

GEOLOGY OF THE RICHARD OXIDE Mine, Kimberly, Nevada

By

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Memorandum
Kimberly, NevadaCONTENTS

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ABSTRACT

The copper of the Richard Oxide deposit occurs essentially as the somewhat rare mineral, delafossite with subordinate amounts of native copper, in a pocket of argillized limestone situated in the sedimentary rocks just outside the margin of, and several hundred feet below, the disseminated ores of the "Porphyry Copper" belt. The pocket of clay, formed by metasomatic replacement of limestone, is partially encased by a rather thick lining of siderite.

A wholly supergene origin is ascribed to the deposit: the clay, the copper minerals and the siderite were deposited through the movement of acid ground waters from a relatively high table in the copper bearing monzonite to a relatively low water table in the adjoining sedimentaries.

INTRODUCTION

The Richard Mine, an oxide copper deposit located in Kimberly, Nevada, is owned and operated by Consolidated Coppermines Corporation. The monthly production is around 2500 tons of direct smelting ore. The deposit occurs within a series of overturned limestone beds (Ely) about 1000 feet south of the disseminated sulphide ores in monzonite porphyry. The major portion of the deposit lies between 600 and 800 feet below the surface; lateral dimensions are roughly 200 by 500 feet. The Alpha, another oxide deposit in the flanking sedimentaries, is located 2000 feet northwest.

DESCRIPTION OF ROCKS AND MINERALS

ROCKS

Limestone. Approximately 500 feet of the Ely limestone formation (Pennsylvanian) is exposed to mine openings in and around the ore deposit. The rock is generally medium gray with numerous sand and chert horizons. The sandy beds contain a maximum of 10% detrital quartz grains in a matrix of calcium carbonate; detrital zircon crystals are usually abundant. Chert occurs as nodules and bands two to three inches in thickness and represents from 10% to 30% of the rock material in certain beds.

Three prominent black marker beds varying from 20 to 40 feet in thickness have been mapped within the ore zone. The upper (stratigraphically) two have the darkest appearance and contain numerous fossils, chiefly coral. The form of these faunal remains is well preserved within the clay which has replaced the encasing limestone. All three beds are slightly sandy and contain moderate amounts of chert. The dark coloration, due perhaps to carboniferous material, appears to be accentuated somewhat by mineralization and alteration characteristic of the ore zone; the contrast with adjoining gray beds is less sharp within the fresh limestones of the wallrocks.

Monzonite Porphyry. The porphyry occurs as narrow dikes one to three feet in width intruded along the west-dipping fault planes. The general appearance is similar to that of the ore-type porphyry of the district -- a soft, light gray mass with no granitic texture discernible. Nearly all ferromagnesian minerals appear to have been altered more or less completely. Occasionally less altered portions show remnants of the large orthoclase phenocrysts. Disseminated pyrite is present throughout, except where oxidized to limonite. Minor amounts of chalcocite on pyrite were noted, but no trace of chalcopyrite.

A thin section (#393)¹ of the less altered rock shows a few euhedral orthoclase crystals with numerous partially altered ferromagnesian minerals. The ground-mass appears as a confused aggregate of rather low birefringent material with indices slightly below the balsam. This material is mainly plagioclase feldspar plus some clay (?). Zircon is present as an accessory.

| | <u>SiO₂</u> | <u>Al₂O₃</u> | <u>CaO</u> | <u>MgO</u> | <u>Fe</u> |
|----------------------------|------------------------|------------------------------------|------------|------------|-----------|
| Altered porphyry Richard | 49.40 | 21.09 | .70 | .80 | 7.40 |
| Copper Flat Mine (Spencer) | 64.73 | 14.41 | .44 | .76 | 2.89 |

A comparison of the two analyses above indicates that the Richard porphyry has undergone alteration similar to that of the ore type porphyry in respect to the loss of Ca and Mg.

Rhyolite. This rock, later than the porphyry, and definitely post mineral in respect to hypogene copper mineralization of the district, occurs as large irregular masses around the eastern margin of the deposit and occasionally as narrow dikes within the ore. The rhyolite intruding the eastern part of the deposit represents the western end of the large intrusive mass which penetrates the southern margin of the Emma porphyry copper ore body.

The narrow dikes are often difficult to recognize as they contain fair amounts of delafossite and have the same general appearance as the ore. The presence of a few clear quartz phenocrysts, however, usually serves as a means of identification. A sample taken from a narrow dike contained:

| <u>SiO₂</u> | <u>Al₂O₃</u> | <u>CaO</u> | <u>MgO</u> | <u>Fe</u> | <u>Cu</u> |
|------------------------|------------------------------------|------------|------------|-----------|-----------|
| 46.20 | 31.17 | .80 | .68 | 3.40 | 2.48 |

No analyses of the fresh, unaltered rhyolite are available, but rhyolites in general usually contain not over 15% alumina and around 60% silica. An introduction of alumina appears to have taken place, accompanied by an apparent loss of silica.

ORE

The average ore, composed essentially of clay carrying 4% to 5% Cu, has a gray, mottled appearance; an effect which on close inspection is seen to be produced by the variations in distribution and size of the small black oxide globules in a rather soft, light gray matrix. Some areas resemble black pepper on cottage cheese. Minor amounts of limonite are present as light brown stains and streaks. Irregular masses of white opaque or light blue translucent clay are not uncommon. The latter usually contains relatively few of the black oxide particles.

The clay minerals occur as metasomatic replacements of both fresh and lightly metasomatized limestones, the latter characterized by a light sprinkling of pyrite and lime-silicates. Sedimentary features such as bedding laminations, chert bands and fossils are quite often well preserved.

Following is a typical smelter analysis;

| <u>Au</u> | <u>Ag</u> | <u>Cu</u> | <u>SiO₂</u> | <u>Al₂O₃</u> | <u>Fe</u> | <u>CaO</u> | <u>S</u> | <u>H₂O</u> |
|-----------|-----------|-----------|------------------------|------------------------------------|-----------|------------|----------|-----------------------|
| .002 | .010 | 4.56 | 46.7 | 17.8 | 8.6 | 1.1 | .20 | 14.57 |

Approximate mineral percentages indicated: Clay--50% (including H₂O), silica (as chert)--15%, as detrital sand --5%, delafossite--11%, limonite and siderite--7%, tremolite--4%(?), H₂O (moisture) --5%.

A selected sample of ore containing no visible chert or siderite and only a trace of limonite, gave the following:

| <u>SiO₂</u> | <u>Al₂O₃</u> | <u>CaO</u> | <u>MgO</u> | <u>Fe</u> | <u>Cu</u> |
|------------------------|------------------------------------|------------|------------|-----------|-----------|
| 33.80 | 40.86 | 1.70 | 1.87 | 6.20 | 5.85 |

Assuming the clay to be essentially halloysite, SiO₂ - 43.5%, Al₂O₃ - 37.8%, this test shows an excess of alumina. Some alumina-silica hydrogel may be present to provide the additional alumina.

Compared to the smelter analysis, the above test of relatively pure clay, shows a much higher ratio of alumina to silica. To

account for this difference something like 15% silica as chert must be present in the average ore. With the exception of a very few narrow veins of chalcedony, no quartz mineral has been recognized in the ore other than the chert and a few detrital quartz sand grains. The sand may be responsible for possibly 4% or 5% of the silica.

ORE MINERALS

Delafossite. This mineral, a black oxide of copper and iron, (Cu_2O , Fe_2O_3) is by far the most abundant of the ore minerals. It occurs as small globules averaging about one mm. in diameter in a matrix of light gray to white clay. Size range includes diameters from .1 mm. to 10 mm. Occasionally the mineral is present as small irregular masses or veinlets.

Micro....Polished surfaces (Fig. 1) show the spherules to be composed of alternating soft and hard concentric layers; the hard material is crystalline with radial arrangement clearly evident. The softer layers do not polish well and are considered to be zones of finely crystalline delafossite with some tenorite. A decrease in crystal size is noticeable along the edges of the hard material. Spherules often contain grains of native copper or pyrite, or composite grains of covellite and pyrite, or quartz grains.

The concentric banding may have been produced by variations in the chemical nature of the depositing solutions; the "wet" and "dry" periods of geologic history quite likely caused fluctuations in the copper, iron, etc. content of the circulating ground waters.

Chem....Though the delafossite globules appear to be relatively pure, it was found that a considerable residue of clay was present after solution in HCl. The following is an analysis of black globules from which all visible clay had been removed:

| <u>Cu</u> | <u>Fe</u> | <u>SiO₂</u> | <u>Al₂O₃</u> |
|-----------|-----------|------------------------|------------------------------------|
| 25.9% | 21.60% | 16.90% | 18.35% |

This test indicates a mixture containing approximately 60% delafossite and 40% clay (including water).

Tenorite. While this mineral (black oxide of copper) may be a minor constituent of the ores, no tests were found which would produce positive identification. The above analysis of delafossite globules shows 25.9% Cu, 21.60% Fe. Comparing this ratio to that of the copper and iron in the formula for pure delafossite, it is apparent that the Richard delafossite contains about 6% excess copper. This additional 6% may well be present as tenorite (CuO).

Native Copper. This mineral occurs in all sizes from microscopic grains to irregular masses weighing several pounds. Hair-like growths and dendritic crystalline forms are fairly common, spear-shaped forms somewhat rare. In certain black beds of "argillized" limestone native and cuprite are the only copper minerals recognized. A chert nodule (Fig. 2) which has been replaced by clay contained a radial arrangement of native copper.

In the southern portion of the mine typical black oxide ore in gray beds carries little more than a trace of native, while in the northern part the native (and cuprite) accounts for 25% to 50% of the copper value.

Cuprite. This mineral occurs as irregular masses and as euhedral crystals. Of the latter, the octahedron is the common form; its luster is adamantine to sub-metallic. The hair-like form, chalcotrichite, is somewhat rare. The cuprite is closely associated with the native copper, the former partially coating or completely enclosing the latter in many specimens. Quite often cuprite crystals, in clusters or individuals are found attached to native. In the "C" black bed octahedrons over 1/2 inch in diameter were found as constituents of a clay gouge along a bedding fault. Here, a few of the cuprite octahedrons were replaced by spongy native copper.

Azurite. Azurite is found massive, but more often crystalline. The common form is a cluster or roseate of elongated, chisel pointed blades, about 1/2 inch in diameter. In economic quantities azurite is found only at or near the upper margins of black oxide ores where it is commonly associated with limonite and siderite. One exception to this: In the 817 stope a sandy bed contained 10% copper as carbonate (mainly azurite as fine particles).

Malachite. This mineral is found in minute quantities as soft or earthy masses, stalactitic forms or thin coatings on native copper. It is usually associated with azurite and limonite, and is of little or no economic importance as a constituent of the ore.

GANGUE MINERALS

Clay. By far the most abundant of the various gangue materials, the clay occurs as a replacement of both fresh and lightly metasomatized limestone. A. Pabst of U. C. examined X-ray patterns of the ore and tentatively classified the clay as an impure halloysite.

Micro....Thin sections of typical ore (Fig. 3) show delafossite, a crystalline clay mineral, amphibole (pargasite?), limonite, detrital quartz and zircon in a matrix of amorphous, colorless material having an approximate mean index of 1.557. According to Winchell² the index of halloysite varies with the water content. The above index was determined by oil emersion of material exposed to room temperature (70 degrees) for several days.

Segregations of relatively pure clay occur as white to light blue masses (sub-translucent before drying) within the ore. This type is more commonly found above the ore in the low grade (1--3% Cu) zones, especially in the central and northern areas of the deposit. It replaces chert (Fig. 4) and occasionally forms narrow veins cutting the chert. A white, sticky variety occurs as coatings or fillings in siderite cavities. A sparse amount of delafossite is usually present. The white, soft, sticky clays and the dense, brittle clays show common optical properties. The indices are variable but usually range around 1.5468, occasionally as low as 1.526. They are in part isotropic, but mainly anisotropic with low birefringence (plus or minus .003). Fragments extinguish as sharply as quartz and exhibit biaxial figures. The anisotropism may be due to strain.

Chemical analysis of the dense light blue clay (H.S.980), 41.20% silica, 38.82% alumina, shows a lower ratio of alumina to silica than the typical ore material, (selected, no chert) 33.80% silica, 40.86% alumina. As a possible explanation it is suggested that the "excess" alumina of the latter combined with some of the silica present (chert, quartz) to form the segregations of more pure clay. In such segregations, perhaps, the crystalline clay was completely altered to halloysite. In the typical ore the additional alumina may be present as a hydrogel of some sort. The more pure clay appears to have been less absorbent than the impure clay and therefore "soaked" up smaller amounts of the delafossite.

Crystalline Clay. The mineral is a prominent constituent of the soft, friable gangue material found in the average ore. It is very sparse to absent in the dense, compact, white to light blue clay masses. The crystals are far too small to be seen megascopically.

Micro....It appears as a felted mass of colorless, small (.004 mm. average thickness) elongated flakes or shreds embedded in an amorphous material previously described as halloysite. Extinction is parallel; elongation, positive; indices, 1.535--1.58 to 1.59. Birefringent colors are low (white) due to the extremely small size of the crystal plates. A thin section (#467) (Fig. 5) of a limestone-clay contact showed the crystals replacing the limestone as flakes and shreds along the rhombic cleavage of the calcite. The crystalline clay in turn appears to have been partially altered to halloysite. Most abundant occurrences are near fresh limestone contacts along the underside of the deposit. The mineral closely resembles hydromuscovite or sericite in respect to optical properties; however, chemical analyses failed to show potassium. Thus, it is possibly a crystalline clay mineral. No sodium determinations were made.

Amphibole. The mineral tentatively classified as the aluminous amphibole pargasite is found in the clay ores and also in the lightly metasomatized limestones of the wall rock in the northern portion of the deposit. Megascopically, it appears as tiny lath-like, light gray to white crystals scattered through the rock; unusual concentrations are occasionally found as replacements of thin beds.

Micro....It appears as individual, elongated, colorless, prisms at random orientation and as sheaf-like aggregates. The approximate indices are, n_x --1.605, n_y --1.62. Elongation is positive and maximum extinction angles range from 16 to 38 degrees in various specimens. No satisfactory interference figure was obtained. The crystals are often partially replaced by clay and (or) siderite. In T.S.394 the clay appears to be replacing the amphibole.

An analysis of material containing about 25% clay (estimate made on oil emersion of powdered rock) (H.S.874) and 75% amphibole (16 deg. ext.) gave the following:

| <u>SiO₂</u> | <u>Al₂O₃</u> | <u>CaO</u> | <u>MgO</u> | <u>Fe</u> |
|------------------------|------------------------------------|------------|------------|-----------|
| 45.40% | 54.4% | 8.70% | 3.94% | 1.80% |

Analyses of three fresh limestone specimens (H.S.936,937,938) showed an alumina content varying from 4% to 6% and a magnesia content of from 1% to 3%. These results indicate roughly an alumina, magnesia,

calcium oxide ratio of 2-1-2 contained in the amphibole. Thin sections of these rocks contained no visible minerals other than calcite and amphibole. The maximum extinction angle of the latter was 38 degrees. In a good many specimens the mineral closely resembles (and may be) tremolite. It is quite possible that the variable optical properties (extinction angle) coincide with variations in chemical content.

In respect to the district in general, the aluminous (?) amphibole is the most widespread product of pyrometasomatism, forming an aureole around the more intensely altered sediments of the disseminated copper sulphide zone. The limestones of this inner zone are almost completely replaced by quartz and lime silicates.

Allophane. This clay mineral, somewhat rare in the deposit, occurs as narrow veinlets, and small masses in the ore. It is blue-green in color, translucent, brittle and optically amorphous.

Siderite. This mineral occurs mainly as a metasomatic replacement of the limestone. It is of widespread distribution but is found chiefly around the margins of the ore body in thicknesses up to 40 feet. However, some aluminum silicate was deposited along with the iron carbonate, as shown by the following typical analysis of what microscopically appeared to be pure siderite:

| <u>SiO₂</u> | <u>Al₂O₃</u> | <u>CaO</u> | <u>MgO</u> | <u>Fe</u> |
|------------------------|------------------------------------|------------|------------|-----------|
| 9.20 | 14.77 | 4.90 | 2.17 | 33.00 |

approximate mineral percentages: Siderite--65%, clay (including some aluminum oxide?)--23%, calcite--9%, amphibole (?)--3%.

Numerous cavities with more or less limonite are characteristically present in the siderite. Occasionally these cavities show a regular pattern, i.e., siderite boxwork. A clean surface on the siderite presents a dull, dark greenish-gray colored, dense appearance. Vugs sometimes contain thin mammillary deposits of the vitreous, translucent variety.

Micro....Thin sections show a compact mass of microcrystalline iron carbonate. A few crystals of amphibole are present with good evidence of an earlier age relationship. The clay minerals whose presence is indicated by analysis are not visible under ordinary powers of magnification.

A polished surface (P.S.567) of siderite contained veinlets of fine grained quartz or chalcedony. Pyrite and an unidentified metallic mineral were present in the vein. The quartz and pyrite here appear to be later than the siderite, and therefore supergene; however, the veinlets could have been present in the limestone and remained undisturbed during the siderite replacement.

MISCELLANEOUS MINERALS

Gypsum. This mineral occurs around the margins of the clay body as euhedral, clear, transparent crystals (selenite) in cavities or pockets in the limestone. The mineral is most abundant immediately beneath the ore deposit where descending sulphate waters have contacted the calcium carbonate of the unaltered rock. Crystals are found in all

sizes, up to 10 inches in length and 2 inches in thickness. The form is usually simple, swallow-tail twins being common. Occasionally the crystals are clouded black with carbonaceous material and contain inclusions of cuprite and native copper.

Pyrite. The mineral occurs in minor quantities as single crystals or small masses in lightly metasomatized limestone wall rocks of the northern portion of the deposit; it is rare to absent in the relatively "fresh" limestone of the southern part. The monzonite porphyry dikes, intruded along fault planes within the deposit and beyond the margins, invariably contain rather even disseminations of pyrite, except where oxidized.

Sphalerite and Fluorite. These minerals occur sparingly as narrow veins in the metasomatized limestone of the northern portion of the deposit. Pyrite and chalcocite are commonly associated with them. In one instance a 2 inch vein of sphalerite (with pyrite, fluorite and chalcocite) was found in a small remnant of the metasomatized limestone within the ore body. A polished surface showed chalcopyrite to be present as minute blebs in the sphalerite. Here "argillization" and the subsequent deposition of delafossite is definitely later than the sphalerite and associated minerals.

Chlorite. A chloritic mineral occurs as a dark green stain and as irregular masses in the metasomatized limestones around the margins of the clay body. Pyrite is a common associate.

Pyrolucite. A soft, earthy black substance, occurring in limestone solution cavities in the footwall of the southwest part of the deposit, contained both copper and manganese oxide; the latter is probably pyrolucite.

ENVIRONMENT AND FORM OF THE DEPOSIT

Churn Drill Hole E-506, located in the southern part of the mine, passed through about 200 feet of sandstone (from the surface), 240 feet of thoroughly silicified, somewhat sandy limestone, 200 feet of "argillized" limestone and into fresh limestone at the bottom. The ore occurred in the lower part of the "argillized" limestone, immediately above the fresh limestone contact. Although sludge boards and detailed geologic logs are lacking for all the old holes drilled in and around the deposit, the above is considered to be representative of the rock sequence throughout the ore zone (Section ~~#1~~ B-B').

Strong silification of a sandy limestone is known to extend from the Veteran to the west end of the Emma, a distance of over one mile. Thin sections of this material show an occasional grain of detrital quartz or zircon in a matrix of fine grained, low temperature type quartz. The silification may be late hypogene; some appears to be supergene -- see paragraph under "Siderite".

The ore deposit as a whole rakes at a low angle to the southwest and lies directly across the outer limit of metamorphism in the limestone. It occupies the bottom of an elongated depression in the limestone, a form defined by local limits of "argillization".

STRUCTURE

General control of clay and ore deposition has been effected by a series of west-dipping faults. This system of roughly parallel structures is composed of three individuals, striking northeast through the south end of the deposit and NW at the north end, forming an irregular, crescent-shaped pattern (see 50 scale plan map). Narrow monzonite porphyry dikes have intruded in and along the fault planes removing the gouge and obscuring to some extent in places, the exact trend of the faults. A minor amount of post-porphyry movement has occurred.

In the southern portion numerous bedding slips (NW strike, NE dip) offset the NE faults a few feet. In some cases movement has been resumed or continued on the NE faults with a resulting sharp warp in the planes at junctures with the bedding faults. Farther north the faults describe a gentle arc and become less sharply defined--appear to split up or feather out. The total stratigraphic separation on the three faults as measured on the black marker beds is well over 200 feet.

COPPER MINERALIZATION

In a general way ore deposition has followed the west-dipping faults, migrating downward along favorable beds and bedding faults. A rude checkerboard pattern has been formed by selective mineralization of the offset segments of the various beds. The black carbonaceous beds, although replaced by clay minerals, have been avoided by the delafossite. However, native copper and cuprite often occur in these beds in quantities sufficient to make ore. This copper, which may have been precipitated by carbonaceous material, is confined mainly to the upper or hangingwall portions of the black beds. It should be noted that the black beds are somewhat more dense and brittle than the light colored beds. They may have been relatively impervious to delafossite mineralization, but contained open fractures which were filled with native and cuprite. The deposition of the delafossite appears to have been for the most part a process of replacement rather than cavity filling.

In the northern part of the deposit sharp control of ore deposition is less evident. The clay is generally of submarginal grade (2-3% Cu) but much greater in extent than the small, well defined bodies of the south end. Around the bottom of the "half-bowl" structure formed partly by the warped fault planes, a 10 to 20 foot zone of 5 to 6% ore occurs--a result of "enrichment" through deposition of finely divided native and cuprite. This condition exists only in a general way; locally, delafossite may be present in sufficient quantities to make ore (plus 4.0% Cu). Notable amounts of native are often found along fault zones and in the chloritic material occurring at the contact between the clay and the lightly metasomatized limestone of the wall rocks.

In the foregoing paragraph it is not meant to imply that all native copper was deposited after the delafossite. It is considered likely that in the southern portion of the deposit much of the native preceded

the delafossite. A few instances have been noted where clay and delafossite appear to coat native copper.

In the extreme north end of the deposit on the 600 level several relatively small bodies of clay and delafossite occur as limestone bed replacements and as almost vertical, narrow veins. The latter are as much as 12 inches in width and contain 4% to 5% Cu.

GENESIS

In a general way the question of origin involves two somewhat diverse theories: (1) the copper and gangue minerals were derived from a remote source and emplaced in their present position through the circulation of meteoric waters (exotic type), (2) the deposit represents a body of primary copper minerals, oxidized essentially in place.

The first stated theory is considered to have by far the greatest weight of evidence in its favor. In a discussion of such a genesis one of the most important factors is the position of the deposit--at the outer margin of the intensely metasomatized limestone and porphyry mass, where relatively deep circulation of ground waters has occurred.

In the disseminated copper sulphide ores of the porphyry and metamorphosed limestone leaching has occurred in the upper two to three hundred feet of rock material. At and below this base of oxidation, chalcocite has been deposited--mainly on pyrite, or as a replacement of chalcopyrite. Doubtless a relatively stable water table existed for some time. The intermingled porphyry and the metasomatized limestone of the "contact zone" have a tendency to hold the surface waters--faults and fractures are sealed to some extent by gouge and by mineralization. Mine openings in these rocks make very little water, a few g.p.m. at the most. In contrast the unaltered limestone (and sandstone) contain open fractures and solution channels through which the meteoric waters may readily pass to basins considerably lower in elevation than the porphyry water table. Thus a draining off has occurred at the margin of the more impermeable rocks. Examples of such water table differentials are found in the bulletin on the Tintic Dist.³ As portrayed on the section through the Swansea and Sunbeam shafts and on the section through the Lower Mammoth Mine, relatively deep oxidation associated with clay occurred in the limestone along a monzonite contact. The water table in the limestone was over one thousand feet lower than the table in the monzonite, within a horizontal distance of less than 2000 feet.

The Alpha deposit, located some 2000 feet northwest, is similar to the Richard in many respects. The more important of these are: (1) The copper occurs chiefly as delafossite in clay, the latter as a replacement of limestone; (2) the deposit is situated in relatively fresh limestones adjacent to the porphyry and metasomatized limestones of the disseminated primary copper zone. However, horizontal dimensions of the deposit are somewhat less, vertical dimensions greater than those of the Richard. The clay and oxide copper occurs from the 900 to the 1800 level along an irregular zone of fissuring.

The water level normally stands at the 1000 level, elevation 6050 feet. Recent continuous pumping for more than a year at over

300 g.p.m. has not drawn the water down below the 1200 level.

The lowest level in Kennecott's shaft at Ruth, about 2 miles east of the Alpha, is in porphyry at a depth of 1600 feet (elevation about 5500). Here, some 1200 feet below the "porphyry" water table (as determined by churn drill data) only a few g.p.m. are pumped from rather extensive workings in porphyry. Thus, generally the water table in the sediments is much lower, but the flow much larger than in the porphyry.

It is concluded that in the Richard and Alpha deposits the circulation of meteoric waters down and near the contact between the rocks of the disseminated copper belt and the adjacent unaltered limestones could have effected the transportation of both the clay (as alumina and silica) and the copper from the zone of oxidation in the upper part of the porphyry copper body to a position well below and somewhat south of the origin.

The locus of the primary ores which provided the copper in the Richard is somewhat obscure. It may have been within the silicified limestone, or within the overlying sandstones, or within porphyry and mineralized sediments of the disseminated copper zone (Brooks area) now leached and partially removed by erosion. The latter seems the most likely source (Section ~~II~~ B-B'

The aluminous silicate which replaced the limestone and formed the clay bodies was probably derived from the rocks containing the primary copper minerals. Ross and Kerr⁴ consider halloysite to be of supergene origin in all cases. They find also that the mineral is not truly amorphous, but is made up of crystals too small for microscopic observation. They state that one important mode of formation is through the action of cold acid waters (sulphuric acid derived from oxidation of pyritic deposits) on aluminous rocks. G. F. Loughlin⁵, in describing the Dragon Iron Mines, states that the kaolin, leached from the hydrothermally altered volcanics, replaced the underlying limestone.

The clays in the Richard mine were probably formed by a similar process, but the sandstones overlying the deposit could hardly be considered as the source of the aluminous silicate. The possibility does exist, however, that the silica and alumina were leached from the highly altered monzonite porphyry to the north and were carried southward down the fresh limestone contacts. These waters (originally acidic, but later becoming neutral or alkaline) may have effected a metasomatic replacement of the limestone by aluminous silicates. The copper was probably transported by the same solutions. Thus an acid solution carrying, at one time or another, copper, iron, oxygen, silica and alumina, was necessary to the formation of the deposit on a wholly supergene basis.

The form of the clay deposit also strongly suggests a supergene origin, namely, the relatively broad lateral extent, the undulating bottom contacts (Section ~~#2~~ A-A'), and the pocket-like form of the various individual ore bodies.

Siderite, as well as clay, has replaced the limestone; however, the age relationship is not clear. Since the siderite occurs commonly at the margins of the clay bodies, it may be logically assumed that the

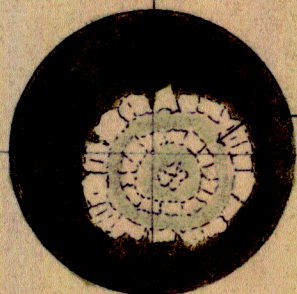
siderite is later. Evidently some aluminum silicate was present in the solutions which formed the iron carbonate, as this substance is contained in all samples analyzed. The siderite occurs in significant quantities in only two localities; beneath the ore body in the northern portion of the deposit and along the western margin of the south end. The eastern part of the latter area contains little or no siderite in the footwall. The siderite on the western margin extends well beneath the clay deposit along the No. 1 and No. 2 faults (Section ~~#21~~ c-c'.

Supergene siderite is generally thought to be formed by the action of ferrous sulphate solutions (derived from the leaching of sulphides) on fresh limestones. At Bisbee, large masses occur below partially leached sulphide ores.⁵ The siderite of the Richard deposit was probably formed by deep circulating ferrous sulphate solutions, subsequent to the formation of the clay and in general coincident with deposition of the delafossite and native. Inclusions of siderite well within the main clay mass suggests that the period of "argillization" overlapped the period of siderite replacement.

During or following the formation of the clay body, copper bearing solutions, circulating below the water table, soaked through the clay and deposited the delafossite in rather even disseminations. Although no information is at hand at the present on the chemical nature of such a process, it is suggested that the neutralizing effect of the clay on acid solutions may have caused the deposition of the delafossite. Certain beds were more favorable than others, which may have been a matter of permeability in some cases, such as the black beds. In other instances bedding faults appear to have deflected the solutions. In addition to the foregoing, various beds of limestone were unreplaced by the clay and were thus impermeable to the copper. Certainly, the delafossite possessed a strong affinity for the clay. That it did not completely replace the clay but formed a solid solution is evidenced by analyses previously mentioned. Possibly, this same relationship may exist in the case of the siderite and clay.

Minor amounts of pyrite present in the ore (mainly in the northern part) have been partially replaced by chalcocite. In places, such as around the outer margins of the porphyry dikes, the pyrite has been oxidized to limonite. Occasionally a particle of chalcocite (or covellite) was found enclosed in the delafossite; however, there is no evidence of replacement by the latter. Often quartz grains or other particles of gangue form centers in the delafossite globules; thus, the chalcocite is considered to be merely incidental. Larger masses of chalcocite observed showed no evidence of being associated with the delafossite. It is concluded that the chalcocite and the delafossite were derived from the same solutions, and that in the absence of pyrite, delafossite was formed; in the presence of pyrite chalcocite was formed.

Conditions somewhat analogous are believed to have existed in the Richard Sulphide body in limestone, located a short distance north and 200 feet above the Richard Oxide. Here, chalcocite occurred in a heavy concentration of pyrite. However, below the pyrite, oxides were found (according to old churn drill logs). Thus, descending solutions lost only a part of their copper in the pyrite zone and continued downward to form oxides in a sulphide-free environment; or, the deposition of the oxides may have followed a lowering of the water table.



Soft, finely
xlline layer

Fig. 1. Polished surface
delafossite spherule in
clay. X 80

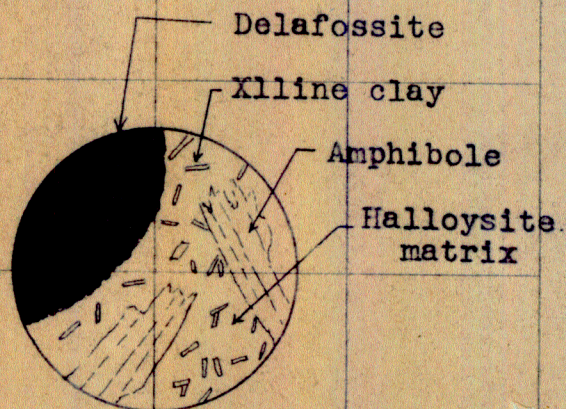


Fig. 3. Thin section of
typical ore, northern portion
of deposit. X 360

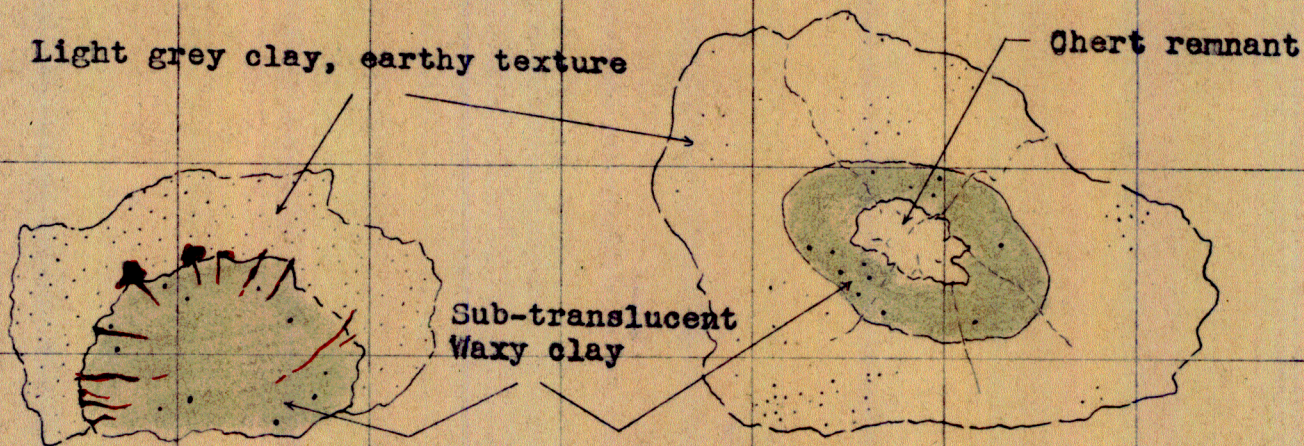


Fig. 2. Sketch showing radial
arrangement of native copper
in clay "nodule". Natural
size. Distribution of dela-
fossite shown by black dots.

Fig. 4. Sketch showing partial
replacement of chert nodule by
sub-translucent waxy lustered
clay. Natural size.

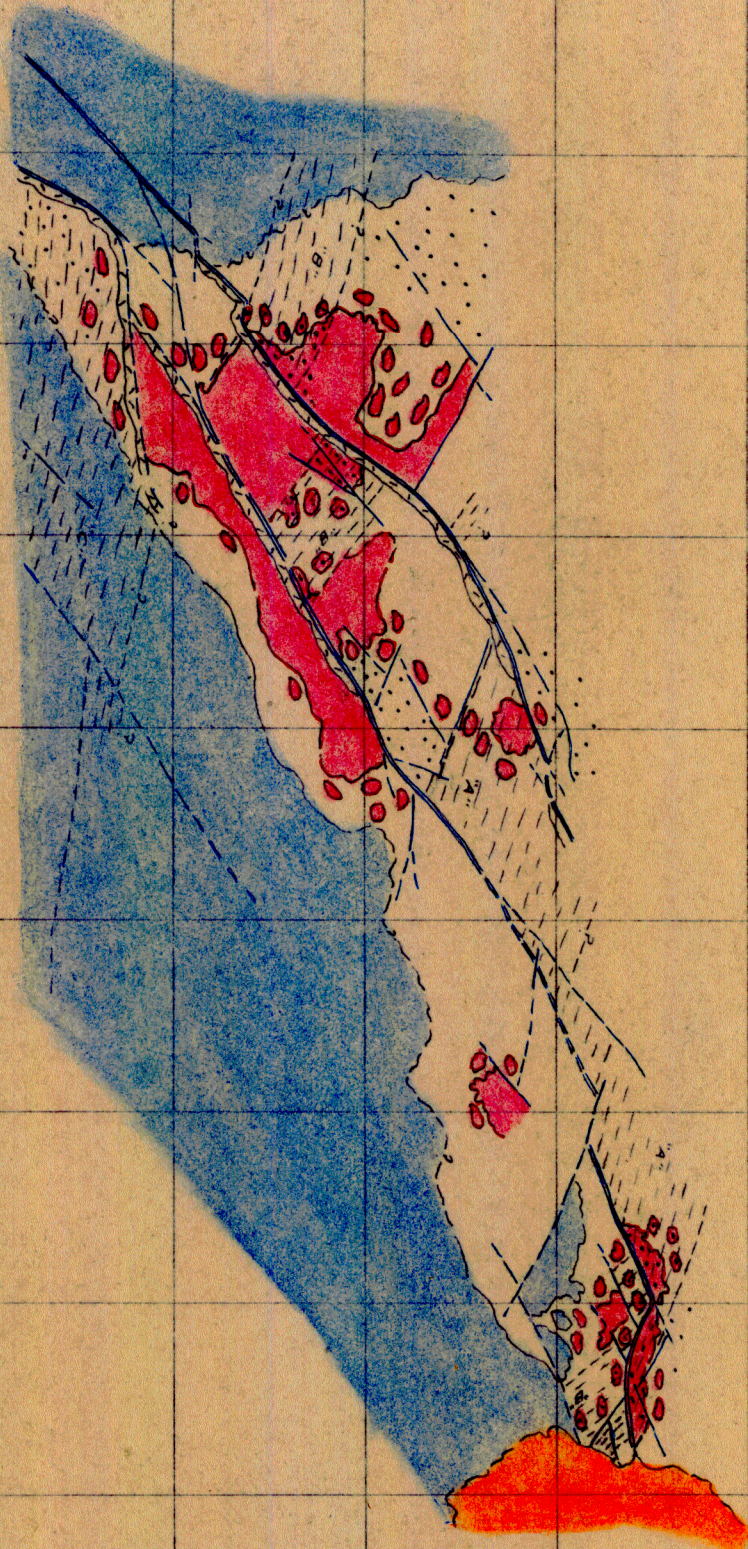
7500E

7400E

5650N

0
50 ft.

Elev 10th Floor



RICHARD OXIDE MINE

SECTION C-C'
Look Northerly
Scale 1" = 50'



Sec. B-B'

ELEV. 6500

LEGEND

- ARGILLIZED LIMESTONE.
- DISSEMINATED SULPHIDE MINERALIZATION.
- SILICIFIED SANDY LIMESTONE.
- MONZONITE PORPHYRY.
- RHYOLITE (POST MINERAL).
- ELY LIMESTONE.
- RIB HILL SANDSTONE.

- RIB HILL LIMESTONE.
- JOANA LIMESTONE.
- PILOT SHALE.
- RICHARD OXIDE ± 5% Cu.
- RICHARD SULPHIDE ± 5% Cu.
- BROOKS, [CHALCOPYRITE] ± 1.0% Cu.
- DIRECTION OF GROUND WATER MOVEMENT

RICHARD OXIDE SECTION

LOOKING NW

SHOWING POSITION OF THE OXIDE DEPOSIT & WATER TABLE RELATIVE TO THE BROOKS DISSEMINATED COPPER ORE & WATER TABLE

KIMBERLY, NEV. 10/1/45

SCALE 1"=250'
J.H. COOPER, JR.

FROM SECTION BY KENYON RICHARD

LEGEND

Ore (+4% Cu)



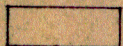
Native Cu



Fresh Limestone



"Kaolinized" Limestone



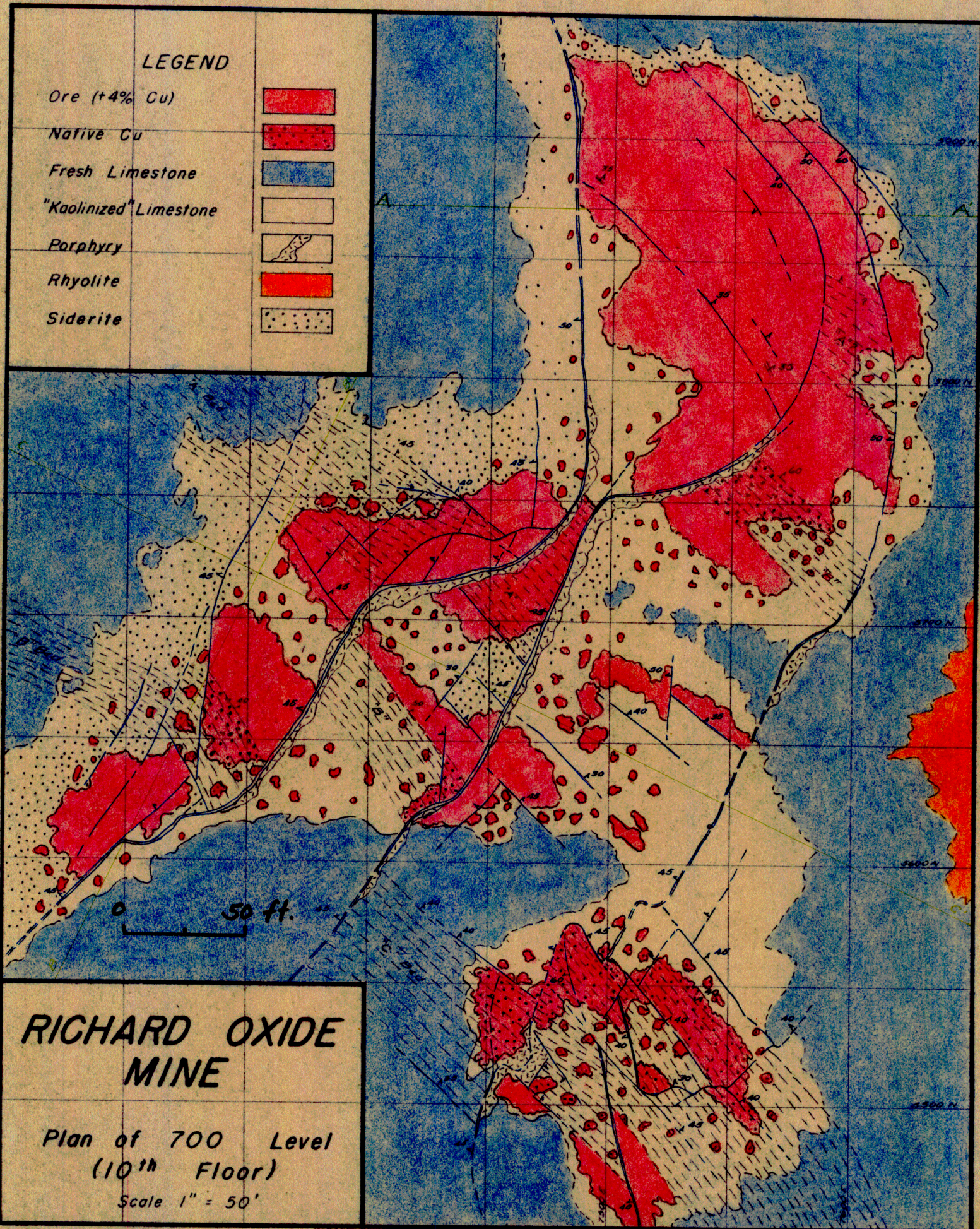
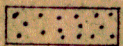
Porphyry



Rhyolite



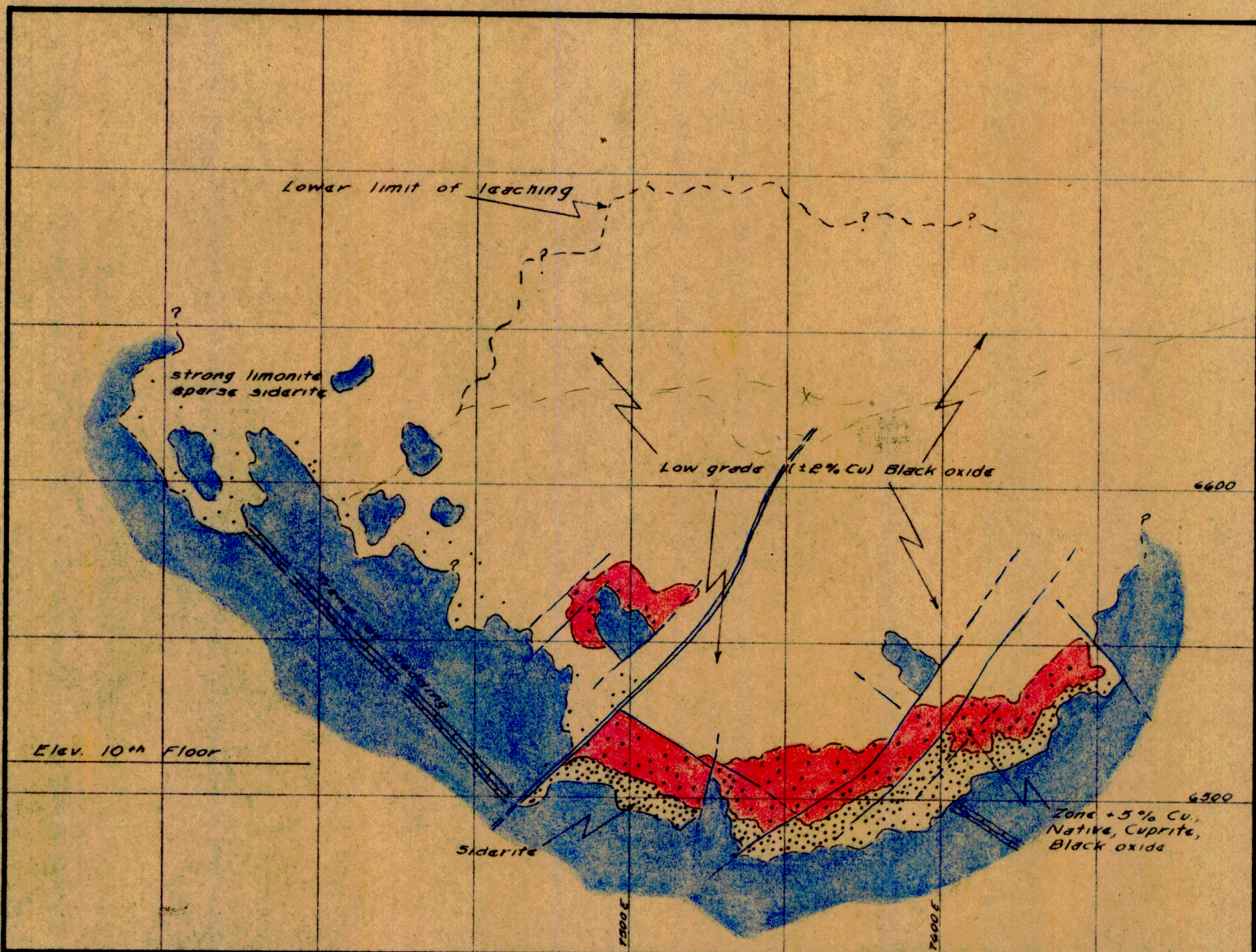
Siderite



RICHARD OXIDE MINE

Plan of 700 Level
(10th Floor)

Scale 1" = 50'



RICHARD OXIDE MINE

SECTION A-A'

Look North

Scale 1" = 50'

Showing ore body formed by native copper and cuprite enrichment around bottom of clay body containing low grade disseminations of black oxide (delafossite).

The Tonopah, a small chalcocite enriched body in quartz veined clay, lying on the north fringe of the Emma porphyry copper zone, is another example of the close connection between supergene processes and argillic replacement of limestone. The clay body here is situated, as in the Richard Oxide, just beyond the margin of complete replacement of the limestones by quartz, lime and ferromagnesian silicates. Apparently, the carbonate rocks only are susceptible to replacement by clay.

Analysis of 17,289 tons of Tonopah ore:

| <u>SiO₂</u> | <u>Fe</u> | <u>CaO</u> | <u>Al₂O₃</u> | <u>S</u> | <u>H₂O</u> |
|------------------------|-----------|------------|------------------------------------|----------|-----------------------|
| 54.7 | 11.4 | 0.7 | 12.3 | 11.7 | 9.0 |

Estimated mineral percentages (from briquettes):

| <u>Quartz</u> | <u>Clay</u> | <u>Pyrite</u> | <u>Chalcocite</u> | <u>Chalcopyrite</u> |
|---------------|-------------|---------------|-------------------|---------------------|
| 38.0 | 36.0 | 23.0 | 1.0 | .5 |

The quartz occurs as a network of veins. Considerable evidence, such as bedding laminations, chert, etc., indicates that the clay body was originally limestone. The water table roughly coincides with the upper contact of an intrusive porphyry mass which also marks the bottom of the ore body.

As stated previously, the pyritic porphyry dikes in the Richard contain no delafossite and but traces of chalcocite, while the rhyolite dikes are quite often well impregnated with delafossite. A possible explanation for the deposition of delafossite in the rhyolite lies in the fact that the rhyolite has been more thoroughly "argillized" than the porphyry. A definite preference of the black oxide for clay is demonstrated by the fact that the limestone inclusions (subsequently "argillized") in porphyry dike margins carry significant concentrations of delafossite. In addition, the porphyry appears to have been somewhat less permeable since chalcocite on pyrite commonly occurs only at the margins of the dikes.

As erosion progressed and the water table was, it appears, lowered, oxidation and leaching processes penetrated the upper portions of the deposit, taking the copper of the delafossite (and chalcocite) into solution. Most of the iron appears to have been precipitated as the ferric hydrate, limonite, judging from the abundance of this material in the leached zone. The lower limit of leaching forms an irregular blanket dipping southerly over the deposit (Section #11.5-5). A part of the copper formed carbonates, the rest may have been carried downward to form native, cuprite and possibly delafossite. In the south end of the mine the deposits of native and cuprite occur in the black carbonaceous beds immediately beneath zones of leaching characterized by abundant limonite and sparse copper carbonates. In the northern part of the deposit black oxide ores of low tenor are supported in value by native and cuprite. These minerals have been deposited chiefly near the siderite contact at the bottom of the "half-bowl" structure.

This zone of leaching is underlain by what might be termed a zone of "secondary oxide enrichment", comparing to the secondary sulphide zone in sulphide deposits.

Strong evidence against the theory of "oxidation in place" is found in the extremely low gold content of the ores. Throughout the district the primary copper (chalcopyrite) contains gold in a ratio which varies little---1.0% Cu to .01 Au. Gold assays of Richard Oxide ore (4.5% Cu) run from .001 to .002 Au---amounts that can be found anywhere in the lightly mineralized limestones or porphyries. The Alpha, an oxide deposit very similar to the Richard, contained like amounts of gold.

PARAGENESIS

A suggested order of formation for the various minerals in the Richard Oxide is shown below:

CLAY -----
NATIVE COPPER -----
- DELAFOSSITE -----
- CUPRITE -----
- SIDERITE -----

Zone of (AZURITE -----
leaching (MALACHITE -----
(LIMONITE -----

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The strongest points in favor of a hypogene origin with subsequent oxidation in place are found in (1) The structural control evident in the deposition of the ores, (2) the selective replacement and mineralization of certain favorable beds, (3) the rather even distribution of the delafossite within various ore bodies (absence of concentration on the surface of structures such as fault planes, footwall fresh limestone contacts, etc.) While (1) and (2) are generally considered features distinctive of hypogene deposits, under the unique conditions which existed in the Richard Oxide deposit such features may well have been present in a supergene process. Commonly, supergene deposition of copper is controlled mainly by the position of the water table. In the deposit under discussion the water table was steeply inclined with a more or less continuous downward movement of water, simulating, to some extent, hypogene conditions. In the metasomatic replacement of the limestone by the clay minerals, the faults as well as the physical and/or chemical nature of the beds exerted considerable influence. In the case of the deposition of the delafossite, structural control is less evident. The clay bodies, in the manner of a sponge, appear to have "soaked up" the copper bearing solutions uniformly, and a more or less uniform distribution of the delafossite resulted. This even distribution is, however, only a local condition; some "argillized" limestone beds are low in grade, others are completely barren of copper. It is not clear whether this selective mineralization of certain beds was due to differences in physical, or chemical nature, or to the effect of structural control on the copper bearing solutions.

References:

1. All specimens referred to are on file in Consolidated Coppermines geological department at Kimberly, Nevada.
2. Optical Mineralogy.
3. USGS Prof. Paper 107, p. 20, p. 221
4. USGS Prof. Paper 185
- 5.