. In the Bunker body the general impression gained from drill records and from assay charts of the 165-foot and 255-foot levels is that the degree of enrichment diminishes progressively toward the south-southwest, so that instead of being definitely terminated in this direction, the ore grades into material that carries less than 1 per cent copper. Although, as already noted, it is probable that enrichment has in no place penetrated below the footwall of the porphyry intrusion, information furnished by drill holes along sections *A–A′* and *B–B′* indicates that toward the southwest the bottom of the enriched material lies well above the porphyry wall, so that the shape of the ore body approaches the blanket form, typical of the masses of enriched pyritic ore that occur elsewhere in the district.

In contrast with the blanket-like Bunker ore mass the Morris body appears to be an inclined tabular body rather definitely bounded by almost parallel walls on the northeast and on the southwest. On the 165-foot mine level the axis of the ore body strikes northwest and its horizontal width is about 175 feet. The northeast wall of the ore is believed to coincide with the footwall of the porphyry intrusion, and the southwest wall appears to be formed by a body of greatly metamorphosed limestone that is supposed to occur as a slablike inclusion in the porphyry sill. The presence of this inclusion of metamorphosed sedimentary rock is indicated by pyritic jasperoid on the 165-foot mine level at the breast of a crosscut that extends 120 feet southwest from the main drift and again in the crosscut that runs northeast from the Morris No. 1 shaft. If the rock dips about 60° SW. the limestone in the crosscut last mentioned corresponds in position with a strip of jasperoid about 60 feet wide which occurs at the surface about 160 feet northeast of Morris No. 1 shaft. The strike of this strip of jasperoid is parallel with the axis of the porphyry intrusion, and though it may continue toward the southeast there are no outcrops whatever northeast of drill hole 32, where similar rock should outcrop to correspond with the jasperoid observed west of the ore body on the 165-foot level.

BEEHIVE AND TONOPAH CLAIMS.

Chalcocite-bearing porphyry was discovered by the Butte & Ely Copper Co. on its Beehive claim prior to 1907. Here the workings consist of a shaft 310 feet deep and several hundred



CROSS SECTIONS OF BUNKER-MORRIS MINE, SHOWING GEOLOGIC RELATIONS OF PORPHYRY ORE.

Data obtained from surface exposures, mine workings, assay charts, and drill records.

feet of laterals, but no details are available concerning the grades and tonnages of the ore developed by these explorations.

Between the Beehive claim and the Nevada Northern Railway tracks on the Tonopah claim a body of chalcocite-bearing porphyry was developed by churn-drill explorations in 1910. The records of 13 holes put down in this locality show from 65 to 210 feet of oxidized capping and from 15 to 125 feet of material that carried from 0.8 to 1.5 per cent copper.

In the annual report of the Giroux Consolidated Mines Co. for the year 1910 this ground was estimated to contain above 4,000,000 tons of ore that has a mean copper content of 1.11 per cent.

North of the railroad the porphyry is entirely unmetamorphosed on the New York claim, but along the eastern border of the porphyry area there is good evidence in the character of the weathered material that the igneous rock has been greatly altered and thoroughly charged with pyrite. Along the railroad the porphyry appears to have been pyritized everywhere east of the New York end line. Toward the northeast the area of the altered rock becomes narrower. It is perhaps 150 feet wide in the northwest corner of the Watson No. 2 claim and wedges out on the Missing Link claim.

WESTPHALIA AND ADJACENT CLAIMS.

The Westphalia claim of the Butte & Ely Copper Co. covers the extreme west end of the porphyry intrusion that contains the great ore bodies developed in the Copper Flat and Liberty pits of the Nevada Consolidated Co. As is shown on Plate VI (p. 112) the porphyry occurs in three patches, one a southwestward extension of the main intrusion, and the others apparently outlying masses. The surface is greatly obscured by loose débris so that the mapping is greatly generalized.

From the records of churn-drill explorations made by the Giroux Co. in 1909 it appears that enriched porphyry that carries as much as 1.5 per cent copper practically occurs only in the northeast corner of the Westphalia claim and the southeast corner of the Liberty Bell claim, though some ore of about this grade was found in the northeast corner of the Herstelle fraction.

In the northwest corner of the Westphalia claim the oxidized capping is 55 to 95 feet thick and so far as data in hand indicate the ore has a maximum thickness of 135 feet.

The amount of porphyry ore that has been developed in this locality would not justify independent mining operations. The reserves that exist will become available through the operations of the Nevada Consolidated Co., in the contiguous Liberty pit.

ORO CLAIM.

The Oro claim, the most easterly parcel of the Giroux property, is separated from the main group by the Josie claim, which belongs to the Nevada Consolidated Co. In 1910 a right of way over the Oro claim was granted to the Nevada Consolidated Co., and during the excavation of an approach to the Liberty steam-shovel pit in 1913 porphyry ore was discovered in the southern part of the claim. Though subsequent explorations are reported to have shown that this ore extends east and west upon the Nevada Consolidated property details in regard to the occurrence are not at hand.

Because of the presence of a complete mantle of surface débris it was impossible to make out the details of the local geology, so that in this vicinity the mapping is greatly generalized.

ELY CENTRAL GROUP.

LOCATION AND HISTORY.

The property of the Ely Central Copper Co. (now merged with the Consolidated Copper Mines Co.) covers an irregular area east of the Puritan and north and east of the Copper Flat groups of the Nevada Consolidated Co. The group comprises 31 claims and fractions which have an aggregate area of about 471 acres.

The original company, which was organized in 1906, appears to have acquired this property on the strength of its proximity to the holdings of the Nevada Consolidated Co., where bodies of porphyry ore had already been developed by underground workings on the Eureka and Star of the West claims. The first use of churn drills [1] in the district was by this company in 1906.

Aside from assessment work very little in the way of exploration had been done before June, 1909, when control of the company's shares was taken over by parties who, during the following year, conducted a stock market campaign, which appears to have been very profitable.[2]

During 1909 and 1910 development work comprised churn drilling and exploration by means of shafts. One shaft on the Clipper claim was opened to a depth of 235 feet and another on the Eureka No. 1 fraction to a depth of 625 feet. Some lateral work was done in both places.

LOCAL GEOLOGY AND RESULTS OF PROSPECTING.

Though the Ely Central area is by no means extensive, six of the eight sedimentary formations of the district occur within its limits, and in addition there is a large body of extrusive rhyolite and several masses of intrusive porphyry. The distribution of the formations indicated on Plates VI and X necessitates the recognition of several profound faults.

In the Ely Central property, on the Globe claim of the Puritan group, the Nevada limestone is everywhere bleached and to a greater or less degree marbleized, but except very locally, as on the Rex claim adjacent to an intrusive body of porphyry, silicate minerals have not been developed in it as a result of metamorphism. Minor bodies of rich copper ore have been found on the Peyton claim and near the west end of the Monarch claim, but nothing of commercial value has been developed.

The shales of the Pilot formation show the effects of baking in a few places and locally they are charged with pyrite, but in general the formation is not greatly altered. The Joana limestone, which outcrops as a northwest-trending band from 100 to more than 200 feet wide, dipping toward the southwest, is almost everywhere crystalline. Locally it carries irregular replacement bodies of metallic minerals, and on the Clipper claim the upper part of the formation has been converted into pyritic jasperoid, which presents rusty outcrops along the parting between the limestone and the overlying shale. In one place on the Clipper claim rather large amounts of chalcocite were found in shallow workings, but elsewhere along the jasperoid reef prospecting has revealed nothing to indicate the presence of ore bodies of commercial size. The Clipper shaft, 235 feet deep, was sunk for the purpose of exploring the parting shale and the limestone, but work was abandoned before this end had been attained.

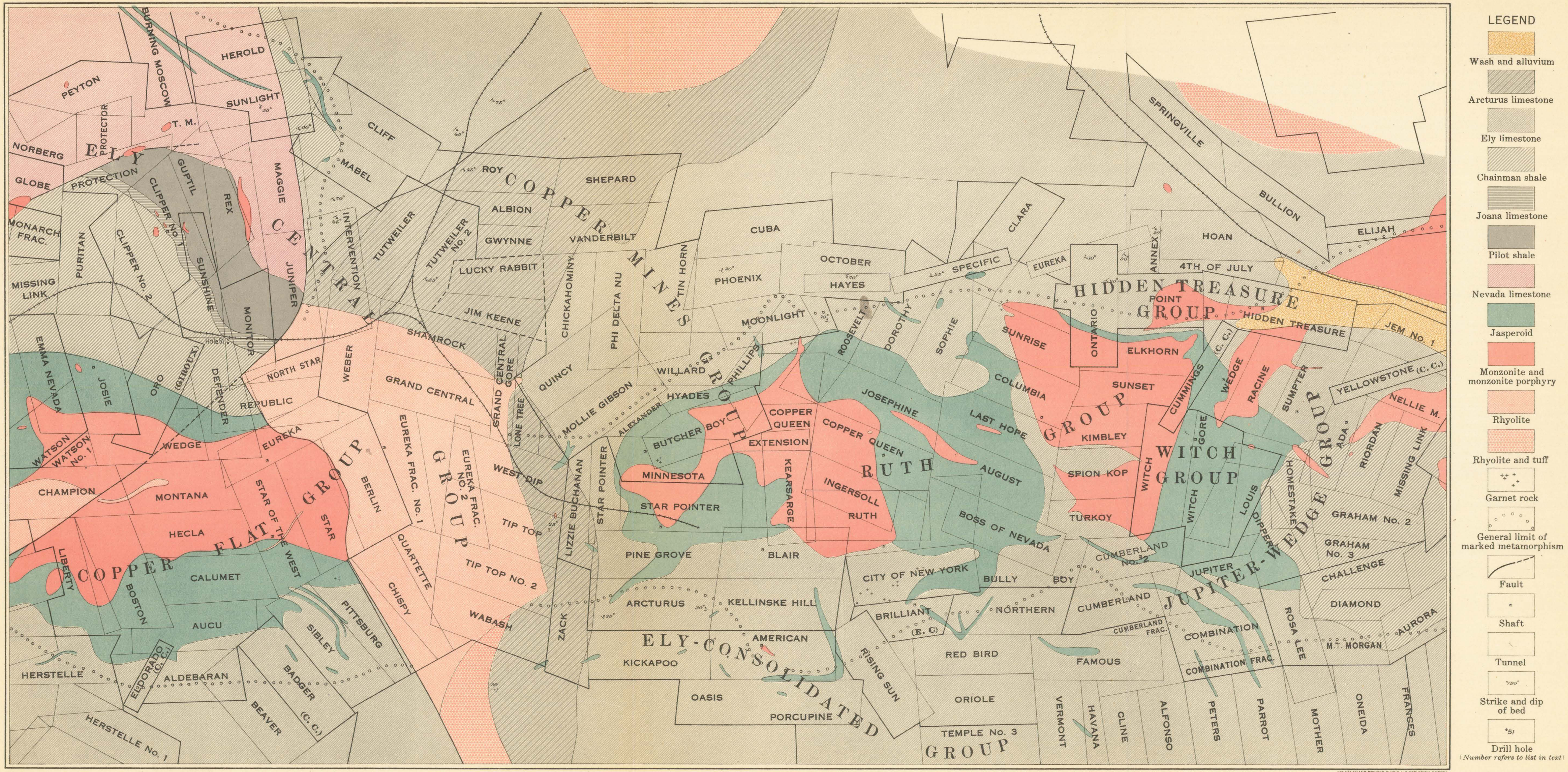
The Chainman shale is rather generally, though by no means uniformly, charged with pyrite both on the Clipper and Monarch fraction claims and on the adjacent claims of the Puritan and Copper Flat groups. In the northern part of the area in which this formation occurs the shales are not strongly baked, but toward the south the degree of metamorphism gradually increases.

Very little detailed information concerning the occurrence of copper minerals in the pyritized shales of the Chainman formation is at hand, but chalcopyrite is reported to have been found in a drill hole on the Puritan claim, and on the Monitor claim in hole 51 of the Copper Flat series copper carbonates were found between the depths of 10 and 75 feet.

In the western part of the group seven separate intrusions of porphyry have been recognized. The largest of these intrusions is an offshoot from the Weary Flat mass that has come up along a fault break. Beyond the end of the porphyry body the Nevada limestone comes into contact successively with the Chainman shale, the Joana limestone, the Pilot shale, and finally with another block of Nevada limestone. On the Protection claim the fault fissure is again occupied by porphyry. The remaining porphyry intrusions appear to have been injected irregularly along the bedding of the invaded formations.

Local metamorphism adjacent to these porphyry intrusions is exhibited on a very minor scale, but garnet may be noted along the walls of the small body of porphyry that cuts the

[1] Pheby, F. S., Prospecting with churn drills: Min. and Sci. Press, vol. 93, p. 786, 1906.
[2] Eng. and Min. Jour., vol. 88, p. 931, 1909; vol. 93, p. 542, 1912.



Base adapted from map of the Robinson mining district by Ed. Millard & Son.

CLAIM MAP SHOWING GEOLOGY ALONG THE CENTRAL PART OF THE PRINCIPAL ZONE OF INTRUSION AND METAMORPHISM, ELY, NEVADA

500 0 500 1,000 1,500 2,000 2,500 Feet

1916

Joana limestone and along the east wall and at the south end of the body that occurs on the Rex claim. So far as observed the igneous rock is nowhere greatly metamorphosed.

The geology of the eastern section of the Ely Central group is less complex than that of the western section. The two sections may be regarded as having their mutual boundary along the curving fault which traverses the Juniper and Maggie claims. West of this fault the sedimentary formations all belong below the Ely limestone, whereas to the east the Chainman and Eli formations occupy very small areas, and the overlying Arcturus limestone is the principal sedimentary formation.

The existence of the fault that is shown on Plates II and X as trending to the northeast from a point on the Juniper-Maggie fault is inferred from the fact that unless an important structural break is introduced the total thickness of the Ely limestone between the Chainman shales, which outcrops on the Mabel claim, and the Arcturus limestone, which is exposed on the Tutweiler claim, would appear to be but 800 feet, whereas in fact the actual thickness of the formation is known to be about 2,500 feet. As shown on the map (Pl. X), the trace of the fault runs parallel with the strike of the strata of both formations.

Minor showings of copper minerals have been encountered in shallow workings on the Intervention, Tutweiler, and Tutweiler No. 2 claims, but nothing of any practical significance has been disclosed. At the Intervention locality, which is near the southwest corner of the Tutweiler claims, green copper minerals occur in the ferruginous cement of surface débris derived from the higher ground toward the south. This cement is supposed to have been deposited during an epoch when the climate was so much more humid than that of the present that springs or seeps existed in the locality, and the iron and copper are regarded as having been furnished by sulphate solutions that originated in the mineralized ground to the southwest. Similar spring deposits occur south of the Nevada Northern Railway, on the Monitor and Defender claims, also on the Wedge and Oro claims.

The southeastern claims of the Ely Central group are almost completely covered by rhyolite. The east ends of West Dip, Tip Top, Tip Top No. 2, and Wabash claims show outcrops of Arcturus limestone, and near the common side line between West Dip and Tip Top the rock carries disseminated pyrite beneath a shallow capping of oxidized material. In this vicinity there are several small intrusions of porphyry, but so far as seen this rock appears not to be charged with pyrite.

On the Chispy claim the southwest boundary of the porphyry area has been drawn parallel with the axis of the claim, so that a strip about 150 feet wide is indicated as occupied by the Ely limestone. Though outcrops are lacking in this locality the limestone on the adjacent Pittsburg claim has been converted into garnet rock and jasperoid.

The exploration carried on during 1909 and 1910 was directed mainly toward the discovery of a possible eastward extension of the porphyry ore of Copper Flat beneath the rhyolite east of the northeast side line of the Berlin claim of the Nevada Consolidated Co. The rhyolite is bounded on the southwest by a fault that dips about 30° NE. A shaft near the western edge of Eureka No. 1 fraction passed through the rhyolite into pyritized limestone at a depth of 462 feet. Between the rhyolite and the pyritic limestone there is a layer of oxidized gouge in which copper carbonate is irregularly distributed. Pyritized porphyry was reached at 555 feet and penetrated to a depth of 70 feet. (See chemical analysis, p. 57.) Pyritic limestone which showed no indication of oxidation was found beneath the rhyolite in a drill hole that was put down about 500 feet southeast of the shaft.

Though the porphyry in the shaft below the depth of 555 feet has the same general character as the primarily mineralized rock beneath the Copper Flat ore body, and can hardly be regarded as other than a part of the same intrusion, the explorations that have been made have failed to discover a body of enriched porphyry in the Ely Central ground.

COPPER FLAT GROUP.

LOCATION.

The Copper Flat property of the Nevada Consolidated Copper Co., situated about 5 miles west of Ely, is the industrial center of the district. The group, which is sometimes called the Eureka group, consists of 28 contiguous claims and fractions that have an aggregate area of about 700 acres. The Oro claim, belonging to the Giroux group, lies within the general boundaries of the property.

HISTORY.

The Copper Flat group of claims appears to have been segregated as early as 1901, and in 1902 was owned by the New York & Nevada Copper Co. During 1902 and 1903 the property was under vigorous exploration and the installation of concentrating and smelting works had been undertaken. Late in 1903 the company became financially involved, and in 1905 its interests were taken over by the Nevada Consolidated Copper Co., which had been organized in 1904.

Already in 1905 underground explorations from two shafts on the Eureka and Star of the West claims had developed more than 3,000,000 tons of ore that carried about 2.2 per cent copper, and when ore shipments began in May, 1908, it is safe to say that fully 10,000,000 tons of ore that had an average grade of 2 per cent had been developed.

Each year since 1908 lower and lower grades of rock have been classed as ore, and on January 1, 1914, the company's engineers estimated that nearly 52,000,000 tons of available porphyry ore showing a mean grade of 1.69 per cent copper had been developed on the Copper Flat and Ruth groups. If 8,000,000 tons of 2.5 per cent ore are assigned to the Ruth ore body, there would be left for the other property an original total of 44,000,000 tons of ore that had a mean copper content of about 1.55 per cent.

The following statistics in regard to the amounts and grades of ore already produced from the mines of the Copper Flat group of claims have been compiled from data presented in the annual reports of the Nevada Consolidated Copper Co.:

Amounts and grades of ore produced by mines of Copper Flat group.

Year.	Sulphide ore.		Siliceous ore.[a]	
	Quantity (tons).	Grade (per cent of copper).	Quantity (tons).	Grade (per cent of copper).
1908	185, 277			
1909	1, 082, 909	2. 34	34, 632+	
1910	2, 236, 434	2. 06	144, 381	2. 5
1911 [b]	3, 324, 438	1. 786	205, 795	2. 91
1912	2, 596, 991	1. 603	88, 428	2. 78
1913	2, 889, 389	1. 511	29, 971	3. 28
1914	2, 513, 241	1. 405	14, 498	2. 51
	14, 828, 679	1. 716	517, 705	2. 77

[a] Siliceous carbonate ore suitable for use in the process of converting matte into blister copper. At the end of 1913 about 125,000 tons of this material had been used, and the remainder was held in storage.
[b] Period of 15 months ending Dec. 31, 1911.

DEVELOPMENT AND MINING METHODS.

The early development work was mainly done by means of two shafts situated on the Eureka and Star of the West claims, in the eastern part of the group. From the Eureka shaft about 3,600 feet of laterals were opened, and from the Star of the West shaft lateral workings amounted to about 1,800 feet. All this work was done prior to 1907. The subsequent explorations of the great ore body have been accomplished by means of churn drills. The ore ground comprises an irregular area about 3,600 feet long and from 400 to 1,400 feet wide. Within and along the borders of this area about 185 holes have been driven to depths of 100 to 650 feet, and of these holes perhaps not less than 140 have penetrated the ore body. By this method of prospecting the boundaries of the ore ground were outlined, at least minimum thicknesses of ore were made known, and the depth of the overburden or capping was determined for all parts of the area. After reaching the sulphide-bearing rock the drill cuttings were sampled in 5-foot sections and the samples were assayed. Thus tonnages and grades of ore were determined and calculations were made to show the amounts of waste material that must be moved in order to make the ore available for open-pit mining.

Although no definite figures have been published in regard to the ratio between tonnages of available ore and of waste material that must be handled, it is estimated from items of mining costs given in the annual reports of the Nevada Consolidated Co. that this ratio may vary for different sections of the ore ground from 1:0.8 to perhaps 1:1.6. In the whole deposit it will probably be necessary to handle approximately 1 ton of waste for every ton of ore that can be won.

The plan of mining this great ore body by means of steam shovels appears to have been decided upon as early as 1906. Preliminary work was commenced in the eastern or Copper Flat section, and perhaps 300,000 cubic yards of waste had been removed before actual production began in May, 1908. From this time on stripping was vigorously pushed; the Liberty pit was opened in 1910 and 1911 and the Hecla pit in 1912. At the close of 1913 nearly 12,000,000 cubic yards of waste had been excavated, and the ore top had been exposed over approximately three-fourths of the ore-bearing area.

In the excavation both of the ore burden and of the ore successive benches have been worked at vertical intervals of about 50 feet. The ground is loosened by blasting to make it available for the shovels. A series of 6-inch holes, about 35 feet apart and the same distance back from the edge of the bench or terrace, are drilled to a depth of 50 or 60 feet. After being chambered by the explosion of a small charge of dynamite, the holes are loaded with black powder and fired.

At the close of 1913 approximately 25 acres of the ore had been exposed ready for mining in the eastern or Copper Flat section. The pit had been opened to a depth of about 260 feet below the original surface of the ground, and five terraces were being carried toward the south and west.

Only a small area had been entirely stripped in the Hecla workings, but in the Liberty pit the ore had been exposed to the extent of perhaps 6 acres, and the lowest level was approximately 130 feet below the original surface.

LOCAL GEOLOGY.

Four of the eight sedimentary formations of the Ely district occur within the limits of the Copper Flat group of claims, and in addition there are bodies of porphyry and rhyolite. (See Pl. X.)

The Pilot shale and the Joana limestone on the Sunshine and Monitor claims are in general but slightly metamorphosed, though locally both rocks have been impregnated with pyrite and minor amounts of copper are present. The Chainman shale, which carries abundant pyrite on the Puritan and Clipper claims, is undoubtedly similarly mineralized on the Sunshine, Oro, and Defender claims, and from the weathered materials that were exposed in 1910 it appears that the intensity of metamorphism is much greater south of the Nevada Northern Railway than north of it. On the Puritan claim a small body of sulphides that carry 1 per cent copper is said to have been found by drilling. This is probably a thin-bed deposit.

In drill hole 51 of the Copper Flat series, situated south of the railroad near the west side line of the Monitor claim and west of the boundary between the Joana limestone and the overlying shale, oxidized material that carries from 0.6 to 3.3 per cent of copper was penetrated between the depths of 10 feet and 75 feet. Beneath these carbonates the record shows 20 feet of "slate" which has a mean copper content of 0.8 per cent and 25 feet of white limestone which carries 0.3 to 1.6 per cent copper. In this locality the strata appear to dip about 60° SW.

Because rock exposures in 1910 were entirely absent in the southern part of the Chainman shale area the southern boundary of this formation could not be located, but the presence of the Ely limestone between the shale and the porphyry intrusion is to be inferred from the occurrence of heavy garnet-magnetite rock near the Josie shaft, and of pyritized limestone in the northwest corner of the Copper Flat pit. For the reason stated the areal geology of the block of ground which lies between the main line of the railroad and the body of porphyry to the south is not actually known, and for this area the positions of the geologic boundaries shown on Plate X are entirely conjectural.

The Ely limestone, as indicated above, is supposed to occur generally along the north side of the porphyry mass. South of the porphyry the beds of this formation have been intensely metamorphosed within an irregular zone from 300 to 1,200 feet in width. Along this zone there are many outcrops of rusty jasperoid and a few showings of garnet rock. Oxidic copper minerals occur, and evidently the altered rock, where unweathered, must be generally charged with pyrite and chalcopyrite. These altered limestones have been exposed along the south side of the porphyry ore body in the Copper Flat pit, and here the rock, though somewhat weathered, is heavy with sulphide minerals.

The mass of porphyry within which the Copper Flat-Liberty ore body occurs covers an irregularly bounded area about 3,900 feet long and from 1,400 to 2,000 feet wide, the longer axis of the area trending nearly east and west. In the Copper Flat pit the south wall of the prophyry mass is inclined about 60° N., and in this place intrusive relations with the Ely limestone are clearly exhibited. Because of inadequate exposures the boundaries of the porphyry area are regarded as only approximately correct. No part of this porphyry body appears to have escaped the effects of the thorough alteration which characterizes the principal metamorphic zone of the district. Everywhere the material at the surface is of such a nature as to show that sulphates were formerly present. Wherever the bottom of the weathered material has been penetrated sulphide-bearing rock has been found, and over the greater part of the area more or less enrichment of the primary sulphides has taken place.

The extensive rhyolite bodies east and west of the porphyry area have been regarded as surface flows.[1] Though the rocks of the eastern area are undoubtedly of this origin some doubt remains in regard to the western area, the rocks of which may be in part extrusive and in part intrusive. Dikes of rhyolite and of rhyolite breccia cut the porphyry on the Star, Star of the West, Champion, and Montana claims.

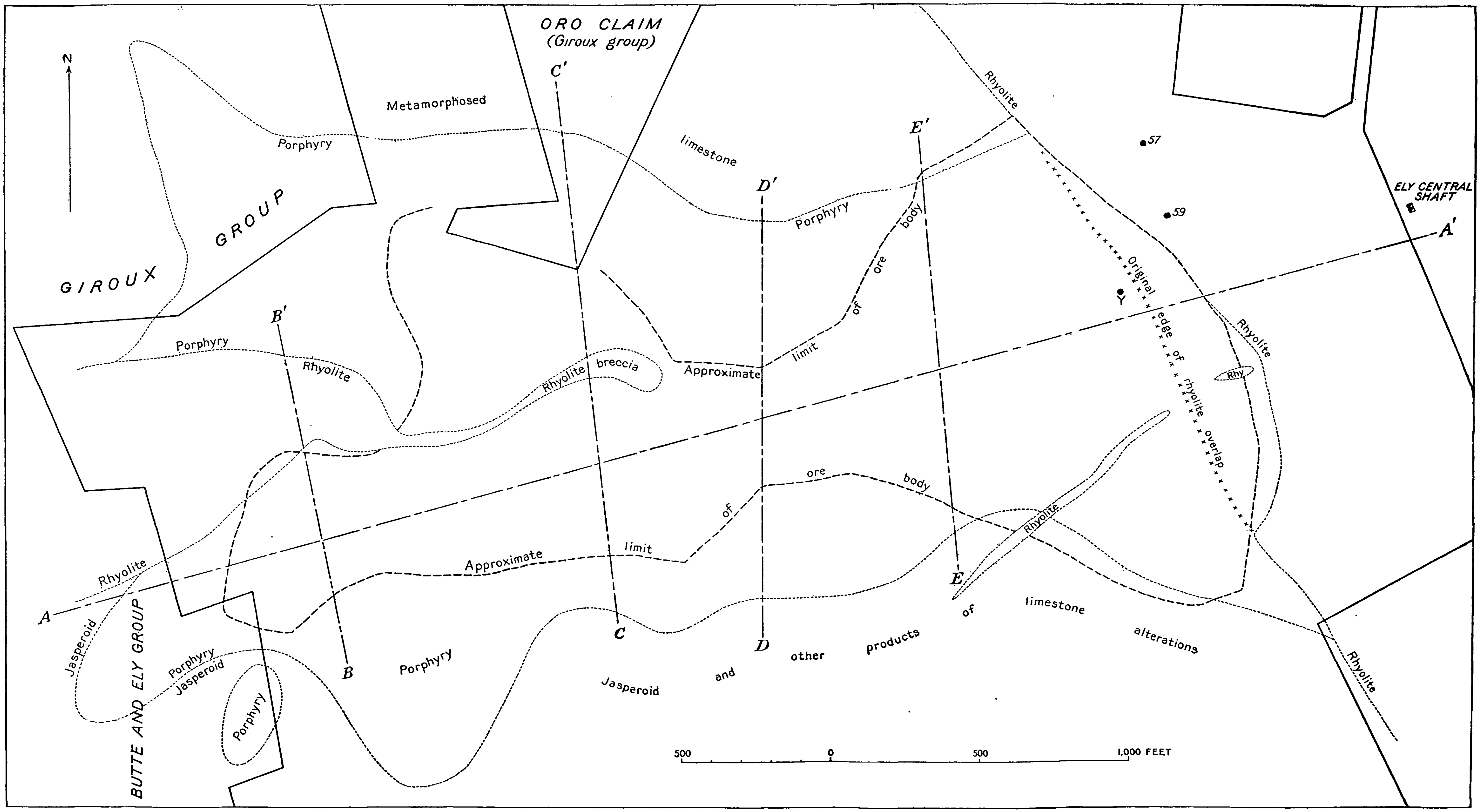
On the geologic maps (Pls. VI and X) three faults have been shown as traversing the Copper Flat group of claims. Toward the east the porphyry mass is limited at the surface by a block of rhyolite that has been thrown down along a fault break which strikes toward the north-northwest. The existence of this fault is perfectly clear in the Copper Flat pit, and the break was found in the Ely Central shaft (situated east of the Berlin claim) at a depth of about 468 feet. The dip of the fault is approximately 30° E.

Near its west end the porphyry area is interrupted by a wedge of rhyolite, which appears to be bounded by two faults that converge toward the northeast. The more northerly fault dips toward the south, whereas the other probably stands nearly vertical. The southerly fault has been shown as extending to the northeast to intersect the Copper Flat fault, but across the Wedge and Defender claims this extension is entirely conjectural, and in the absence of exposures the porphyry edge and the limestone and shale parting have been represented by random lines without offsets where they cross the line of the supposed fault. Farther to the northeast a fault is required to account for the termination of the southeast-trending limestone band on the Monitor claim.

COPPER FLAT-LIBERTY ORE BODY.

The chalcocite-bearing porphyry ore of the Copper Flat group of claims occurs as a blanket-like body about 3,500 feet long, from 400 to 1,200 feet wide and from 200 to 500 feet thick as measured along the principal or eastward-trending axis.

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, pp. 347-349, 1906.



MAP SHOWING PLAN OF ORE BODY AND AREAL EXTENT OF PORPHYRY IN COPPER FLAT-LIBERTY MINE.

Data in part from annual report of Nevada Consolidated Copper Co. for 1913. *A-A′*, etc., Lines of sections shown in Plate XII.

The ore has been formed through the deposition of secondary chalcocite in the great body of pyritized porphyry which covers an area of perhaps 80 acres and, though workable ore is not present everywhere in this area, the ground plan (see Pl. XI) of the ore body conforms in a general way with the outlines of the porphyry mass.

Pyritic porphyry occurs beneath the ore and assays of samples of this material usually show from 0.3 to 0.6 per cent of copper, corresponding with 1 to 2 per cent of primary chalcopyrite. The downward extent of the enriched material differs greatly from place to place, and the principal variations in the thickness of the ore body appear to be due to undulations of the bottom.

Above the ore lies material that has been oxidized and leached under the action of atmospheric waters. This oxidized capping is in large part heavily stained with iron compounds that have been derived from pyrite, but locally the rock is nearly white, and in such material the former presence of sulphide minerals can only be determined from the presence of abundant cavities that correspond in size with the grains of sulphide in samples of the ore. Here and there the rock of the capping contains green copper minerals in noteworthy abundance, and in a few places large masses of the weathered material carry from 1 to 2 per cent of copper.

The capping and the ore are everywhere rather sharply distinguishable, one against the other, but the surface between the fully weathered material and the sulphide-bearing rock is one of very marked irregularities. As the result of the deeper penetration of surface waters along joints and crevices numerous narrow wedges or conical masses of the capping extend downward into the ore mass, and between these bodies there are pinnacles of ore.

The thickness of the capping ranges from 20 to somewhat more than 200 feet, and in 1911 the average thickness, over the ore body as then developed, was estimated at 102 feet, according to the annual report of the Nevada Consolidated Copper Co., for the year 1911.

The relations of the ore to the capping and the unenriched porphyry that occurs below the ore body are illustrated in a general way by the longitudinal section and the cross sections given on Plate XII. These drawings are based on sections that are published in the annual report of the Nevada Consolidated Copper Co. for the year 1913. They may be taken as showing the relations of the capping and ore in an accurate manner, but the lines representing the ore bottom are subject to revision, because in many places the ore has been represented as extending only to depths actually determined by drill explorations; locally the ore may be found to have thicknesses greater than those which have been indicated. Examination of the drill-hole records shows that in many places the transition from material carrying above 1 per cent to material carrying less than 0.6 per cent copper is rather abrupt, but elsewhere a gradual diminution of grade occurs over vertical ranges between 50 and 150 feet. The general rule in regard to the vertical distribution of the ore is that the best occurs in the upper third or half of the ore body, but many exceptions to this generalization are to be noted.

Detailed information concerning the position of standing water is not at hand, but in the eastern part of the ore ground the water top appears to have been found at an elevation of about 6,920 feet and in the western part at about 6,970 feet. If these figures represent the general position of the water table it appears that a very considerable portion of the rock that has been enriched through the deposition of secondary chalcocite lies below the original groundwater level.

Though the ore body constitutes a continuous mass of enriched material the average copper content of the rock differs widely in different sections of the ore ground. The largest quantity of the ore of better grade was found in the eastern part of the deposit. Here, from the Copper Flat or Eureka pit, 3,500,000 tons of porphyry ore which carried as an average about 2 per cent of copper were mined prior to November 1, 1910, and during the 15 months next succeeding more than 3,000,000 tons of 1.8 per cent ore were produced. In this section the porphyry ore is terminated on the south by the strongly mineralized limestones of the Ely formation, and the parting between the two sorts of rock, which dips toward the north, forms the footwall of the ore. Locally material of ore grade occurs in the altered limestone adjacent to the porphyry mass. Along the east side of the pit, within an area about 200 feet wide, the ore was for the most part immediately overlain by rhyolite, but in one place a sliver of pyritic limestone was observed between the ore and the rhyolite, and in the Ely Central shaft, situated about 626 feet east of the pit edge, 90 feet of limestone was found below the rhyolite and above the pyritized porphyry that was found at a depth of 555 feet. On the north side of the Copper Flat pit there are exposures of metamorphosed limestone heavily charged with pyrite, which appear to represent masses of the sedimentary rock that are surrounded by porphyry.

During the excavation of this pit the porphyry ore was found to be interrupted by two dikes of rhyolite and by a dikelike body of breccia, which contains fragments of rhyolite. These dikes, which are from 20 to 50 feet wide, strike somewhat east of north and dip steeply toward the northwest. In one place finely disseminated metallic copper was noted in soft decomposed rhyolite near the walls of one of these dikes.

Near the eastern side of the Copper Flat pit a flat-topped body of unenriched porphyry was found about 150 feet below the original ground surface. This mass of worthless rock, which occupies a rudely elliptical area about 250 feet long and from 100 to 200 feet wide, is known from drill records to carry from 0.2 to 0.7 per cent copper down to an explored depth of 150 feet below its top. Above this essentially barren rock there was 100 feet of ore of nearly 2 per cent grade, which is flanked on all sides by ore, that extends to additional depths of 50 to 100 feet. The material of this horse has escaped the enrichment that has converted the adjacent rock into ore probably due to the presence of a flat-lying dike of fine-grained rhyolite, which prevented the copper-bearing waters from penetrating it. This suggestion is based on the observation of a thin body of rhyolite in three places, and, though it is not known that this rhyolite was coextensive with the area of the horse, it seems probable that it was and that the intrusive rock had been for the most part removed by the shovels when the overlying ore was mined.

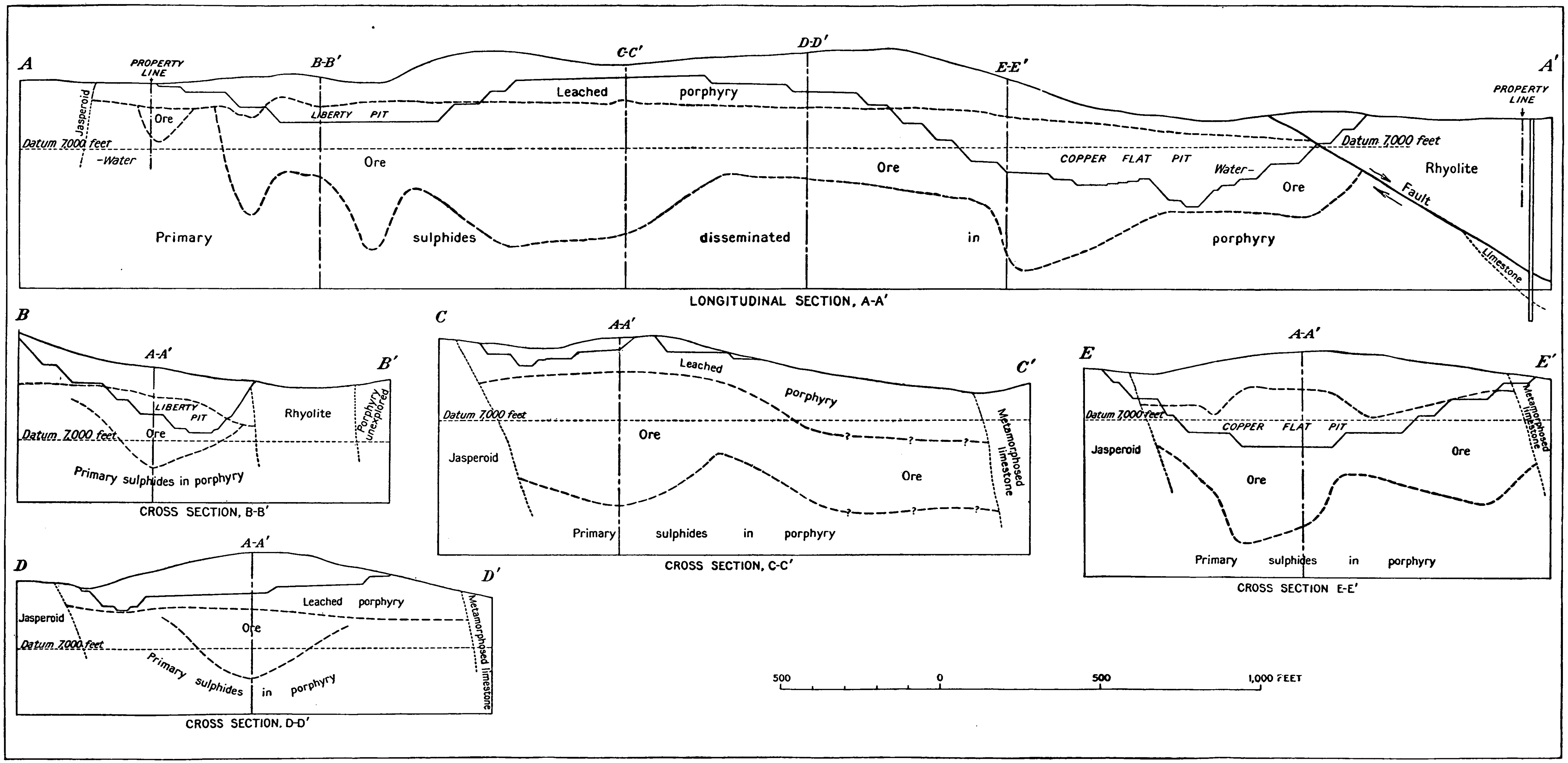
For the eastern or Copper Flat section of the ore ground the average thickness of the ore was estimated in 1911 to be 190 feet, and that of the immediate overburden to be 87 feet. As indicated on Plate XI the width of the ore ground is here from 700 to about 1,300 feet.

Mining began near the eastern part of the Copper Flat section and as operations were extended toward the west a change in the composition of the ore was noted. The chemical composition of approximately 3,000,000 tons of ore mined prior to September 1, 1910, indicates the presence of less than 5 per cent of pyrite, and ore of this sort, as treated in the milling plant, furnished about 1 ton of concentrate for every 10 tons of ore. Ores from the west side of the Copper Flat section and from the Liberty pit are reported to carry considerably greater proportions of pyrite, and this is indicated by the fact that during 1913, when most of the ore treated came from the localities stated, the average ratio of concentration dropped to 6.94, or, in other words, 6.94 tons of ore furnished 1 ton of concentrate. Where pyrite is most abundant it occurs in the form of films deposited along joint fractures, and in general it appears that this film of pyrite has been much less effective in precipitating chalcocite than the sulphides that are disseminated through the body of the rock.

The siliceous carbonate ore that has been mined by the Nevada Consolidated Co. came from the Copper Flat pit. This material consists mainly of quartz of the type that usually occurs in veins, but samples examined by means of the microscope were found to contain a little orthoclase. Material obtained from the lowest exposures in 1910 contained chalcopyrite in grains coated with chalcocite, but to a depth below the original surface of nearly 200 feet this ore appears to have contained very minor amounts of sulphide minerals, and the copper present occurred mainly in the form of malachite and probably in part as brochantite.

This material occurred as a body of irregular shape surrounded by porphyry ore. As exposed in 1910 it had a length from south to north of nearly 600 feet and an apparent width of 100 to 200 feet.

In the central section, opened by the pit named after the Hecla claim, explorations have shown that the compact body of enriched material that carries more than 1 per cent copper occupies only the central part of the porphyry intrusion, and that its width is locally hardly



LONGITUDINAL AND CROSS SECTIONS OF COPPER FLAT-LIBERTY MINE, SHOWING ORE BODY AND EXCAVATIONS.

For position of sections see Plate XI. Data mainly from annual report of Nevada Consolidated Copper Co. for 1913.

more than 400 feet. The average thickness of the ore body was estimated in 1911 at 280 feet and that of the overburden at about 100 feet.

In the western or Liberty section, the ore ground was supposed, prior to explorations carried on during 1913, to have a width of 400 to 500 feet. Estimates made in 1911 indicated an average thickness of about 193 feet for the body of available ore and of about 155 feet for the overburden.

As the result of excavations along the approach to the Liberty pit from the north, ore was discovered on the Oro and Josie claims during the summer of 1913, and by churn-drill explorations this body of enriched material was found to extend over portions of the Wedge, Champion, and Montana claims. Between the Josie-Montana section and the previously developed Liberty section there is a dike of rhyolite-bearing breccia, from 15 to 100 feet wide, which trends nearly east and west and dips steeply toward the south.

RUTH GROUP.

LOCATION.

The property of the Nevada Consolidated Copper Co. that is known as the Ruth group consists of 36 claims and fractions which have an aggregate area of about 455 acres. The property extends along the central mineralized zone for a distance of about 1½ miles; its east limit is about 3½ miles west of Ely, and its west limit somewhat more than half a mile east of the Copper Flat ore pit. In the southeastern part of the group the Turkoy and Bully Boy claims adjoin the Cumberland claims of the Jupiter group of the Nevada Consolidated Co.

HISTORY.

The body of porphyry ore covered by the Ruth and adjacent claims appears to have been discovered in 1901 by Grey and Bartley. The ore top was reached in an inclined shaft at a depth of 120 feet, and after explorations had been extended to a depth of 300 feet control of four claims, including the Ruth, was acquired by M. L. Requa and F. W. Bradley. Several adjacent claims were secured during 1902 and 1903 and in 1903 the White Pine Copper Co. was organized for the purpose of more fully developing the property. During 1904 explorations were continued in the Ruth mine, shafts were sunk on the Columbia and Last Hope claims, and the Ruth ores were tested by means of an experimental mill erected at the mouth of the shaft.[1] In 1904 the Nevada Consolidated Copper Co. was organized, and the properties of the White Pine Copper Co. and of the New York & Nevada Copper Co. were transferred to the new company in 1905. At this time the proved ore in the Ruth mine was estimated to amount to 2,400,000 tons, showing an average grade of 2.6 per cent copper. Underground development was continued during 1906 and 1907, and by means of churn drills the general limits of the ore body were determined in 1909 and 1910. In 1909 the Ruth ore body was estimated to contain 8,000,000 tons of ore that had a copper tenor of about 2.5 per cent.[2]

From 1909 to 1911 churn-drill explorations were made in parts of the Ruth group where masses of mineralized porphyry occur. Though the chalcocite-bearing rock was found to be essentially coextensive with the porphyry no ore bodies of commercial value were developed as a result of this work.[3]

LOCAL GEOLOGY.

Except for a narrow strip of Arcturus limestone on the Lizzie Buchanan claim and a small patch of obsidian on the Copper Queen claim, the area of the Ruth group is occupied by porphyry and by limestone belonging to the Ely formation. The area lies within the principal zone of intrusion, and as elsewhere along this zone both the masses of sedimentary rock and those of the invading porphyry have been for the most part intensely metamorphosed and thoroughly charged with pyrite or with pyrite and chalcopyrite.

[1] Requa, M. L., Experimental mill of the Nevada Consolidated Co.: Min. and Sci. Press, vol. 97, pp. 90–95, 1908.
[2] Nevada Consolidated Copper Co. Third Ann. Rept., for the year ending Sept. 30, 1909.
[3] Nevada Consolidated Copper Co. Fourth Ann. Rept., for the year ending Sept. 30, 1910.

Two large bodies of porphyry that lie mainly within the group and two smaller bodies on the Josephine, August, and Last Hope claims are shown on the map (Pl. X). The outlines of the smaller bodies are very much generalized because of poor exposures, and probably there are other occurrences which were not detected on account of surface débris.

According to the data obtained from underground workings and from drill-hole records it appears that the walls of the porphyry bodies are almost everywhere highly inclined. This attitude, taken in connection with the extremely irregular outlines and the broad rather than narrow plans of the porphyry masses, indicates that the intrusions are essentially cross-breaking in relation to the stratified rocks which they invade. Comparison of the relative positions of the porphyry edge at the surface and in the workings of the Ruth mine indicate that the wall on the south has a northerly dip of about 60° and that what may be called the lateral walls on the east and west are both steeply inclined in a westerly direction.

Although the local structures of the invaded limestones have not been made out from direct observations of strike and dip, it is apparent from the areal distribution of the Ely limestone and of the formations that lie next above and next below it (see Pl. X) that the lower beds of the Ely formation outcrop toward the east and the higher beds toward the west, so that in a general way the average strike of the strata seems to be nearly north, or transverse to the axis of the intrusive zone, and the dip to the west. Along the edges of the metamorphic belt, both to the north and to the south, the strike and dip are extremely variable, so that there is no evidence in the structure of the surrounding rocks which would tend to show that the porphyry intrusions have caused any general arching of the strata such as should be discoverable if the porphyry masses were laccoliths rather than stocks.

The rock of the porphyry masses of the Ruth area has been almost wholly sericitized and charged with pyrite and with minor amounts of chalcopyrite, but along the borders of the two larger intrusions there are a few places where very minor portions of the rock have escaped the otherwise general metamorphism. Such essentially unmineralized rock was noted at the southwest corner of the Kearsarge claim and on the Turkoy and Roosevelt claims.

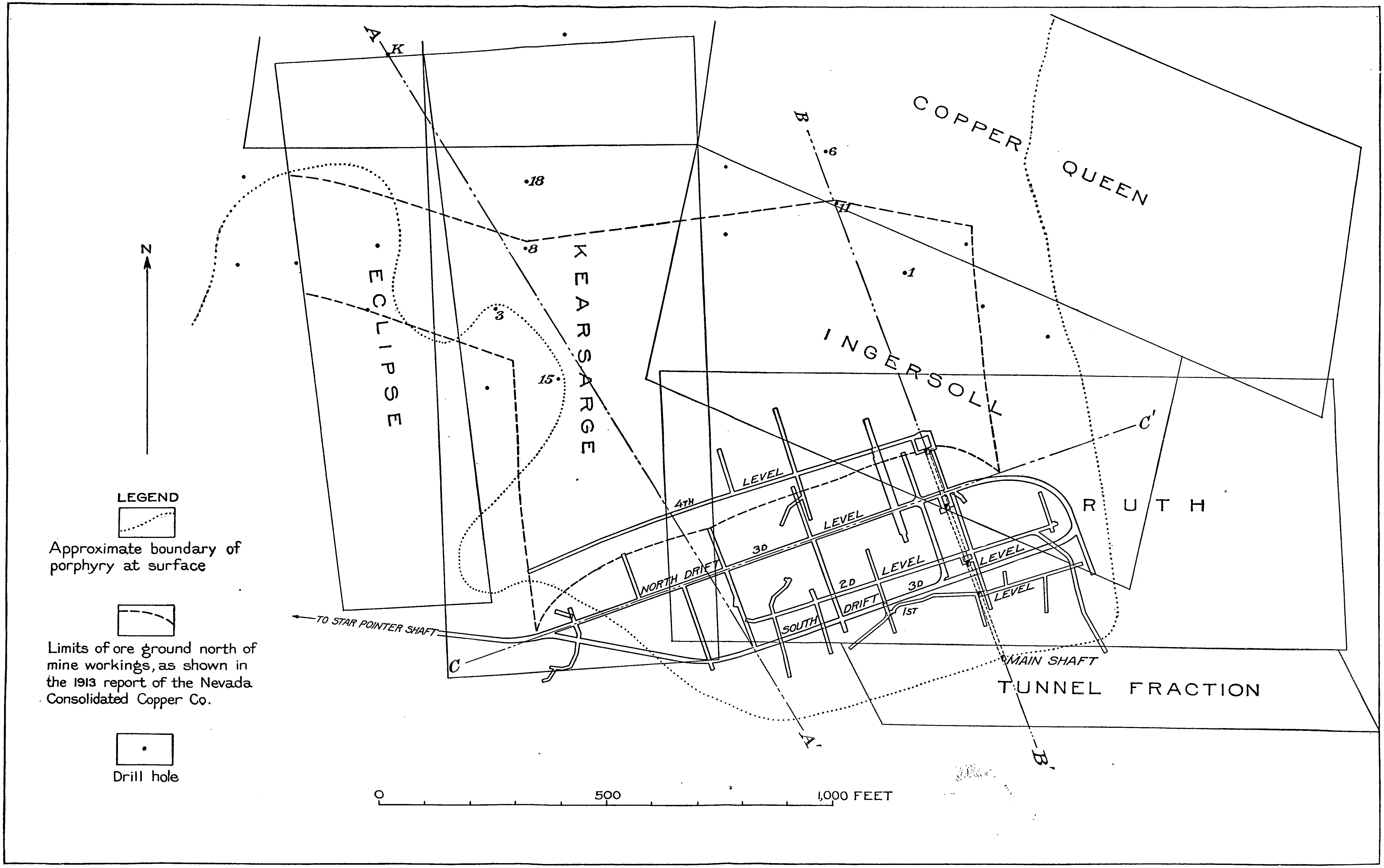
Within the Ruth group the limestones of the Ely formation have been almost everywhere more or less intensely metamorphosed. Though the detailed separation and mapping of the alteration products has not been attempted on Plate X, several areas within which numerous or large masses of jasperoid or bodies of partly silicified limestone occur have been outlined, some of the outlying ledges of jasperoid have been shown, and localities where outcrops of garnet rock were noted have been indicated.

At the surface the jasperoid is almost invariably deeply stained with iron compounds, showing that the unweathered rock carries abundant pyrite. Massive outcrops occur from place to place, but elsewhere the presence of the jasperoid is indicated by the occurrence of loose gravelly material composed of angular fragments in which cavities are present that formerly contained pyrite.

Where the jasperoid bodies present bold outcrops they generally have more or less tabular forms and very sharp boundaries. In several localities these occurrences are flanked by marble, whereas elsewhere they are bordered by limestone that shows very slight alteration. Prospecting along the walls of these jasperoid ledges has revealed the presence of copper carbonates in a few places, but nothing of particular promise has been discovered.

The assay plans of the levels of the Ruth mine show that locally at least the silicified and pyritized limestones of this general section carry a few tenths of 1 per cent of copper, and most of the jasperoid probably contains some chalcopyrite in addition to the invariably abundant pyrite. However, the record of drill hole 17 (situated 525 feet east of the Star Pointer shaft) shows copper in only one of 46 samples that represent a 260-foot section of pyritic jasperoid.

Outside the areas in which large masses of jasperoid occur the limestones are very unevenly metamorphosed. From existing exposures garnet rock seems to have been extensively formed only on the City of New York and adjacent portions of the Kellinske Hill, Blair, and Brilliant claims. In this neighborhood most of the material at the surface is so decomposed and rusty



PLAN OF ORE BODY AND MINE LEVELS OF RUTH MINE.

A–A', etc., Lines of sections shown in Plate XIV.

that the nature of the alteration can not be satisfactorily determined, but on the City of New York claim there are showings of massive yellow and green garnet in a matrix of rather coarsely crystalline marble. Pyrite and chalcopyrite are intimately associated with the garnet, and the garnet sulphide aggregates are intermingled with irregular masses of dense magnetite. Limonite, which occurs with the magnetite, has doubtless been derived from the oxidation of pyrite. The garnet and magnetite outcrops occur within an area that measures about 400 feet from north to south, and the most northerly exposures are nearly 200 feet from the edge of the Ruth mass of porphyry.

South and immediately west of the porphyry mass of Kimbley Hill on the Turkoy, August, Last Hope, and Columbia claims, and within the general area occupied by the porphyry on the Spion Kop claim, the limestones have been but slightly altered, though the igneous rock has been thoroughly charged with sulphides and only a short distance to the west jasperoid occurs in large amounts.

In the northern part of the group the limestones that adjoin the principal masses of jasperoid have been to a greater or less degree bleached and marbleized, but the more strongly altered phases of the rock are very irregularly distributed and general metamorphism does not extend as far as the northern portions of the Roosevelt, Dorothy, and Sophie claims.

RUTH ORE BODY.

The mass of porphyry ore which has been developed in the Ruth mine is a blanket-like deposit that covers an area of about 30 acres on the Ruth, Blair, Ingersoll, Kearsarge, and Eclipse claims, and in addition a few acres on the Minnesota and Butcher Boy claims, which belong to the Consolidated Copper Mines Co.

The ore body was discovered in an inclined shaft, the mouth of which is situated on the Tunnel Site fraction about 50 feet from the south side line of the Ruth claim. This shaft, the inclination of which is approximately 41° NNW., was carried down to a vertical depth of about 430 feet. Four levels were opened, as follows (see Pl. XIII): First level at 125 feet; has 350 feet of workings east and 330 feet of workings west of the shaft. Second level, at 187 feet; has drifts east 200 feet, and west 500 feet, and a total of 800 feet of crosscuts. Third, or main level, at 302 feet; has two parallel drifts about 180 feet apart, which aggregate about 2,000 feet in ore, and 2,200 feet of crosscuts. Fourth level, at 416 feet; has a drift 880 feet to the west and two crosscuts which amount to 420 feet. Sublevel workings above the second level amount to about 460 feet. In addition to the horizontal openings, which aggregate more than 8,000 feet, there are raises, mainly from the second and third levels, which amount to 1,850 feet, so that including the shaft the total extent of the exploratory workings is approximately 11,000 feet.

To provide for the operation of the Ruth mine, the Star Pointer shaft was sunk to a depth of 460 feet and a haulway 1,400 feet long was driven from the 359-foot level to connect with the third level of the mine at a point about 1,060 feet west of the Ruth incline.

By means of the workings noted above, all of which were completed previous to July, 1907, a block of ground which measured approximately 1,200 by 250 to 400 feet had been systematically explored and found to contain a blanket of ore from 100 to nearly 250 feet thick. The extension of the ore toward the north of the mine workings was determined by means of churn-drill explorations, carried on mainly during the year 1909, and as a result of this work the previously known area of the deposit was more than doubled.

The origin of the Ruth ore, its general nature, and the manner of its occurrence are essentially like that of the ores of the other porphyry mines of the district. From the character of the weathered material at the surface it is known that the rock of the porphyry mass in which the ore occurs has been very generally metamorphosed and pyritized. Not only so, but everywhere that the rock has been penetrated by drills it is found to contain copper, and as a rule there is good evidence in the assay records that the material just beneath the fully oxidized capping has been enriched through the deposition of secondary chalcocite. Though the distribution of the chalcocite-bearing rock is thus to be regarded as corresponding essentially with the distribution of the porphyry, the body of material that is rich enough, thick enough, and sufficiently uninterrupted to be of value occurs in the southern part of the porphyry mass and occupies hardly more than half of its entire area. (See Pls. X and XIII.)

In the mine workings which have explored the southern part of the ore ground the horizontal limits of the ore blanket toward the east, south, and west coincide with the walls of the porphyry mass, but toward the north the workable ore is either flanked by mineralized porphyry that carries only minor amounts of copper, or the ore blanket becomes so thin as to have no practical importance.

Wedges of oxidized rock extend downward into the ore mass so that the surface between the capping and the ore is one of great irregularity. If these irregularities are neglected, it appears that the ore top reaches its greatest elevation in the southeastern corner of the porphyry area and that the general surface between the capping and the ore lies at lower and lower elevations from the vicinity of the shaft toward the west, and from the southern edge of the ore blanket toward the northwest and north. (See Pls. XIII and XIV.) The general slope of the ore top appears to be toward the northwest within an area approximately 900 feet wide, but several drill holes show that beyond this area the surface between the capping and the sulphide-bearing rock rises, so that in the northwestern part of the ore ground this surface stands considerably above its minimum elevation. As is indicated on the diagrams the oxidized capping over the blanket of chalcocite-bearing ore ranges in thickness from about 110 feet to about 435 feet. Its average thickness appears to be considerably more than 300 feet.

It is difficult to make any general statement concerning the thickness of the Ruth ore blanket. The block of ground developed by the mine workings is hardly more than 400 feet wide. Though on the third level ore of average grade has been exposed at the ends of six crosscuts, which trend north-northwest, between these workings and a line joining the nearest drill holes beyond there is an unexplored area more than 300 feet in width. North and northwest of this undeveloped area there are nine holes which show 50 feet or more of rock that contains more than 2 per cent copper, and of these nine holes four show from 95 to 150 feet of this material.

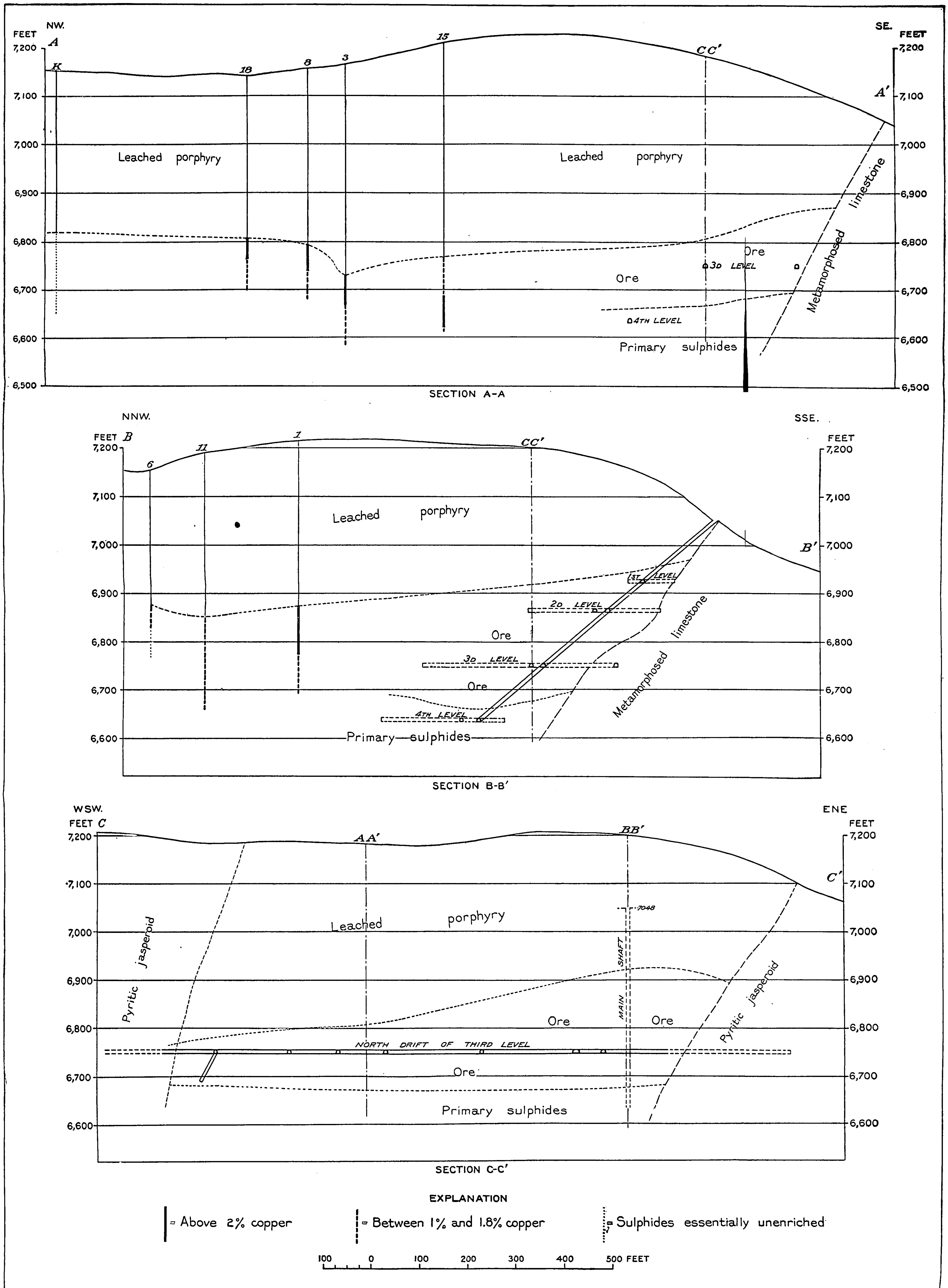
In hole 2, and also in hole 18, 150 feet of good ore was found, and assays of samples from the greatest depths showed, respectively, 2.2 per cent and 4.0 per cent copper. Another place where the full thickness of the ore may not have been determined is in hole 15. Here 85 feet of rock which averaged 2.5 per cent copper was penetrated. A sample of the third 5-foot section from the bottom showed 2.2 per cent copper, and samples from the two sections below showed 1.9 per cent and 1.4 per cent.

Within the block of ground developed by the workings from the Ruth incline the thickness of the enriched material that is regarded as being of workable grade appears to range from 100 or perhaps 120 feet in the western part of the mine to a local maximum of 250 feet in the eastern part. Though the ore top is approximately 200 feet higher in the vicinity of the shaft than it is in the western part of the mine, the bottom of the body of ore that carries say, more than 1.8 per cent copper does not exhibit a corresponding slope but is so nearly horizontal along a line parallel with the mine drifts that, though practically all of the third level workings are in ore of average grade, only subgrade material appears in the drift on the fourth or bottom level, which is 114 feet deeper than the third level.

In August, 1910, water was standing in the Ruth shaft at a point about 70 feet above the lowest mine level or at an elevation slightly less than 6,700 feet.

A chemical analysis of a composite sample of material from 5,000 feet of mine workings, made in 1904 by Herbert Ross,[1] showed, for the Ruth ore, copper 2.61 per cent, iron 6 per cent, and sulphur 5.34 per cent. If the assumption is made that the ore carries 0.6 per cent of chalcopyrite, corresponding with 0.21 per cent of copper, the copper remaining would allow for 3 per cent of chalcocite, and the sulphur then left would be sufficient for 8.5 per cent of pyrite.

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 337, 1906.



SECTIONS THROUGH ORE BODY AND MINE LEVELS OF RUTH MINE.

For position of sections see Plate XIII.

This calculation indicates that altogether the sulphide minerals in the average ore amount to about 12 per cent, but the estimate is not entirely satisfactory, because about 1.8 per cent of iron shown by the analysis is not provided for.

Extensive tests made in 1904 showed that in milling approximately 7 tons of the Ruth ore will furnish 1 ton of concentrates.

CHALCOCITE IN THE KIMBLEY HILL PORPHYRY MASS.

The rock of the intrusive mass that outcrops on the Kimbley and adjacent claims has been metamorphosed and charged with sulphides in essentially the same manner as the rock of the Ruth intrusion. Though churn-drill explorations have shown more or less enrichment of the primarily mineralized rock, beneath the oxidized capping the distribution of material that carried more than 1 per cent copper was found to be so irregular that it seems entirely unlikely that any of the chalcocite-bearing rock can be profitably mined.

MINOR PROSPECTS IN THE RUTH AREA.

Before the discovery of the body of porphyry ore in the Ruth mine, prospecting had revealed several occurrences of copper ore on claims now included within the Ruth group, and in one place a body of oxidized ore is reported to have been worked as a source of gold. Though these deposits do not offer any particular promise of commercial value, they are of interest in a consideration of the ore deposits of the district as a whole.

The material mentioned above as carrying gold occurs near the center of the Kellinski Hill claim. As seen in shallow workings the deposit appears to have been a gossan derived from a somewhat siliceous pyritic replacement body in limestone. Along the outcrop the ore has been excavated for a distance of perhaps 30 feet and the thickness of the deposit appears to have been from 2 to perhaps 6 feet. The ore layer strikes northwest and dips northeast, apparently at an angle of about 20°. Above the ore layer white marble is exposed, and the deposit probably conforms with the original bedding of the limestone. No information is at hand in regard to the assay value of this ore.

About 250 feet west of the common end line of the Blair and Pine Grove claims a jaspery vein from 1 to 3 feet wide has been opened by a shaft. The strike of this vein is nearly north and its dip about 65° W. The shaft is perhaps 50 feet deep, and though green copper minerals were found no lateral work was done, so that the conclusion is warranted that no body of ore was discovered. The wall rock is limestone that has been only slightly metamorphosed. Though the attitude of the bedding was not determinable, appearances indicate that this vein breaks across the stratification.

On the Blair claim, near the southwest corner of the Kearsarge claim, there is a shaft, 150 feet deep, which is inclined about 55° in a direction somewhat north of west. Immediately below the soil and to a depth of about 30 feet there are strong showings of copper carbonate, then for an additional depth of 60 feet the material is deep red, and below this green copper minerals appear and are more or less abundant to the bottom of the shaft. The gangue material is mainly rusty jasperoid that occurs in irregular layers, and in the lower half of the shaft there are large amounts of white clay. Because of the layered nature of the leached jasperoid and the presence of the white clay, which is probably kaolin, this deposit resembles the ore bodies of the Alpha mine in the western part of the district.

About 1,100 feet north of the Ruth shaft, near the center of the Copper Queen claim, a small body of rich copper ore was discovered a few feet beneath the surface. Though the ground in the vicinity is almost completely mantled by loose débris, this ore body appears to occur in jasperoid at a point about 100 feet from the east boundary of the Ruth mass of porphyry. Several tons of ore, estimated to carry at least 20 per cent copper, that had been piled near the shaft mouth, is said to have been mined in 1900. The ore is siliceous material that contains green and blue copper carbonates and probably some brochantite and cuprite. Though the shaft was not accessible in 1910, its depth is probably not more than 30 feet.

On the Sophie claim, 1,400 feet northeast of the Copper Queen shaft, there is a tabular body of jaspery material that occurs in slightly metamorphosed limestone. The rusty lodestuff outcrops at intervals for a distance of nearly 100 feet and shows thicknesses of 1 to 3 feet. The strike of the ledge is about N. 50° W., and its dip about 45° NE. Though the inclosing limestone is so massive that its stratification can not be definitely recognized, it seems probable that this deposit follows the original bedding. As shown by an inclined shaft, material that carries abundant azurite was found practically at the surface. Though the character of the workings indicates that several small pockets of ore were cut by the incline, there are no lateral workings to speak of and the lode appears to pinch out entirely at a depth of about 50 feet.

Though the metallic deposits of the Ruth area are essentially copper deposits, such as are characteristic of the central part of the metamorphic belt throughout the Ely district, the more northerly claims of the group extend beyond this central zone and take in part of the flanking zone, within which there are deposits of silver-bearing or silver and gold bearing lead ores. Ores of this general type have been mined from a vein on the Hayes claim, and there are minor replacement deposits of jaspery material that carries lead on the Specific, Clara, and Sunbeam claims.

ELY CONSOLIDATED GROUP.

LOCATION AND HISTORY.

The property of the Ely Consolidated Copper Co., which is situated south of the Ruth group of the Nevada Consolidated Co., comprises 19 claims and has an area of about 370 acres. The present outlines of the property are somewhat different from those of the group as it was constituted when the company was organized, in 1906, several of the more southerly claims having been acquired by purchase, and the Rising Sun, Northern Red Bird, and Famous claims having been relinquished to former owners. As a result of these losses the Brilliant claim is now surrounded by lands belonging to other interests.

During the year 1907 the property was under continuous development, and more or less exploratory work was carried on during each succeeding year to and including 1913. Though several lots of ore from the Zack and Brilliant mines have been shipped, at no period has either mine been a steady producer.

LOCAL GEOLOGY.

The area of the Ely Consolidated group is occupied mainly by Ely limestone, though the overlying Arcturus limestone is supposed to occur on the Zack claim and a small body of porphyry outcrops on the American claim. (See Pl. X.) Most of the claims of the group lie entirely south of the zone within which the rocks are affected by thorough metamorphism, but in the northern parts of the Zack and American claims and on the Brilliant claim the limestones are rather generally, though not uniformly, altered.

DEVELOPMENT AND ORE OCCURRENCES.

The principal development work on the Ely Consolidated property has been done on the Zack, American, and Brilliant claims.

The Zack shaft was opened to a depth of 435 feet in 1907. The materials penetrated are said to have been highly ferruginous, and at a depth of about 400 feet a body of copper carbonates was found from which a carload of 20 per cent ore was shipped in May, 1907. Explorations on the 400-foot level during the autumn of 1910 resulted in the development of some ore and the shaft was deepened to 500 feet. In 1911 ore was discovered at several places on or below the 500-foot level, and assays were reported to show from 3 to 9 per cent copper and from $1 to $3 in gold per ton.[1] Previous to December, 1913, the shaft had been carried down to a depth of 800 feet and levels had been opened at 600 and 700 feet. On the 600-foot level copper ore is said to have been found about 264 feet south of the shaft.

[1] Min. and Sci. Press, vol. 102, p. 642, 1911; vol. 103, pp. 61, 789, 1911.

As the Zack workings were flooded at the time when it would have been convenient to examine them, no detailed statement can be made in regard to the geologic features of the ore occurrences. The level of standing water is about 400 feet below the surface, which is approximately the depth at which the first ore was discovered. On the 400-foot level the ore carried only oxidized copper minerals, but in the lower workings some chalcocite occurred. Material collected from the mine dump in 1910 includes marble, pyrite-bearing garnet rock, jasperoid, and sericitized limestone. White clay, which is reported to occur in association with the ore minerals, is probably kaolin which has been derived from altered limestone that carried abundant sericite.

In the vicinity of the American shaft the limestones are generally somewhat metamorphosed, and several ledges and bunches of rusty jasperoid outcrop. The shaft is situated near the edge of a small body of porphyry which comes to the surface in the bed of a ravine. The shaft was opened to a depth of 520 feet in 1907. Jaspery material found during the progress of this work carries copper, lead, and silver. Water is reported to stand more than 100 feet above the bottom of the shaft.

North of the Brilliant shaft, on the City of New York claim, the limestones of the Ely formation have been altered to marble, garnet rock, magnetite, or jasperoid. At the surface on the Brilliant claim there are several bodies of jasperoid, but the intensity of the general metamorphism diminishes very notably from north to south, and in the southeast corner of the claim the limestone beds are essentially unaltered. In this immediate vicinity the strata strike nearly east and west and dip perhaps 40° N. Though the rocks exposed at the surface near and south of the shaft are only moderately metamorphosed, on the 400-foot level of the mine the limestones were thoroughly silicified and heavily charged with sulphides, not only at the shaft but toward the south as far as explorations had been made, so that here the movement of the solutions which caused the metamorphism was closely controlled by the stratification of the limestone formation.

The Brilliant shaft was sunk to its present depth, 625 feet, in 1907. In 1910 explorations were in progress on the 400-foot level, and at that time water was standing in the shaft about 35 feet below that level. All the accessible workings showed thoroughly metamorphosed limestone irregularly charged with sulphides, and a large part of the rock exposed was dense jasperoid that carries pyrite and very minor amounts of chalcopyrite. Small irregular bodies of massive pyrrhotite which carries irregularly distributed chalcopyrite are associated with the pyritic jasperoid. In workings west of the shaft a veinlike body of mixed sulphides had been discovered and somewhat extensively explored. This deposit, which, as seen, had a thickness of 2 to 8 inches, appears to follow the original stratification of the metamorphosed limestone. It carries pyrite, chalcopyrite, sphalerite, and calcite, the relative abundance of the several sulphides changing greatly from place to place. An assay of a sample of ore from this vein is reported to have shown 3.42 ounces gold and 12.60 ounces silver to the ton, and 13 per cent copper.

COPPERMINES GROUP.

LOCATION AND HISTORY.

The property here called the Coppermines group, consisting of 33 claims and fractions with an aggregate area of about 500 acres, lies north and east of the Ely Central group and north and west of the Ruth group.

Though ores carrying silver or silver and gold associated with lead were mined in the northeastern part of the area many years ago, no extensive developments were undertaken until 1906, when the claims of the group were segregated by the Ely Mines Co. The property was transferred to the Coppermines Co. in 1907 and to the Consolidated Coppermines Co. in 1913.

The Ely Mines Co. began active exploration in the summer of 1906, and within the ensuing year shafts had been opened on the Sunlight and Minnesota claims. The Coppermines Co.

continued development by means of underground work on the Minnesota and adjacent claims during 1907 and 1908, and by means of churn drills during 1909 and 1910. As a result of these and subsequent explorations a body of porphyry ore was discovered which in 1913 was estimated[1] to contain 1,900,000 tons of ore, the average copper tenor being 1.29 per cent.

LOCAL GEOLOGY.

As indicated on the geologic map (Pl. X), four of the sedimentary formations of the district occur within the area of the Coppermines group of claims, and in the eastern part of the area there are outcrops of porphyry. No exposures of rhyolite were noted at the surface, but this rock occurs in the mine workings on the Minnesota claim.

In the western part of the property, on the Herold and Sunlight claims, the Nevada limestone is more or less bleached and from place to place is rather coarsely crystalline. Though the rock is thus generally metamorphosed the stratification has not been entirely obscured, and from observations in several places it appears that the average direction of strike is toward the northwest and dips are from 45° to 60° SW. Within the area covered by this formation there are very few indications of metallic mineralization, but in two or three places shallow pits have disclosed small amounts of copper-stained material, and on the Burning Moscow claim a small pocket of chalcocite ore was encountered.

Two parallel ledges of dense jasperoid, from 25 to 50 feet wide and about 100 feet apart, occur on the Sunlight and Herold claims. These ledges may be traced more than 2,500 feet toward the northwest, in which direction they diverge somewhat and are accompanied by flanking and intervening ledges of the same material. All these tabular bodies appear to stand nearly vertical and they must have been formed as the result of replacement along a set of fractures that break across the stratification of the limestone. Though most of the jasperoid occurrences in the district present rusty outcrops, these bodies are almost free from iron stains, so that the conclusion may be reached that they originally contained little or no pyrite.

The Nevada limestone area is bounded on the east by a strong fault, beyond which the Chainman shale appears at the surface within an area from 250 to 500 feet in width. Material from several shafts (including the Sunlight shaft, said to be nearly 300 feet deep) shows that, though the shale is so slightly baked that it retains its characteristic black color, much of the rock is heavily charged with pyrite. The stratification of beds exposed in a pit on the fractional claim that lies south of the Sunlight claim strikes somewhat north of east and dips 60° SE. Though the dip of these beds conforms with that of the Ely limestone to the south of the shale area, to the north on the Sunlight and Herold claims the general attitude of the shale is probably more nearly horizontal.

The shale area is flanked on the east and south by limestones of the Ely formation. So far as exposed these rocks appear not to have received any noteworthy metamorphism, except in the vicinity of the boundary between them and the Chainman shale. Along or near this parting on the Sharon, Cliff, and Mabel claims there are rugged outcrops of iron-stained jasperoid that contain irregular cavities which were formerly occupied by pyrite.

As already noted in describing the Ely Central property the area occupied by the Ely limestone is supposed to be bounded on the southeast by a fault which trends northeastward across the Intervention, Mabel, and Roy claims. Though the existence of this break has not been fully demonstrated, east of the fault trace, as mapped, there are prospect pits which contain yellow and red earthy materials, such as are known in other localities to result from the weathering of beds that belong to the Arcturus limestone, and fossils that serve to fully identify this formation occur on the Ely Central Tutweiler No. 1 claim and on the Vanderbilt claim of the Coppermines group.

Along the northwest side of the Arcturus area dips observed at two localities are toward the southeast. Along the eastern boundary the attitude of the bedding is not definitely determinable, but as the Ely limestone, which lies stratigraphically below the Arcturus,

[1] The Coppermines merger: Min. and Sci. Press, vol. 106, p. 889, 1913.

appears to the east the general structure in this vicinity is evidently synclinal. (See Pl. II, in pocket.) The brilliant coloring of the decomposed materials that have been exposed in shallow pits at several places is not regarded as an indication that the unweathered rocks are charged with pyrite.

Immediately east of the Arcturus area, on the Cuba, Phoenix, and October claims, the limestones of the Ely formation are essentially unaltered, but as the porphyry intrusion is approached these rocks are more or less bleached and locally they have been marbleized or changed to a soft white material rich in sericite, and in a few places nests of garnet have been developed in them. Compact bodies of massive jasperoid, most of them small, outcrop from place to place within the area of general bleaching, and beyond this area, on the Tin Cup, Cuba, Phoenix, and Hayes claims, there are veins and bed deposits from which silver or gold-bearing lead ores have been mined.

The limestones immediately surrounding the porphyry intrusion are known from the underground workings to be irregularly silicified and generally charged with pyrite, but because the surface is almost entirely mantled by loose débris the areal distribution of these pyritic materials can not be accurately delimited. Samples of the pyritic limestone which were assayed during the progress of exploration work are reported to have contained from 0.1 to 0.5 per cent of copper.

The porphyry that occurs on the Butcher Boy and Minnesota claims is part of the mass which outcrops mainly on the claims of the adjacent Ruth property. Though the limits of the porphyry area are not everywhere accurately determinable from a study of the surface, it is believed that the outlines shown on Plate X are substantially correct, and that the extent of the area within which this rock appears at the surface on the Butcher Boy and Minnesota claims is not more than 8 or 9 acres. It should be noted, however, that in the mine workings the porphyry was found from 200 to 250 feet farther west than at the surface, also that porphyry ore is reported to occur beneath a capping of rusty jasperoid near the east end of the Minnesota claim, so that the extent of the porphyry mass evidently increases at lower and lower levels.

PORPHYRY ORE IN THE MINNESOTA MINE.

In 1910 the underground developments on the Minnesota claim comprised tunnel workings, which amounted to about 1,300 feet, and a shaft 230 feet deep, which had 1,800 feet of lateral workings on the 215-foot level. These workings are mainly in altered limestone or in a soft gougy material which passes under the name "gumbo." That this gougy material is decomposed rhyolite is known from the fact that all of it carries minute crystals of quartz, such as are characteristic of the rhyolites of the district.

On the tunnel level it is evident from the brown color of the weathered materials that all the limestone formerly contained pyrite, and locally unoxidized remnants of this mineral may be observed. On the 215-foot level the limestone is for the most part heavy with pyrite.

Leached porphyry was found in the most easterly workings on the tunnel level. There were showings of copper minerals in several places, and explorations below the level revealed some sulphide ore that carried about 2 per cent copper.

On the 215-foot level very little thoroughly weathered material was found, and here, in two crosscuts about 450 feet apart, the edge of the porphyry mass is farther to the west than on the level above. The more southerly of the two crosscuts that trend eastward from the shaft bed entered the porphyry for a distance of 300 feet.

Though the rock exposed is cut by veinlets of quartz and is thoroughly pyritized, the presence of chalcocite was first noted about 180 feet from the contact and just beyond a strong, nearly vertical fracture which apparently strikes toward the north-northeast. The body of enriched material, which is here about 100 feet wide, is limited toward the southeast by porphyry, which, as exposed in two places, is seen to be almost free from sulphide minerals.

At the time the observations were made, upon which these notes are based, 16 holes had been drilled for the purpose of exploring the porphyry ground in the vicinity of the Minnesota workings. Although five of these holes are situated within the area of the porphyry outcrop, and eight others are believed to have penetrated the mass of intrusive rock at different depths, material that carried sufficient copper to warrant its classification as ore was reported from only four holes. Records of 10 of these 16 holes show that the materials penetrated are fully oxidized to depths ranging from 200 to 450 feet, or down to an extremely irregular surface ranging in elevation from 6,770 to 6,880 feet. The position of standing water, as noted in the records of five holes, corresponds with elevations between 6,560 feet and 6,620 feet.

PHOENIX AND HAYES VEINS.

The Phoenix and Hayes veins carry complex ores mainly valuable for silver or for silver and gold. The veins belong to the general type of cross-breaking replacement veins, but parts of the lodestuff may have been deposited in open spaces. Associated with the Phoenix vein there are bodies of ore that conform with the stratification of the limestone country rock.

The Phoenix is a nearly vertical vein which strikes nearly east and west and which may be traced at the surface for a distance of perhaps 150 feet. The following description is quoted from Lawson: [1]

> On the Phoenix claim a considerable amount of development work has been done and the character of the deposits can to some extent be observed. The ores are for the most part distributed along the planes of bedding in the limestone. The latter is inclined at low angles (18° to the northeast) and mineralization has occurred at different stratigraphic horizons one above another. These successive sheets of ore are connected with one another by a vertical, mineral-filled fissure, and the tabular deposits so connected seem to pinch out at no great distance from the vertical vein. The tabular deposits near the vertical vein vary from 1 to 3 or 4 feet in thickness and the vertical vein was at one place observed to be 2 feet wide; but both in the vertical vein and the tabular deposits parallel to the strata the thickness varies rapidly. The occurrence of the ores in the deposits is also, so far as could be observed, far from uniform. The prevailing color of the ore in the mass is light ocherous yellow and iron minerals appear never to have been abundantly represented in the deposits. The chief gangue is silica, which appears to be a replacement of the limestone, and the croppings on the surface resemble closely the quartz blout of the neighboring porphyry. Some of the limestone immediately adjacent to the deposits is of a dead-white chalky character and is somewhat slickensided; it resembles massive kaolin but effervesces freely with acid. The siliceous vein matter carries galena, a sample of which was found to contain 22.4 ounces of silver to the ton and $1.49 in gold. Besides the galena there are azurite, malachite, and chrysocolla in sparing quantities, a little cerusite, and considerable calamine. With the quartz of the gangue there are also chalcedony, opal, fluorspar, and calcite. There are also some dendritic films of manganese oxide.
>
> While in general the chief feature of the mineralization has been silicification there is abundant evidence of minor fracturing and crustification and much of this has occurred after the chief deposition of silica.

The Hayes vein strikes nearly east and west and dips steeply toward the south. The vein, which has a width of 2 to 8 feet, may be traced at the surface for nearly 150 feet, and the old workings are said to have had a horizontal extent of not less than 300 feet. The depth of the inclined shaft is supposed to be about 300 feet. The value of the ore in gold and silver is said to have been from $20 to $150 per ton,[2] and it contained lead, copper, iron, arsenic, and antimony. Though most of the veinstuff on the old dumps is cellular jasperoid, some white quartz and some fluorite were noted.

In 1873 the county assessor reported an output from this mine of 145 tons of ore valued at $22 a ton.

HIDDEN TREASURE GROUP.

The property of the Ely-Hidden Treasure Consolidated Mining Co. is situated north and east of the Ruth group, near the upper end of Lane Valley. The area of the group, which is about 65 acres, includes the Bedlam and Mineral City claims, two of the oldest mining locations in the district. Other old locations in the immediate vicinity are the Eureka and Cummings. Small amounts of ore, mainly valuable for silver and lead, were produced between 1870 and 1885. During 1909 and 1910 there was an output of about 800 tons of ore, which is said to have averaged 23 per cent lead and to have contained about 6.5 ounces of silver to the ton.

The claims of the group, which extend about three-fourths of a mile westward from the mouth of Red Gulch, cover part of the northerly side of the extensive porphyry mass of Kimbley

[1] Lawson, A. C., The copper deposits of the Robinson mining district, Nev.: California Univ. Dept. Geology Bull., vol. 4, p. 352, 1906.
[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, pp. 169, 171, 1873.

Hill and the whole width of a smaller body of the intrusive rock that lies to the north. (See Pl. X.) From the nature of the weathered material at the surface it is apparent that the rock of the larger porphyry mass was generally affected by metamorphism and that beneath the oxidized capping the altered porphyry carries disseminated sulphides. Although there are approximately 5 acres of this rock on the Ontario claim, it is not probable that this ground contains any commercially valuable body of enriched porphyry, for the results of prospecting on the near-by claims of the Ruth group have not been encouraging.

The rock of the more northerly porphyry intrusive is essentially unmetamorphosed where it has been exposed on the Point and Dixie claims, but materials from a shaft situated near the north side of the porphyry area on the Hidden Treasure claim show considerable alteration, and all the rock from a shaft situated near the south side line of this claim has been very completely metamorphosed and thoroughly charged with pyrite. Some of the rock from the more northerly of the two shafts just mentioned contains galena and fluorite, and these minerals occur also in narrow veins which cut the altered rock.

Within the Hidden Treasure area the massive beds of the Ely limestone are but slightly folded and dips are nearly flat or inclined 10°–30° SE. These limestones have not been generally affected by intense metamorphism, though heavy bodies of jasperoid occur within a zone about 100 feet wide adjacent to the larger porphyry mass, and there are minor occurrences of the same material from place to place along the north wall of the smaller intrusion.

The ores that have been mined from the Hidden Treasure ground have been mainly those carrying lead and silver, but some gold has also been produced. The deposits include veinlike replacements along vertical or steeply inclined fractures that cross the beds of the Ely limestone, and bed deposits that follow the stratification. Most of the veins trend slightly north of west. Some of the bed deposits are connected with well-defined veins, but others are not obviously related to cross fractures.

Only the weathered parts of the lodes have been mined. Though the ores are for the most part in a wholly oxidized condition, cores of primary sulphides are commonly found. Lead occurs mainly as cerusite, though locally anglesite and sulphate minerals containing iron and lead are abundant. Where zinc is present it occurs mainly as the carbonate smithsonite. Copper occurs in the form of carbonate minerals, but in most of the ores is present in but small amounts. Fluorite is a rather common gangue mineral.

The ratio of silver to gold in these ores is known to range from 8:1 to about 200:1. Assay records at hand show lead 5 to 20 per cent; iron 15 to 30 per cent; silica 12 to 20 per cent; silver 3 to 20 ounces, and gold 0.04 to 0.4 ounces to the ton.

Though no systematic study of these deposits was attempted, it appears from the old workings that the ores occur within the lodes in the form of shoots. Some of the ore bodies were from 3 to 4 feet wide, and it is reported that several of them were stoped out for distances as great as 100 feet.

WITCH GROUP.

The lands of the Ely-Witch Copper Co. comprise an area of about 54 acres that lies east of the Kimbley, Spion Kop, and Turkey claims of the Ruth group and is flanked on the north, east, and west by claims of the Jupiter and Wedge groups. The company was organized and the property was acquired in 1906. Development work was in progress during 1907, but, though some work appears to have been done in 1908, the mine was idle in 1909 and operations had not been resumed at the beginning of 1914.

The geologic features of the ground are similar to those of the Ruth and Jupiter-Wedge groups.

Mineralized porphyry occupies the west half of the Witch claim (see Pl. X), but as churn-drill explorations carried on by the Nevada Consolidated Co. within the same intrusive mass, only a short distance to the west, failed to reveal commercial ore bodies, this ground can hardly be regarded as of any great prospective value.

East of the large porphyry intrusion there are few exposures of rock in place, but the siliceous and rusty nature of the surface débris indicates that here the limestones have been very generally and very intensely altered. The 300-foot shaft situated on the Witch Gore claim appears to have penetrated materials that were in a fully oxidized condition, but some of the lateral workings found rock heavily charged with sulphides, and material seen on the mine dump in 1910 included several tons of ore composed of granular magnetite, pyrite, chalcopyrite, and chalcocite.

JUPITER-WEDGE GROUP.

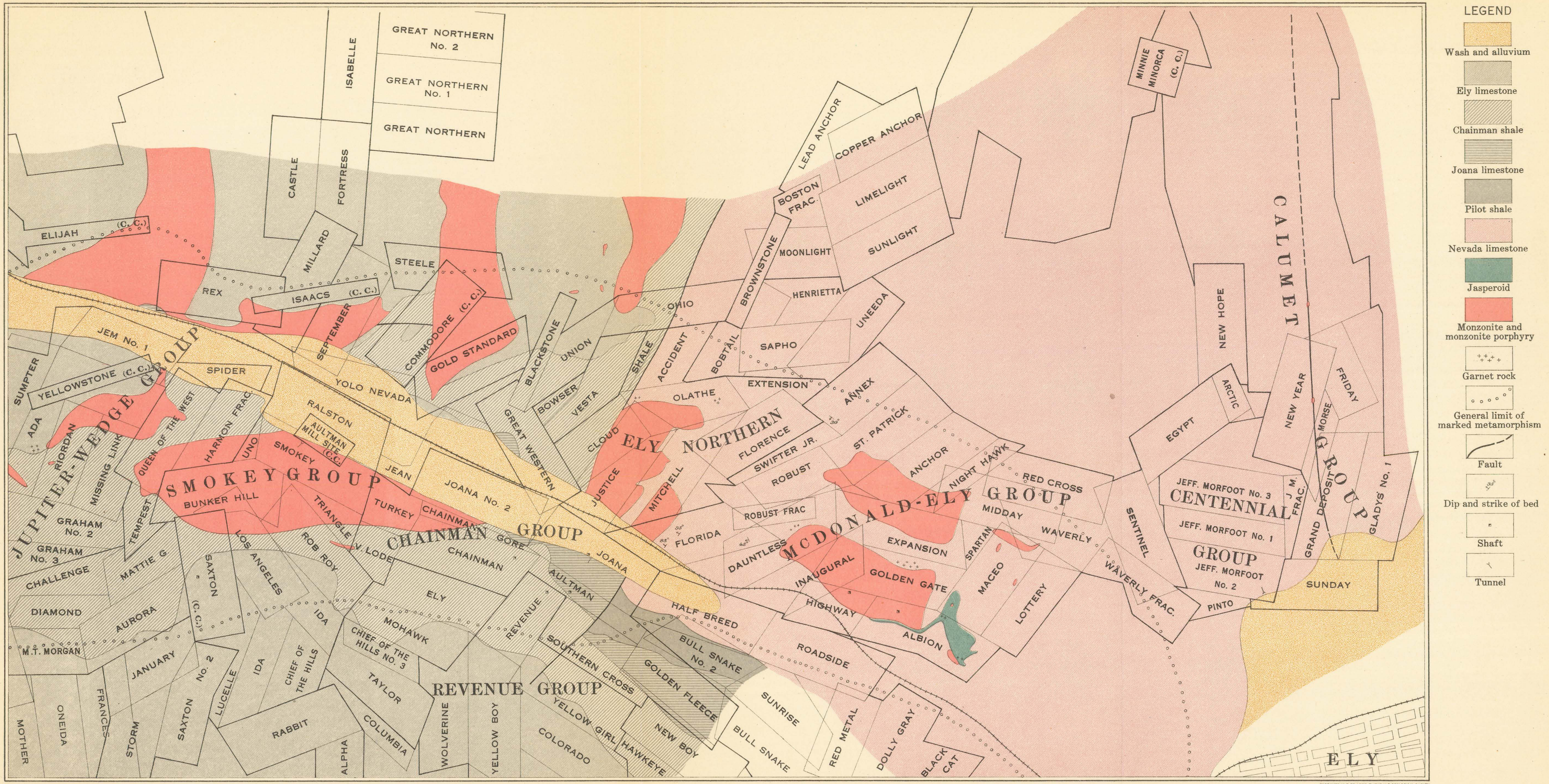
The property here called the Jupiter-Wedge group, which adjoins the Hidden Treasure, Witch, and Ruth groups on the west, comprises 22 claims and fractions which have an aggregate area of perhaps 260 acres. The property was brought together by the Cumberland-Ely Copper Co. in 1905, and though rather extensive explorations were carried on during the two years following, practically no development work has been done since 1908. In 1910 these lands, together with the Puritan and Veteran groups, came under the ownership of the Nevada Consolidated Copper Co.

The rocks of this group of claims comprise porphyry, limestone, and shale. In the main they are thoroughly metamorphosed, and from the prevalence of iron-stained material at the surface it is evident that where altered they carry much pyrite deeply stained by brown iron oxide. The principal alteration product of the Ely limestone is pyritic jasperoid, though bleached or marbleized limestone outcrops in a few places, and underground workings on the Jupiter, Cumberland No. 2, and Ada claims have disclosed the occurrence of garnet rock that carries abundant pyrite, usually more or less chalcopyrite, and here and there some magnetite. To a very large extent, the jasperoid masses occur in the form of upright ledges that present sharp walls against limestone, and several of these ledges are traceable for distances of several hundred feet. As represented on Plate X the distribution of the jasperoid has been very much generalized. The compact area between the Jupiter and Rosa Lee claims on the south and the Racine and Sumpter on the north has been shown as occupied by this material, because although outcrops are absent the surface débris consists almost entirely of rusty jasperoid fragments.

Copper carbonate ores are said to have been mined from old workings on the Cumberland, Cumberland No. 2, and Jupiter claims, but extensive explorations from a shaft known as the Jupiter shaft, situated on the Cumberland No. 2, are reported to have been almost entirely in materials that carried only unweathered sulphides. Though rock that contained considerable chalcopyrite was found, it appears that no commerical ore bodies were discovered. The results of several hundred feet of explorations from the Ada shaft appear to have been likewise unpromising, though here, too, much of the altered limestone carries irregularly distributed chalcopyrite.

The shales of the Chainman formation, which occupy the east central claims of the group, are everywhere thoroughly baked and charged with sulphides. As outcrops are few the indicated position of the boundary between the shale and the overlying Ely limestone (see Pl. X) is undoubtedly subject to correction in many places.

The porphyry intrusions that have been noted within the limits of this property occur in the northern or Wedge section of the group. In addition to the masses which cover several acres on the Wedge, Rex, Racine, Riordan, Missing Link, and Nellie Harmon claims, three or four smaller bodies have been noted in the same general locality and it is probable that other minor intrusions have escaped observation. South of Lane Valley, so far as excavations have been made in the porphyry, the rock appears to have been generally metamorphosed and charged with pyrite, and explorations by means of shafts which penetrate the two large intrusions have shown that, locally at least, it carries chalcopyrite and has been enriched as the result of chalcocite deposition. Development work on the Missing Link and Nellie Harmon claims is said to have disclosed no compact body of chalcocite porphyry, but on the Wedge claim several thousand tons of porphyry ore, which carries more than 2 per cent copper, were developed in 1907. North of Lane Valley, the porphyry on the Rex claim has been but slightly metamorphosed, so that here there is no reason for expecting the occurrence of disseminated chalcocite.



Base adapted from map of the Robinson mining district by Ed. Millard & Son.

CLAIM MAP SHOWING GEOLOGY ALONG THE EASTERN PART OF THE PRINCIPAL ZONE OF INTRUSION AND METAMORPHISM, ELY, NEVADA

500 0 500 1,000 1,500 2,000 2,500 Feet

1916

QUEEN OF THE WEST GROUP.

The Queen of the West property of the Federal-Ely Copper Co. comprises three fractional claims which lie between the Wedge and Smokey groups.

In 1910 the principal development work consisted of a shaft 110 feet deep on the Queen of the West claim, from which a small amount of lateral work had been done.

The rocks at the surface are porphyry and metamorphosed shale, both of which at comparatively shallow depths are generally charged with pyrite. Though secondary chalcocite was noted in some of the mineralized porphyry from the mine workings, the conclusion seemed to be warranted that no extensive body of enriched material had been encountered. From the position of the shaft it is thought that the workings penetrated only the porphyry mass which entered the claim from the west, and that the larger body of this rock, which occupies an area of several acres on the southeast corner of the Queen and in the southern part of the Harmon claim, has not been explored at all.

SMOKEY GROUP.

The lands of the Smokey Development Co., which were formerly owned by the Turner-Ely Copper Co. and the Williams-Ely Copper Co., are situated on the south side of Lane Valley about 2 miles west of Ely. The group comprises 12 claims and fractions and has an area of about 175 acres.

The claims of the group extend from the tracks of the Nevada Northern Railway toward the south for a distance of about 4,000 feet. On the north the Ralston claim lies entirely within the flat of Lane Valley, and though its surface is completely hidden by the loose material which floors this valley, shale was encountered in a drill hole situated about 200 feet north of the common side line of the Smokey and Ralston claims. South of this shale an area of 55 acres or more is occupied by mineralized porphyry, which is part of a mass that extends westward upon the Queen of the West claim, and eastward upon the Chainman group. (See Pl. XV.) During 1912 this porphyry mass was prospected by means of churn drills, and seven holes were put down. The records of these holes showed that the porphyry is generally pyritized and in places has been enriched by the deposition of chalcocite. A tunnel driven across this eastward-trending mass of porphyry in 1913 traversed 300 feet of ferruginous weathered porphyry, then 250 feet of chalcocite-bearing rock, and beyond this, to a point 1,200 feet from the portal, heavily pyritized but unenriched porphyry that contained numerous seams of calcite. Immediately south of the mineralized porphyry material which appears to have been originally shale is heavily charged with pyrite, and a sample of material from a point 45 feet south of the porphyry wall is composed of dense pyritic hornstone probably derived from shale.

The preceding notes are based on data and specimens furnished to the writer in July, 1913, by Mr. S. H. Williams, the president and general manager of the Smokey Development Co. In volume 11 of the Copper Handbook it is reported that the tunnel had been extended during the year 1913 to a total length of 1,700 feet, and that ore which carried 10 per cent copper had been discovered in the metamorphosed sediments south of the porphyry intrusion.

A study of the surface shows that the porphyry mass is bordered by Chainman shale both on the Triangle and Rob Roy claims and to the west on the Saxton claim, and though shale outcrops were not observed on the Los Angeles claim it is believed that there is here a strip of this formation perhaps 200 feet wide between the porphyry and the limestones that appear toward the south. From the distribution of the shale and of the limestone in this vicinity, it seems that the strata must dip very gently toward the south.

Rusty siliceous materials which occur along or near the parting between the shale and the overlying Ely limestone on the Rob Roy claim were formerly worked, it is said, as a source of gold, and there is an outcrop of copper-bearing material about 200 feet northeast of the southwest line of the Los Angeles claim, where the northernmost exposures of limestone occur.

On the Saxton and Los Angeles claims the limestones have been irregularly marbleized and there are outcrops of jasperoid at several places. Toward the south the general metamorphism becomes less and less noteworthy, but bunches of jasperoid occur, and on the Ida and Chief of the Hill claims there are veinlike bodies of jaspery lead ore.

On the Rob Roy and Smokey claims there are several strong springs, the highest one of which emerges near the contact of the shale and the porphyry at a point nearly 200 feet above the level of Lane Valley.

RABBIT MINE.

The property known as the Rabbit mine comprises the Rabbit and Alpha claims, which adjoin the Smokey group on the south. In this vicinity the Ely limestone shows no general metamorphism, but small deposits of lead ore which carries silver and gold have been prospected in several places.

At the Rabbit mine the limestone beds strike about N. 30° W. and dip at a low angle toward the southwest. The ore consists mainly of a mixture of lead carbonate and limonite, though in some of it galena and pyrite are present. The occurrence is in the form of an irregular bed deposit, apparently from 2 to 12 inches thick, which follows the parting between calcareous shales and an overlying stratum of massive limestone. Jasperoid, though present locally, is not a prominent feature of the deposit.

This ore horizon has been explored by means of a tunnel which trends southeast across the Rabbit claim and extends about 200 feet on the Alpha claim. Several lots of ore shipped in 1902 to 1904 are reported to have given average returns of about 0.8 ounce gold and 20 ounces silver to the ton and 50 per cent lead.

In addition to the workings noted above there are tunnel workings, which amount to about 800 feet, at a level about 100 feet lower, and the tow levels are connected by a winze.

CHAINMAN GROUP.

LOCATION AND HISTORY.

The Chainman group of 12 claims and fractions is situated in the eastern part of the district somewhat more than a mile west of the town of Ely. The greater part of the area lies south of Lane Valley, but the Joana and Joana No. 2 claims extend part way across the valley, and the Great Western claim covers a portion of the hillside to the north.

Six of the claims of this group were among the earliest mining locations in the district. The first production of ore appears to have been from the Aultman claim, which in 1873 was owned by the Canton Mining Co. and had been developed by a tunnel 750 feet long and by 11 shafts from 30 to 250 feet deep. In 1884 ore that carried $40 to the ton is reported to have been mined from shallow workings on the Joana claim.

In 1886 the Aultman mine was leased by W. N. McGill and associates, who located the adjacent Chainman claim and in 1889 organized the Ely Gold Mining & Milling Co. A stamp mill was erected by this company at Ely in 1889. The mine appears to have been worked more or less continuously until 1892. The total recorded production [1] for the years 1887 to 1892 was 4,472 tons of ore, which yielded bullion valued at $30,989.

In 1896 the property, which seems to have been by this time extended to cover all the claims now included in the group, was purchased under bond and lease by C. D. Lane, and during 1897 mine pumps were installed, a 10-stamp mill and a cyaniding plant were erected at the mine, and a hydroelectric power plant was built at Ely. Though a large sum of money was expended, the results of the work were not satisfactory, and in 1898 the option was relinquished.

During 1899 the mine and mill were operated by the Ely Gold Mining & Milling Co., but in the following year the property was sold to the Chainman Mining & Electric Co. In 1901 this company built a new mill,[2] which was operated from May to November, 1902. In 1907 the company was reorganized as the Chainman Consolidated Copper Co. and in the same year a new shaft was opened to a depth of 300 feet. In 1913 the property was transferred to the Consolidated Copper Mines Co.

[1] U. S. Geol. Survey Mineral Resources, 1887 to 1892.
[2] A wet-crushing cyanide plant at Ely, Nev.: Eng. and Min. Jour., vol. 72, pp. 753-755, 1901.

According to Mr. W. N. McGill, of Ely, who has been in close touch with the Chainman property for many years, the value of bullion produced between 1886 and 1902 amounted to not more than $300,000.

LOCAL GEOLOGY.

The formations that occur within the area of the Chainman group include the Chainman shale, the Joana limestone, the Pilot shale, the Nevada limestone, and a body of porphyry which is the eastward extension of the intrusive mass that occurs on the Smokey group. (See Pl. XV.)

The porphyry covers the greater part of the fractional Turkey claim, adjacent portions of the Chainman and Chainman Gore, and the southwestern part of the Joana No. 2; but the east end of the intrusion is hidden by the loose débris that forms the floor of Lane Valley. From the nature of material that outcrops on the Turkey claim it is known that in this vicinity the porphyry has been generally metamorphosed, but rock exposed in a road cutting near the southern boundary of the porphyry area on the Chainman Gore was found to be only slightly altered.

On the north side of the valley the shales of the Chainman formation are thoroughly altered and generally charged with pyrite. Here on the Great Western claim there are outcrops of greatly metamorphosed limestone, and though the stratigraphic identity of this rock is not actually known it is believed to belong to the Joana limestone.

South of the valley on the V lode, Chainman, and Ely claims, the shales have been moderately indurated, but they are not generally impregnated with pyrite, and the effects of metamorphism become less and less pronounced to the southeast.

The Joana limestone appears at the surface on the Aultman, Joana, Southern Cross, and Golden Fleece claims, and, as already noted, limestone exposed on the Great Western claim is supposed to belong to the same formation. On the Joana and Aultman claims west of the northeast-trending fault which is represented on Plates II and XV the heavy limestone beds have been affected by the most thorough metamorphism, being irregularly marbleized and silicified and locally strongly mineralized. East of the fault the limestones are not generally altered, but locally they carry bodies of jaspery material which have been prospected for gold. The most persistent deposits of this sort occur along the parting between the limestone and the overlying shale formation. The Pilot shale was penetrated in the Joana shaft, situated west of the fault, and the formation appears at the surface east of the fault on the Southern Cross, Aultman, and Joana claims. Immediately north of the Pilot shale area limestones that belong to the Nevada formation occur in the eastern part of the Joana claim.

JOANA GOSSAN ORES.

The body of metamorphosed Joana limestone on the Joana and Aultman claims contains large masses of limonitic gossan, which have been exposed by surface workings over the Joana claim, by a shaft on the Aultman claim, and by a tunnel about 700 feet in length. These gossans were doubtless derived from pyritic replacement bodies as the result of weathering.

No adequate conception can be gained in regard to the form or size of the replaced portions of the limestone, but east and west along the valley wall excavations show a continuous body of gossan for a distance of 400 feet, and in the Joana tunnel the width of the ground in which limonite was found is more than 600 feet. From the poor exposures it appears that these oxidized replacement deposits occur mainly in the lower part of the Joana limestone, which is estimated to be about 200 feet thick in this part of the district.

The section in the Joana tunnel measured by pacing shows limonite 190 feet, marble 120 feet, limonite 40 feet, marble 20 feet, and limonite 55 feet to the Aultman shaft. At the shaft the course of the tunnel changes from southwest to southeast and the workings continue in limonite for a distance of 270 feet. Beyond the limonite the tunnel passes through shale of the Pilot formation, which belongs stratigraphically below the Joana limestone but which has here been thrown up along the southwest side of a fault break that trends toward the northwest.

These gossan ores were used as flux in the smelting operations that were carried on during the early years of mining activity in the district, and it is reported that some shoots of ore that carried gold to the value of $10 to $100 to the ton have been found. Systematic sampling of the limonite bodies exposed in the Joana workings are reported to have shown from $1 to $3 gold, the iron ranging from 20 to 50 per cent.

The boss of limestone which occurs north of Lane Valley on the Great Western claim contains an irregular body of limonite that resembles the oxidized material of the Joana locality and like it carries some gold.

CHAINMAN MINE.

The most extensive precious-metal deposits that have been developed in the Ely district are those of the Chainman mine and of the adjacent property of the Ely-Revenue Copper Co. No adequate description of these deposits can be given, but the studies that could be made in abandoned workings, taken in connection with what is known of the general geologic features of the locality, are sufficient to show that they are replacement deposits which follow the stratification of the sedimentary formations in which they occur.

The deposits were discovered early in the history of the district, and the first mining was done near the west end of the Aultman claim. Here, as early as 1873, several shafts, said to be from 30 to 130 feet deep, had penetrated shale and encountered gray and yellow siliceous ore that carried lead carbonate. After 1886 workings were extended toward the west and south, and eventually the ore-bearing horizons were more or less extensively explored within an area measuring 800 feet from east to west and about 500 feet from north to south. Although the extent of the mineralized ground is probably considerably greater than would be indicated by these figures, most of the ore that was mined came from an area of less than 3 acres, which lies east and west of the common end line of the Aultman and Chainman claims. This ground was partly developed by means of an adit, known as the Aultman tunnel, and later by means of an inclined shaft. A vertical shaft was sunk to a depth of 300 feet in 1907, but no systematic mining has been done. In 1910 the position of standing water was estimated to be about 100 feet below the adit level, or about 75 feet below the surface of Lane Valley.

The workings had been so long abandoned that no systematic study of the mine was attempted, but from what was seen at accessible points it seems fairly clear that there are two mineralized horizons, one at the top of the Joana limestone and the other 20 or 30 feet higher in the Chainman shale.

Viewed in a broad way, the stratified rocks in this general vicinity lie nearly flat, but in the mine there is a noticeable dip to the west, and in detail the strata are warped or corrugated parallel with axes which plunge toward the west dip.

From a study of the mine map it appears that in the Chainman-Aultman workings the ore stopes in the two ore deposits were about equally extensive. Locally they appear to overlap, but most of the mining in the copper bed was south of the point where the lower bed proved to be most productive.

The ore bodies are said to have been in most places from 8 to 10 feet thick, though in the Revenue shaft the uppper deposit was formed in a siliceous stratum at least 20 feet thick. The stopes of the mine are all above the level of standing water, and the ores are said to have been almost entirely oxidized.

The better ores consist of spongy siliceous material that is gray or yellow from the presence of lead carbonate or of lead-iron sulphate minerals. Such ores have doubtless been derived from silicified limestone that carried distributed galena or galena and pyrite. Locally, where the lodestuff is highly ferruginous, which indicates abundant pyrite previous to oxidation, the precious metals are said to be relatively low as a rule. From one large stope in the lower of the two bed deposits the ore is said to have had a combined gold and silver value of $80 to $90 to the ton. Other stopes furnished rock that carried $40, but the general run of the ore appears to have been worth from $8 to $12.

On the north side and about 300 feet from the west end line of the Southern Cross claim, a mass of siliceous material occurs in the Joana limestone near the parting between this formation and the shales that outcrop to the south. At this place gold-silver ore has been mined from the surface to a depth of about 30 feet, and combined values of about $8 to the ton are reported. The workings are not extensive, so that the form of this siliceous mass can not be made out, but its stratigraphic position appears to correspond with that of the lower ore bed in the Chainman mine, and its occurrence may perhaps indicate that it would be worth while to explore this horizon in the adjacent ground to the south and west.

On the surface the boundary between the Joana and Chainman formations is hidden by a mantle of loose débris, but as the ore bodies found in the western part of the Aultman claim seem not to outcrop, it is supposed that this boundary coincides locally with the trace of a fault which courses northwest. The general position of the boundary can be made out, and its trend is essentially that of a line joining points in the Joana and Aultman workings where the existence of fault breaks may be noted. In the Joana tunnel the southerly block is uplifted, whereas in the Aultman tunnel it is depressed, so that the break appears to be what has been termed a scissors fault.

EXTENSION OF THE CHAINMAN DEPOSITS.

Although the history of the Chainman mine indicates that the aggregate expenditures which have been made by different companies in the development and operation of the property have exceeded the value of the bullion that has been produced, to the writer it appears not at all improbable that in the future bed deposits like these may be profitably developed.

One of the ore beds has already been found south of the Chainman group of claims, on the Ely-Revenue property, and there is no obvious reason why this deposit should not extend into the Ely claim, which lies west of the Revenue and south of the Chainman claims. It would seem that the same sort of selective metamorphism which is manifested in the deposition of the two ore beds in the Chainman locality may very well have produced similar deposits within the area north of Lane Valley, where baked and pyritized shales appear at the surface, and perhaps also within the shale area which lies west of the Saxton claim. Although the thickness of the Chainman shale in this part of the district is not accurately known, it is believed to be about 250 feet, and this would be the probable maximum depth at which shafts or bores starting in shale would reach the top of the Joana limestone.

The eastern of the two shale areas mentioned is regarded as more promising ground than the western, first because it is nearer the Chainman locality, and second, because here the deposits, if they exist, probably lie above the water table, and are likely to have been oxidized, as are those of the Chainman mine. In this general vicinity the average dip of the formations is supposed to be toward the south.

REVENUE GROUP.

The property of the Ely-Revenue Copper Co. is situated south of the Chainman group. It comprises nine claims and fractions and has an area of perhaps 140 acres.

These claims appear to have been segregated by the present company in 1907 and prospecting was immediately started. A shaft was sunk on the Revenue claim to a depth of 215 feet, and lateral workings were opened to the extent of about 1,000 feet. In 1913 no further development work had been done.

These lands are occupied by limestones and shales that belong to the Ely and Chainman formations. The limestones cover the more southerly claims of the group and the shales outcrop on the Revenue and Yellow Girl claims. Over the greater part of the area the rocks have not been affected by general metamorphism, but on the Revenue claim the shales are somewhat indurated, as they are on the contiguous Ely, Chainman, and Southern Cross claims.

The Revenue shaft penetrated indurated shale to a depth of 165 feet, where a silicified stratum was reached which appears to correspond with the upper ore bed of the near-by Chainman mine. At the shaft this body of siliceous material is about 30 feet thick, and its base has been explored by means of a drift, which extends for a distance of about 250 feet toward the southwest and approaches within 200 feet of abandoned ore stopes in the southeast corner of the Chainman claim. The material exposed in these workings is spongy silica essentially free from limonite. Though it is known to carry gold and silver, information is not at hand in regard to the distribution of these metals or the average grade of the ore.

ELY NORTHERN GROUP.

The lands of the Ely Northern Copper Co., which comprise nine claims and fractions, have a combined area of nearly 100 acres. The property lies north of the lower end of Lane Valley contiguous to the Chainman group on the south and the McDonald-Ely group on the east.

Some of the early smelting operations in the Ely district were based in part on ores derived from claims now included within the Ely Northern group, but no mining has been done for many years, and there has been no systematic prospecting since the property was brought together under the present organization in 1906.

The area is occupied principally by porphyry and by limestones that belong to the Nevada formation, but on the extreme west there are shales which belong to the Chainman formation.

On the Cloud claim of this group and on the neighboring claims to the west the shales have been very thoroughly baked and are charged with pyrite. On the Justice and Cloud claims the shale area is bounded on the east by an intrusive mass of porphyry, but farther north there is a strong fault, which has a northeasterly trend, along which the shales come into contact with the Nevada limestone. The displacement along this fault is probably more than 1,000 feet. West of the boundary between the shales and the porphyry the shales have been thoroughly baked and pyritized, but toward the north the intensity of the general metamorphism diminishes, and beyond the Ohio claim these rocks are essentially unaltered. The advisability of deep explorations within the area covered by the Chainman shale has been suggested on page 173.

The two porphyry masses that occur on the Cloud, Justice, Olathe, and Mitchell claims are believed to be essentially stocklike intrusions. These masses have not suffered the same thorough metamorphism that has affected all the porphyry bodies farther west along the principal zone of intrusion, but the rock exhibits incipient stages of alteration and contains more or less pyrite.

Within the limits of the Ely Northern group the normally dark-gray limestones have been rather generally, though irregularly, bleached and to a greater or less extent they have been rendered crystalline. In a few places garnet has been formed in the limestone next to or near the porphyry masses and elsewhere in the group there are minor bodies of jasperoid along the contacts.

North of the smaller and east of the larger porphyry mass rusty jasperoid occurs on the Mitchell, Olathe, and Florence claims. Some of these occurrences are mere bunches; others are more or less tabular masses and seem to conform to the original bedding of the limestone, and still others are veinlike bodies that appear to cross the stratification. On the Mitchell claim there are two irregular jaspery veins which have northeast courses. One of these veins is traceable for nearly 500 feet from a point near the center of the claim, and the other, in the northwestern part of the claim, is continuous for about 200 feet. Shallow workings along these lodes show maximum widths of 4 or 5 feet. All the veinstuff is rather ferruginous, and copper stains are noted in a few places. A vein of similar appearance occurs east of the porphyry area on the Olathe claim. Here the limestone beds dip toward the southwest, and as the vein courses northeast it was evidently formed along a fissure transverse to the stratification. This vein has a width of 1 to 6 feet, and it may be traced throughout a distance of about 300 feet. Near the northeast end of the line of outcrops copper ore has been mined from shallow workings.

On the Florence claim, about 500 feet southeast of the vein last mentioned, there is a strong showing of rusty jasperoid and of limonite on the crest of a prominent ridge. From shallow workings at this place considerable amounts of copper carbonate ores were produced many years ago. Inspection of the surface outcrops and of the old excavations suggests that the original sulphide body was formed by the replacement of limestone at a place where two nearly vertical fractures which have a northeast strike meet an eastward-trending fracture that dips toward the north. The two parallel fractures which flank the ridge are about 90 feet apart, and between them the principal segregation of lode matter occurred along the eastward-trending fracture. The ore body appears to have been about 50 feet long and to have had a maximum width of about 12 feet. The depth of the workings is about 35 feet. The eastward-striking vein is recognizable, though its width is diminished for a distance of about 150 feet west of the old stope. Toward the north there is more or less jaspery material along the northeast fractures for a hundred feet or more, but these veins do not appear south of the ore body.

McDONALD-ELY GROUP.

The property owned or controlled by the McDonald-Ely Copper Co. is situated in the eastern part of the Ely district. It comprises 28 claims and fractions that have an aggregate area of about 325 acres.

In November, 1898, gold ores from the Robust and St. Patrick claims were tested to determine whether they could be treated by the cyanide process,[1] and the results of this experimental work having been regarded as satisfactory, a milling plant of 50 tons daily capacity was completed in 1900 by the Ely Mining & Milling Co. In the meantime [2] this company (which appears to have been organized in 1899 or in 1900) had added the Florida, Dauntless, and Quadrant claims to its previous holdings and had developed the Robust vein by means of a tunnel and shaft.[3] The activities of the Ely Mining & Milling Co. were short lived and from the size of the pile of tailings at the mill it is evident that only a few thousand tons of ore were treated.

In 1906 the group essentially as now constituted was acquired by the McDonald-Ely Copper Co. and during 1907 and 1908 explorations were directed, though without success, to the discovery of commercially valuable copper deposits. Development work was again under way in 1913, and at the close of that year the workings on the property were reported [4] to comprise the Robust shaft, 165 feet; the Golden Gate and Mill shafts, 405 feet and 250 feet, respectively; three other shafts, from 65 to 80 feet, and a tunnel 415 feet.

The claims of the group cover the east end of the belt, which has been termed the principal zone of intrusion of the district. Two large and several small bodies of porphyry occur within the west two-thirds of the area and the Florida claim covers part of one of the two porphyry masses that have been mentioned in describing the geology of the Ely Northern lands. Aside from these intrusive rocks the only other formation represented in this general area is the Nevada limestone. (See Pl. XV.)

Though the rusty nature of many outcrops indicates that some of the porphyry carries a good deal of pyrite, it is evident, both from a study of the surface and from inspection of material from deep workings, that in this vicinity the porphyry masses are by no means as thoroughly impregnated with metallic sulphides as are those which occur along the principal zone of intrusion westward from the vicinity of Lane.

In several places next to or near the porphyry masses the limestones have silicate and sulphide minerals developed in them or they are changed to sulphide-bearing jasperoid.

Within a zone 3,000 feet or more in width from southwest to northeast the limestones have been bleached and crystallized, and this zone of alteration extends toward the southeast for a distance of fully half a mile beyond the large porphyry intrusions.

The metalliferous deposits which have been worked or prospected within the limits of this group include those of copper, lead-silver, and gold.

Although some rich copper ore was discovered during the development of the Robust gold vein in 1898, and though there are surface showings of copper carbonate minerals on several of the claims, no extensive explorations for copper ore were made until 1907. During this and the following year the Golden Gate shaft, situated on the Albion claim, was sunk to

[1] Min. and Sci. Press, vol. 77, p. 534, 1898.
[2] Idem, vol. 82, p. 42, 1901.
[3] Idem, vol. 80, pp. 436 and 675, 1900.
[4] Weed, W. H., The Copper Handbook, vol. 11, p. 570, 1914.

a depth of 405 feet. According to Mr. A. J. McDonald,[1] under whose management this work was done, after penetrating 80 feet of porphyry the shaft entered white limestone in which occurred bunches of copper ore that carried from 20 to 40 per cent copper and from $2 to $4 gold to the ton. The shaft continued in altered limestone to a depth of 230 feet, below which the rock was porphyry to the bottom.

South of the Golden Gate shaft the porphyry is seen at the surface to be bordered by rusty jasperoid, which outcrops as a prominent ledge from 10 to 50 feet wide. This ledge is traceable from a point near the west end of the Albion claim 600 feet eastward along the south wall of the porphyry intrusion, and then 300 feet toward the northeast to a junction with a larger body of limestone alteration products, which covers an area of several acres on the Albion and Maceo claims. Prospect pits within this area have disclosed greatly weathered materials that consist mainly of jasperoid, garnet, and limonite, but contain bunches of copper carbonates at several points. All these materials are very ferruginous, so that beneath the weathered capping the altered rocks must be thoroughly impregnated with sulphides. In 1910 no explorations had been made beneath these extensive outcrops of mineralized limestone, but this ground is reported to have been the object of development work undertaken in 1913.[2]

Small and irregular jaspery veins or bed deposits which occur at several points on the Red Cross, Midday, Waverly, and Sentinel claims carry silver-bearing lead ore. The only noteworthy development of a lode of this sort has been on the Sentinel claim. Here there is a bed deposit, now thoroughly oxidized, which follows a parting between two beds of massive limestone. The strata dip toward the south about 20°, and the intersection of this parting with the ground surface may be followed for nearly 1,300 feet, as a curving line marked by outcrops of limonite or of iron-stained jaspery material. The apex of the lode lies on a prominent north-south ridge and the length along its strike appears to be about 700 feet. It has been explored by a slope about 300 feet long, which follows the dip. An adit about 100 feet long connects with the bottom of this slope.

The lode matter is in part more or less siliceous spongy limonite and in part soft yellow sulphate ore, which carries lead and iron. The limonitic portions of the deposit are locally as much as 3 feet thick. The distribution of the lead ore appears to be very irregular, and where present the ore layer as a rule has a thickness of only a few inches. No data are at hand concerning the metallic content of the ore which has been mined

The gold ores produced by the Robust mine came from a vein which has been opened by means of a shaft 165 feet deep and a connecting adit about 300 feet long. The workings on the vein extend nearly 800 feet from the shaft toward the northeast. This vein probably belongs to the general class of replacement veins, but as only its oxidized portions have been explored its original characteristics can not be satisfactorily recognized, and the possibility is open that it was formed in part by the filling of an open fissure. Though jasperoid occurs from place to place, the ore as a whole appears not to have been very siliceous, and the original vein matter may have been composed largely of pyrite, perhaps in a gangue of calcite. The attitude of the vein is nearly vertical, and it evidently crosses the bedding of the inclosing crystalline limestones, which, though obscure, appears to strike northwest and to dip toward the southwest. The width differs greatly from place to place but is said to have averaged about 5 feet in the mine workings.

Evidence that the vein has served as a channel through which surface waters have passed is seen not only in the complete oxidation of the original sulphides but also in the presence of several open chambers. One of these caves is said to have been 200 feet long and more than 50 feet high. In caves that extend out into the bedding of the limestone the walls and roof are coated with beautifully crystallized white aragonite.

CENTENNIAL GROUP.

The lands of the Centennial Development Copper Co. comprise five claims and fractions which aggregate about 75 acres. The property is situated a short distance north of the town

[1] Oral communication.

[2] Weed, W. H., The Copper Handbook, vol. 11, p. 570, 1914.

of Ely and between the McDonald-Ely and the Calumet-Ely groups. The present company was incorporated in 1911 as the successor of the Ely-Centennial Copper Co.

Limestones of the Nevada formation are the only rocks within this area. Though not strongly or even generally altered, these limestones are locally bleached and in places exhibit a minor degree of crystallinity or are somewhat silicified. The strata have a general northeast strike and dips are at moderate angles toward the southeast.

The basis for the explorations which were made on this property during 1910, 1911, and 1912 is the occurrence at several places of irregular bodies of more or less jaspery gossan, some of which carry copper carbonate minerals and in two of which shoots of chalcocite ore were found near the surface. In a 2,000-foot tunnel, driven toward the north from a point on the Jefferson Morfoot No. 1 claim, several streaks and bunches of sulphides were disclosed, and it is reported that oxidized copper ores also occurred.[1] Lateral workings were opened to develop some of the ore streaks, and a 200-foot winze was sunk.[2] During 1913 mining of small ore bodies was being done by lessees.

CALUMET GROUP.

The lands of the Ely-Calumet Copper Co. are situated north of the town of Ely in the extreme eastern part of the zone within which metalliferous deposits are known to occur. The 22 claims of the group occupy an area 8,600 feet long from north to south and from 1,200 to 2,000 feet wide from east to west.

Though not generally metamorphosed to any noteworthy degree, the limestones of the Ely formation have locally lost their normal dark color, are greatly broken and fissured, and have been penetrated by mineralizing waters, so that here and there they have been to a certain extent silicified and in places metalliferous replacement deposits have been formed in them.

The area is traversed by a strong northward-striking fault, the existence of which is recognized by the fact that the limestone beds to the east and to the west show very divergent strikes and dips. On the east the general or average strike is toward the northwest and dips range from 20° to 40° toward the southwest, whereas on the west side of the fault the strikes are generally toward the northeast and dips toward the southeast.

Throughout the Ely district it is generally difficult to indicate the actual position of faults and throughout the greater part of its length the break here under consideration offers no exception to this rule. In most places the rocks immediately adjacent to the fault are not exposed, and though in its vicinity the limestones are much fissured, in general they are not greatly brecciated. At two places, on the Alta and New Year claims, the position of the fault is marked by narrow dikes of rhyolite, and on the Grand Deposit claim there is an obscure outcrop of weathered porphyry only a few feet east of the place where the fault is supposed to be located.

A short distance south of the porphyry exposure there are heavy outcrops of gossan, and at this place considerable amounts of copper carbonate ore are said to have been mined from old workings, which in 1910 were about 30 feet deep. From what can be seen at the surface the original or unoxidized deposit appears to have been formed by the replacement of the limestone along a spur which diverges from the main fault toward the southwest. The lode matter may be traced for a distance of perhaps 150 feet in a southerly direction from the supposed junction.

Since 1910, when the foregoing notes were made, considerable work has been done in the way of developing the Grand Deposit and adjacent claims; shafts have been sunk on the Gladys and Sunday claims, and several hundred feet of laterals have been opened. Both lead and copper ores are said to have been disclosed in these workings.[3]

Copper ores have been mined by lessees from shallow workings on several of the claims in the northern part of the group, but none of these deposits appears worthy of extensive development.

[1] Min. World, vol. 33, p. 1119, 1910.
[2] Min. and Sci. Press, vol. 103, p. 61, 1911. Weed, W. H., The Copper Handbook, vol. 11, p. 222, 1914.
[3] Weed, W. H., The Copper Handbook, vol. 11, p. 346, 1914.

OUTLYING CLAIMS OF THE CONSOLIDATED COPPERMINES CO.

HISTORY.

When the original Coppermines Co. was organized in 1906 it took over the lands of the Ely Mines Co., which in this report has been called the Coppermines group, and several scattered claims, most of which were acquired from the Willard-Ely Copper Co. The Willard-Ely Co. appears to have been the direct successor of the McKinley Mining & Smelting Co., organized in 1901, which in turn had succeeded the Canton Mining Co., which was active as early as 1871. As a result of the merger effected in 1913 these properties now belong to the Consolidated Coppermines Co.

CARBONATE AND ELDORADO CLAIMS.

The Carbonate and Eldorado claims, which were among the earliest mining locations in the district, are situated south of the Nevada Consolidated Liberty pit. The locations appear to have been based on the occurrence of irregular jaspery veins, which are presumed to have carried lead as the principal metal. Although ores from the Carbonate claims are reported to have contained silver and gold to the value of $100 to the ton, it is evident that neither of the two properties was ever extensively worked.[1]

BADGER CLAIM.

The Badger claim is situated south of the Copper Flat pit of the Nevada Consolidated Co. In the northern part of the claim the Ely linestone shows a moderate degree of crystallinity, and immediately to the east and north there are evidences of more intense metamorphism in the occurrence of prominent ledges of jasperoid and a few nests of garnet rock.

Within the area of moderate rock alteration occurs a vein of silver-lead ore from 1 to 2 feet wide. The vein strikes about N. 45° W. and dips about 65° NE. It may be traced by means of local outcrops for a distance of nearly 500 feet, and it has been developed by underground workings for perhaps half this distance. The depth of these workings is about 100 feet. Though the greater part of the ore that has been produced is said to have been entirely oxidized, specimens of galena were collected from the mine dump. Portions of the ore are red or yellow from the presence of iron compounds, but other portions carry sufficient manganese to render them almost black. Nine samples taken to represent ore exposed in the mine (in 1907) are reported to have shown 14 to 39 per cent of lead, 1 to 4.5 ounces of silver to the ton, and a small amount of gold.

CUMMINGS CLAIM.

The Cummings claim is situated south of the upper end of Lane Valley. Though the greater part of the area is covered by loose débris the distribution of porphyry in the vicinity indicates that this rock occupies the south half of the claim. The only exposures of rock in place are found in shallow prospects or mine workings along a steep bank on the east side of Ruth Gulch. These workings have disclosed yellow and red earthy materials which evidently have been derived from thoroughly metamorphosed limestone masses. The extent of the old workings indicates that considerable mining was done, and, though no record of production has been found, the claim bears the name of one of the early operators in the district and the ores were probably worked as a source of gold.

YELLOWSTONE CLAIM.

The Yellowstone claim is situated east of the Cummings on the south side of Lane Valley. Though several bodies of intrusive porphyry occur in this vicinity, the limestones where exposed are very irregularly metamorphosed. In the central part of the Yellowstone claim the rock is rather crystalline, but different layers exhibit different degrees of alteration, so that it is here

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1870, p. 158, 1872.

possible to recognize that the stratification strikes somewhat north of east and dips toward the northwest. The mineral lode which appears to have been the object of this location has been explored only by shallow trenches. It is a narrow and irregular deposit, apparently conformable with the stratification of the limestone. The fully oxidized material seen at the surface is reported to carry lead and silver. Most of it is black from the presence of manganese oxide.

SAXTON CLAIM.

The Saxton claim is situated south of Lane Valley and about 1,800 feet southwest of the Yellowstone claim.

The north third of the claim is occupied by metamorphosed porphyry and shale, both of which appear at the surface in a greatly weathered condition, and the remainder of the area shows bleached and more or less marbleized limestone that carries irregular bodies of jasperoid.

In 1901 the development of this property was undertaken by the McKinley Mining & Smelting Co., and more or less work was done during this and the following year. In 1903 the mine was examined by J. A. Snedaker, who states [1] that the shaft was then 385 feet deep and had lateral workings on the 120 foot level, 613 feet; 212 foot level, 290 feet; 300-foot level, 410 feet. The 120-foot and 212-foot levels were reported to have exposed oxidized material that carried small amounts of copper, gold, and silver, and on the 212-foot level nuggets of copper were found. A series of assays of material from the 300-foot level showed copper 1.68 per cent and gold 0.06 ounce to the ton. Stringers of ore carrying from $40 to $140 in gold are said to have been found and on the 300-foot level the occurrence of ore carrying 4.5 per cent copper and gold to the value of $5 to the ton was reported.[2] The material on the mine dump includes silicified and pyritized limestone and shale that is more or less thoroughly charged with pyrite. Though chalcopyrite is present in some of the altered rock, on the whole it appears to be by no means abundant.

ELIJAH CLAIM.

The Elijah claim is situated north of the upper end of Lane Valley and about 1,600 feet north of the Yellowstone claim. The location was made in March, 1868, and in 1874 the mine was credited with an output of 400 tons of ore, which yielded bullion valued at $17,500.

The area of the claim is occupied by limestone and by porphyry, which occurs in the form of an apparently thick sill, the top of which conforms with the bedding of the limestone. The strata dip gently toward the southwest, and as the trend of the claim is east and west, parallel with the general contour of the hill slope, the parting between the two sorts of rock rises toward the east-northeast and runs diagonally across the claim. In this immediate vicinity the porphyry has been metamorphosed to the extent of having calcite and epidote and a little pyrite developed in it, but the degree of alteration is comparatively slight. The limestones in the vicinity are not generally altered, though along the immediate contact small amounts of garnet or other silicate minerals are present.

In 1910 the mine was being worked by lessees, whose operations were based on ore said to carry 20 to 30 per cent of lead, and an average of about 16 ounces silver and a maximum of 0.5 ounce gold to the ton. The lead occurs as galena or as the carbonate, and certain specimens which were examined in detail contained small amounts of wulfenite, the molybdate of lead. The gangue is mainly jasperoid, but in places fluorite is present in considerable amounts.

The outcrop of the deposit shows an interrupted vein, two sections of which may be traced along a general eastward-trending course for 175 and 375 feet respectively. Between these sections, for a distance of 400 feet, the vein is capped by a massive layer of limestone. In the mine workings, which in 1910 were about 60 feet deep, the vein dips steeply toward the north. Just beneath the cap rock a body of veinstuff projects into the stratification, so that a cross section of the deposit resembles a long-stemmed mushroom having a thick arching cap. The width of the nearly upright vein ranges from a few inches to 2 or even 3 feet.

[1] Snedaker, J. A., The McKinley Mining & Smelting Co., pamphlet, 16 pp., 1903.

[2] Min. and Sci. Press, vol. 84, p. 142, 1903.

In the eastern part of the mine ore has been stoped from irregular bed deposits which occur both south and north of the vein. In most places there is a single ore layer, but locally two layers, which had about 18 inches of limestone between them, were noted. These bed deposits occur within a few feet of the top of the porphyry sill. The greatest thickness observed was about 6 inches.

ISAACS CLAIM.

The Isaacs claim is situated on the north side of Lane Valley about 1,500 feet east and south of the Elijah. Like the Elijah it is one of the oldest mining locations in the district.

The geology is very similar to that of the Elijah claim, the area being occupied principally by limestones that border a porphyry intrusion which covers the hill slope to the south. The porphyry mass connects with the sill, which is exposed toward the west, but in this vicinity the contact with the limestones appears to be nearly vertical. As is indicated on Plate XV porphyry occurs on the southwest corner of the claim, but for the most part the northern boundary of the porphyry area lies a short distance south of the south side line of the claim. The attitude of the limestone beds is nearly horizontal.

The porphyry, though not well exposed, appears to be slightly metamorphosed, and within a zone from 200 to 250 feet wide the limestones have been whitened and rendered crystalline. In the western part of the claim there are two narrow jaspery veins, about 40 feet apart, which may be traced for a distance of about 120 feet. Toward the east the ground is covered by loose débris for about 900 feet, where a vein outcrops at a point about 180 feet west of the Isaacs end line. Though perhaps not actually continuous, this vein may be traced to the east end of the claim and for a distance of 150 feet or more beyond. In shallow workings, which are supposed by the writer to be situated on the September claim, this vein stands nearly vertical and has a width of 2 to 3 feet. Silver-bearing lead ore has been mined from these workings, and the same vein is said to have been worked on the Steele claim, which lies just to the east.

On the Millard claim, between the edge of the porphyry and the Isaacs south side line, silver-lead ore has been mined from an irregular deposit, which, though the ore is now fully oxidized, was doubtless formed by the replacement of limestone. The material is spongy limonite gossan that carries lead carbonate and yellow lead-iron sulphates. Though the outcrops do not suggest the presence of a definite or continuous vein, ore has been won from a series of tortuous workings which extend from east to west for a distance of 100 feet or more. About 300 tons of ore mined by lessees in 1910 contained 5.5 to 10 per cent lead, 1 to 2.4 per cent zinc, 20 to 35 per cent iron, about 5 per cent manganese, and 5 to 19 ounces of silver and 0.03 to 0.07 ounce gold to the ton.

COMMODORE CLAIM.

The Commodore claim, situated on the north side of the valley near Lane, deserves mention because of the occurrence within its limits of a body of limonite that has the nature of a bed deposit, and which is regarded as derived from a deposit of pyrite.

A knoll situated near the center of the claim is capped by horizontal limestone beds which represent the base of the Ely limestone. Between these beds and the underlying shale there is a layer of somewhat siliceous gossan about 6 feet thick. The gossan appears to have the same extent as the limestone.

BLACKSTONE AND UNION CLAIMS.

The Blackstone and Union are old mining locations that adjoin the Great Western claim of the Chainman group on the north.

The area of these claims is about equally divided between pyritized Chainman shale on the south and strongly altered Ely limestone on the north. Old workings at points within the limestone area show the presence of metal-bearing deposits, though in general very little that is definite can be made out in regard to these occurrences. The Blackstone workings, which appear to have been most extensive, are near the north end of the claim. Yellow earthy material collected at this locality proved, under qualitative chemical tests, to be free from lead or copper but to contain sulphate and iron. This material is associated with gypsum.

The workings on the Union claim comprise an open pit, from which it is evident that several hundred tons of cellular and crumbly yellow gossan were mined or quarried. This material is said to have been used in some of the early smelting operations in the district. Though exposures are very poor, this deposit appears to cover an area about 100 feet wide and 400 feet long, and its longer axis trends northeast.

MINNIE MINORA CLAIM.

The Minnie Minora claim is situated about 1½ miles north of Ely. At this locality there are shallow workings in an irregular body of white jasperoid, which is surrounded by essentially unmetamorphosed limestones that belong to the Nevada formation. It is reported [1] that in the fall of 1873, about 75 tons of ore that contained gold to the average value of $80 to the ton had accumulated on the dump of this mine.

[1] Min. and Sci. Press, vol. 27, p. 130, 1873.

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