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NOTES ON THE COPPER ORES AT ELY, NEVADA

BY
ALFRED R. WHITMAN

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CONTENTS

INTRODUCTION

In the summer of 1913 the writer spent several weeks studying the geology of the porphyry-copper belt near Ely, Nevada. At that time the most complete study of the geology available was the paper by Professor A. C. Lawson,[1] for which the observations were made in 1904. The mining operations that have been carried on since then have made it possible to observe several new points of interest. The writer's attention being directed to the genetic relations of the ores, the general geology of the district did not receive special attention. The main features may, however, be briefly summarized.

The oldest rocks are limestones and shales, probably of Devonian age. Upon these rests a series of Carboniferous limestones. After the deposition of these sediments, the region was subjected to compression, which resulted in the production of gentle folds of a north-

[1] Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, no. 14, pp. 287–357, May, 1906.

westerly trend. Following this event, monzonite and monzonite-porphyry were intruded along an east-west belt through the center of the district in a series of bosses. Then followed extensive erosion, which was succeeded in Tertiary time by the extrusion of rhyolitic lavas and tuffs. Normal faulting of an easterly and northwesterly trend followed, and then continuous erosion to the present time.

The copper ores now being mined are disseminations of secondary sulfids through monzonite-porphyry. On this account, from the point of view of economic geology, interest centers in this intrusive rock, its relations, and its history.

THE ORE-PORPHYRY

The forms of the masses of ore-porphyry, in plan, are irregular and elongated on east-west axes. In cross-section they appear to be nearly vertical, with irregular, branching walls, giving them in some cases the appearance of laccoliths. In the lowest mine workings, about 300 feet in Eureka Pit (pl. 31, fig. 1) and 500 feet at the bottom of 33 W winze in the Veteran Mine, where the rock is least altered, it shows an hypidiomorphic groundmass containing large porphyritic phenocrysts of orthoclase. The rock has been much altered, but an examination of the least altered portions with the aid of a microscope shows the groundmass to consist essentially of plagioclase and hornblende. These minerals are generally altered to a brown mica, sericite, kaolin and secondary quartz, which are accompanied usually by cupriferous pyrite, and by the secondary sulfids of copper.

ORE-PORPHYRY INTRUDED BY A LATER MONZONITE-PORPHYRY

It was suggested by Lawson[2] that the ore-bearing porphyry was later than the monzonite of Weary Flat which had penetrated the deformed Carboniferous sediments, and probably belonged to the same period as the post-Jurassic granites of the Sierras. But the writer has found that a monzonite-porphyry, probably the correlative of the Weary Flat Mesozoic monzonite, was intruded into the ore-porphyry, probably after the latter had undergone some alteration. Evidence of this was found in the workings extending from the bottom of 33 W winze in the Veteran Mine just north of Weary Flat. It consists of fifty feet of contact between the ore-porphyry and the Veteran mon-

[2] *Op. cit.*, p. 289.

zonite-porphyry. Along this contact the orthoclase phenocrysts in the latter are uniformly oriented parallel to the contact for two or three inches back from it, the phenocrysts losing their parallelism gradually, until at a distance of six inches from the contact their arrangement bears no relation to it. The parallelism in the arrangement of the constituents of the rock is not limited to the orthoclase, but is shared also by the hornblendes, which in many cases are half an inch long. This flow structure points conclusively to the later age of the Veteran monzonite-porphyry. Furthermore, the latter rock is much less altered, and contains no notable amount of magnetite or epidote as compared with the other. The ore-porphyry, on the other hand, has suffered extreme alteration, and in many places has been completely replaced by the magnetite along the contact, and at most points contains conspicuous amounts of magnetite, and often of epidote. The striking difference in the degree of alteration of the two rocks is taken as indicating that by the time the alteration of the latter had begun, that of the former was well under way; since the two rocks appear to be petrographically similar and therefore equally susceptible to the same agencies of alteration.

INCLUSIONS IN ORE-PORPHYRY

The ore-porphyry is characterized by the presence of immense included blocks of limestone, as seen in the Eureka Pit (pl. 30, fig. 2, and pl. 31, fig. 2). These are of indefinite form and outline as a result, largely, of the alteration they and their carrier have undergone; but it is safe to say they range up to three hundred feet in diameter. Their alteration is largely metamorphic, their constituents having been changed chiefly to lime-garnet and epidote in a greenish silicious matrix of uncertain composition, the chief minerals now being epidote, magnetite, garnet, gypsum, calcite, quartz, and iron and copper sulfids.

ALTERATION OF ORE-PORPHYRY

The most conspicuous change which has affected the ore-porphyry is the alteration to sericite and secondary quartz, with accompanying shrinkage of the whole mass and attendant fracturing and general collapse. In general the alteration is greatest near the present surface, and along the central portions of the areas exposed. The rock is scarcely to be found near the surface in an unaltered condition, but it occurs in its freshest state at points deep below the surface, as for example, the bottom of Eureka Pit and the deepest workings of the Veteran Mine. The alteration is also least where the ore is poorest, in general.

The progress of alteration, as traced from the least to the most altered portions, is, first, kaolinization of the feldspars; then a development of sericite and of a brown mica, accompanying the disappearance of the hornblende; and, lastly, a more or less complete replacement of the whole by silica. At the stage where kaolinization is the characteristic alteration, the original structure of the rock is vaguely preserved in a mottled appearance, with here and there the form of a large orthoclase phenocryst remaining. This mottling gradually disappears with the increase of sericite and quartz, until finally nothing remains but a bluish-white, soft friable mass, of mixed sericite and silica, blotched in places with brown mica and speckled with chalcocite, chalcopyrite, pyrite, and molybdenite.

The alteration appears to have extended outward from anastomozing, more or less vertical fractures, thus leaving central lenses of less alteration in which the mottling is quite conspicuous. However, no continuous channels of dominant sericitization or of silicification are distinguishable, and it appears that the alteration could not have been effected at distinct periods in which first one and then the other process was dominant, but that the different phases of alteration must have been performed by the same solutions according to varying local conditions. Also, since the quartz of the veinlets contains secondary sulfids, the two must have been formed simultaneously.

DEPOSITION OF SECONDARY SULFIDS

The secondary sulfids are disseminated through all the altered phases of rock, but are most abundantly associated with sericite or silica. This applies particularly to the chalcocite, which is commonly found as an original constituent of the anastomozing veinlets of silica. Chalcocite is the dominant copper sulfid, but pyrite is probably in greater proportion, in most of the ore, in the form of small cubes or dodecahedrons or irregular masses. The pyrite contains variable amounts of copper, and the massive pyrite grades so imperceptibly into chalcopyrite as to point strongly to the derivation of the latter from the former by secondary enrichment in copper. It also appears that the chalcocite had a similar origin, for in many cases grains which

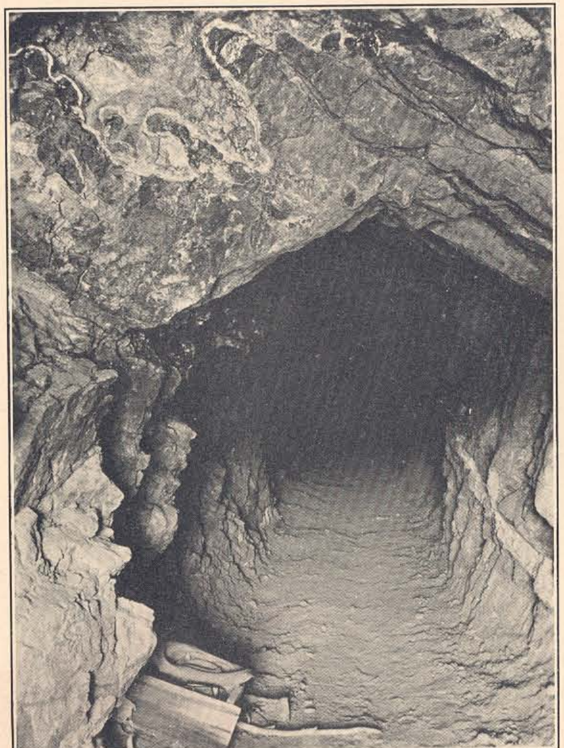

Fig. 1. The irregular white line above the tunnel is the bottom of a mass of blout, five feet below the surface. The tunnel is in limestone dipping to the right.

Fig. 2. Inclusion of limestone (dark) in ore-porphyry of Eureka Pit, overlain by rhyolite tuff.

appeared to be chalcocite on the outside, when broken up, are seen to be pyrite or chalcopyrite within. Molybdenite occurs among the secondary sulfids and seems to have been deposited by the same solutions. It is worthy of note also, that pyrite occurs along with the secondary sulfids in precisely the same manner, and is evidently secondary with them. It was found chiefly as cubes in the ore proper, and as dodecahedrons in the limestone inclusions. Gypsum and calcite also enter into the composition of the ore, and alum incrustations containing cubes of pyrite were found on surfaces where seepage had occurred, indicating that sulphuric acid, liberated by the oxidation of pyrite at the surface, had had a solvent effect upon the kaolin or sericite of the rock, producing a basic sulphate of aluminum, and that this substance coexisted in solution with the pyrite or with ferrous sulphate which, without a recognized reducing agent, was transformed into pyrite, upon the evaporation of the solvent. Perhaps, since there are no carbonaceous or ferromagnesian substances present and aluminum compounds are the chief active agents, some reaction may have occurred with the aluminum minerals during the migration of the mixed ferrous sulphate and sulphuric acid, by which oxygen was taken from the sulphate, producing sulfid which was kept in an ionized state by the presence of the basic sulphate of aluminum or the potassium silicate or sulphate resulting from the reaction. Perhaps colloidal kaolin might have supplied infinitesimal centers of crystallization, causing the mechanical precipitation of ionized pyrite.

LOCI OF GREATEST ALTERATION AND ENRICHMENT COINCIDENT

Neither the alteration of the ore-porphyry nor its mineralization can be discussed separately, for the factors involved in one process were evidently involved in the other also. If hydrothermal agencies were factors in this process, it could only have been to initiate it by producing the first kaolinization, thus rendering such portions more susceptible to vadose alteration. It may be that in the vagaries of their attack they were diverted along the underside of the contact in 33 W winze, rendering the ore-porphyry more susceptible to the subsequent action of the vadose waters, which were responsible for the final alteration, supplementing it by mineralization.

In a general way the extreme alteration and the greatest enrichment are distributed along the main axes of the ore-porphyry exposures, and penetrate to the greatest depths along those axes, and, as has been pointed out, the channels of greatest alteration are anastomozing with a general vertical trend. Still another significant thing is the fact that many small, nearly flat, gouge-filled faults dip toward the central parts of the ore-porphyry masses. This all points to the main axes of these masses as the loci of greatest alteration and enrichment. It was above these axes that the greatest thickness of ore-porphyry was eroded away, with accompanying liberation of sulphuric acid, metallic sulphates, and other active agents. Also, as soluble substances were abstracted from the rocks, the first being taken from the central parts where action was the earliest, the consequent shrinkage must have converged toward that region, resulting in small, flat-lying faults; and the coincidence of anastomozing steep channels of extreme alteration, and of downward circulation is readily understood as that of effect and cause.

If the chalcocite can be taken as an indication of the mode of origin of the most extreme alteration, since it is characteristically associated with it, then the weight of that evidence would be in favor of alteration by descending meteoric waters.. The evidence of the chalcocite consists essentially in the fact that it originates through the enrichment of the yellow sulfids in copper. This is seen in the general occurrence of yellow sulfids in the interior of small masses of chalcocite, and the coating of grains of yellow sulfids by replacement of bornite and chalcocite. And this phenomenon is distributed and diminishes radially with reference to the main axes of the ore-porphyry areas and the surface, the enrichment diminishing outward and downward.

There are extreme irregularities in the distribution of the chalcocite which appear to contradict this rule, but they may usually be accounted for by barriers of impervious gouge, minor flat slips or less permeable rock, which have diverted the enriching solutions along their upper or lower sides according to local conditions of circulation.

The general character, also, of the alteration, would seem to point to meteoric waters, since all the minerals present, with the possible exception of molybdenite, are such as are recognized to be of shallow origin; and the silicification, instead of being a general impregnation, is localized along the minor steep channels of circulation. But the molybdenite occurs universally disseminated through the ore in small grains like the chalcocite, and, like it, is also found in small fractures in the ore-porphyry and inclusions of altered limestones as if it had migrated in the same way as the chalcocite.

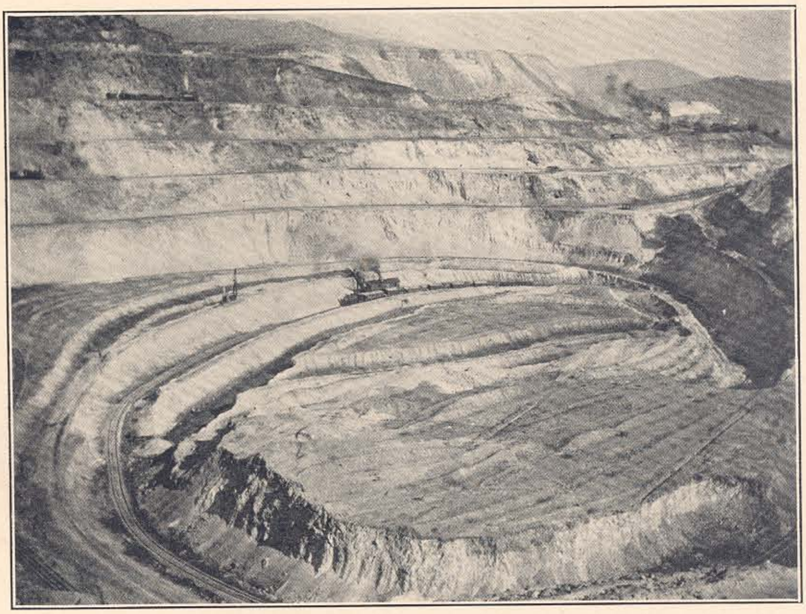

Fig. 1. Eureka Pit, looking northwest. The "island of waste" in the center of the pit is part of the bottom of the ore body.

Fig. 2. Inclusions of limestone in ore-porphyry of Eureka Pit, west side.

PRECIPITATION OF SULFIDS ABOVE WATER TABLE

Pyrite has been precipitated in kaolin in the laboratory[3] under conditions similar to those of vadose circulation; and the writer believes that either sericite or kaolin is capable of producing the same effect in nature, without reference to the ground-water level. If this is true, then meteoric waters carrying the soluble products of oxidation of cupriferous pyrite, in percolating down through a porous and much altered rock like the ore-porphyry, would here and there have precipitated from it grains of pyrite which in turn would precipitate, by a process of metasomatism, chalcopyrite, and this in turn chalcocite.

That this process might have occurred and that these ores might have originated above the ground-water level is a possibility which cannot be ignored. The writer regards it as a plausible hypothesis. If the massive cupriferous pyrite deposits of Shasta County, California, can be regarded as typical of ores formed by the regrowth of sulfid bodies at ground-water level, from sulphate solutions descending from the zone of oxidation, then this Ely ore is a notable exception which challenges explanation. Certainly a water-table intersected by a vertical downward circulation constitutes a rather definite locus for the precipitation and massive growth of sulfid bodies, whether the sulphate solutions originate from the oxidation of disseminated sulfids or from a massive sulfid body; but the Ely sulfids are diffused through a vertical range of over six hundred feet, being of essentially the same character and richness throughout, save where concentrated along gouge-seams or impervious contacts, which fact in itself indicates not stagnation but active circulation such as characterizes the vadose region.

The question then arises as to the mode of reduction and precipitation of sulfids from sulphate solutions in the zone of oxidation. The answer to this involves a subdivision of that zone into (1) an upper region of general and complete oxidation, characterized by the universal oxidation of iron compounds to limonite or hematite resulting in the formation of gossan or in the discoloration of the rock, and (2) a lower region of localized oxidation along channels of more active circulation, such as fractures and joints. In this region the general mass of rock not immediately adjacent to such channels is not completely oxidized, but is undergoing a slow alteration under the influence of diffused moisture.

[3] Econ. Geol., vol. 8, no. 5, pp. 455–468, August, 1913.

Pyrite could not, of course, form in the upper zone of oxidation, but it can exist unimpaired in the lower zone of oxidation away from the open fissures, and therefore might easily form there, since those conditions must be conditions of stability for pyrite. And in this region it is conceivable that the pyrite should have an irregular distribution, that is, being disseminated sporadically through the rock away from open fissures, on account of the diffused and slow circulation there. This being granted, the rest follows, since the conditions of precipitation of the copper sulfids are supplied by local centers consisting of grains of pyrite.

Presumably those main channels of descent for the vadose waters must terminate at or near the ground-water level, and in the neighborhood of those points of entry deposit their metallic burdens in more or less concentrated form; but nowhere in these excavations do these channels terminate nor do such concentrations of sulfid occur. Thus, the evidence for which one would naturally look to indicate the present or past level of the ground water is not to be found.

QUARTZ BLOUT

An interesting phenomenon of the district is the "blout"[4] or jasperoid. This is a compact granular silicious rock, generally of a yellowish-brown color, forming bold outcrops along the copper belt. In a general way it is arranged peripherally to the ore-porphyry; but the arrangement is irregular and ambiguous. Lawson has advanced the hypothesis that these deposits may be of the nature of an encasing shell about the porphyry due to contact action. But the better exposures due to mining operations of recent years have revealed evidence which does not support this view. The blout in many cases caps the porphyry but is nowhere found within it, while it is certain that a considerable thickness of the intrusive has been eroded away over the points where it is found. The occurrences of blout are also notably conformable to the present topography. Had it originated from magmatic emanations it must have incrusted the original periphery of the intrusion in addition to being distributed through the neighboring limestones and shales as it is. These hard shells of silica, then, should have controlled the topography, preserving the underlying rock from weathering and erosion. But this is not the case. Many of the hills have jasperoid outcrops on the summits, but they

[4] Lawson, *op. cit.*, pp. 324–330.

also have the same sort of outcrops in places here and there on the sides, even to the bottoms.

In a few places the undersides of these outcrops have been exposed in prospect tunnels (pl. 30, fig. 1) ; and in such cases are seen to extend irregularly down as fingers into the underlying limestones as complete replacements of it, as if they had resulted through the agency of slowly descending surface waters. Deep drilling operations have shown that masses of jasperoid occur at various levels within the limestone; and that fact may account for their exposure on hillsides as well as hilltops, and it is also consistent with the idea that they originated from emanations given off by the cooling ore-porphyry. However, within the limestone in certain places, concretions of metasomatic silica have formed, from one to ten or twelve inches in diameter. These resemble the jasperoid and evidently resulted from the weathering of the limestone.

In places the ore-porphyry weathers to a soft brown earth which is easily eroded away, while in others it becomes silicious and resembles the jasperoid, demonstrating that this igneous rock as well as the neighboring limestone is capable of yielding a compact silicious rock like the jasperoid, as a result of weathering processes alone.

Thus it is argued that, since the blout caps over the ore-porphyry areas cannot be parts of any original shell of silica, because they are conformable to the present topography, and since similar silicious rock evidently results from the weathering both of the ore-porphyry and the limestone, and since an intimate examination of the undersides of the outcrops of jasperoid reveals an irregular contact resulting from replacement of the limestone, such as might have resulted from the action of descending waters, therefore the weight of evidence is in favor of the origin of the jasperoid through the action of descending meteoric waters.

PYROCLASTIC DYKES

In connection with the geological history of the region, and throwing light on the age of the ores, there is still another phenomenon which is also of interest in other connections. This is the occurrence of pyroclastic dykes in the ore-porphyry. These were studied at two points about a mile apart, namely in Liberty Pit of the Nevada Consolidated Copper Company, and in the Morris workings of the Giroux Mining Company. The dykes are extremely irregular, not being confined by walls which in any sense could be regarded as those of a fissure. Evidently the material had made room for itself by stoping or similar mechanical process. In the neighborhood of these dykes there are dyke-shaped zones of extremely altered and softened ore-porphyry in which, in many cases, nothing is left save soft ash-like sponge of silica, blackish or grayish, and suggesting attack by hot alkaline solutions which might have ascended from the source of the clastic dykes. The suggestion is therefore ventured that these mud dykes were preceded by gaseous or fluid emanations which softened the rock, rendering it removable by the mechanical stoping effect incident to the pulsating ascent of the material. This is somewhat borne out by the occurrence, in the dykes, of fragments of this same ash-like material.

In the dykes were found fragments of limestone, monzonite, spongy psilomelane, and secondarily enriched ore-porphyry exactly similar to that now being mined. There are also fragments of rhyolite similar to that ejected in Tertiary time as flows and pyroclastics, which are taken as indicating that this manifestation must have been a waning phase of the eruption of the rhyolite.

The particular significance of the occurrence is that the fragments came both from the depths and from near the surface, and that they are in many cases rounded as if by abrasion due to pulsations or surging in the ascent of the material, and that the date of the event was subsequent to the chalcocite enrichment of the ore-porphyry. Incidentally it is of interest as another proof that volcanic agglomerates may form not only at a vent, but also in the depths below it, and be poured out on the surface ready made as a volcanic mud flow.

CONCLUSION

Briefly, the conclusions drawn from these observations may be thus recapitulated: first, that the matrix of the ores is an altered monzonite-porphyry, and that this rock is the oldest of the local monzonitic rocks which have intruded the Devonian and Carboniferous sediments, as a series of stocks; second, that the chief agency in producing the present state of alteration of this rock was descending meteoric water, and that the present ores are due essentially to a diffused secondary deposition of chalcocite by this process; third, that this enrichment occurred above the ground water-level; and fourth, that it had occurred before the eruption of the rhyolite.

Transmitted September 26, 1914.

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