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The Silica Outcrops OF THE *Warren Mining District, Arizona*

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BISBEE DISTRICT[15]

BY CARL TRISCHKA[16]

INTRODUCTION

Each succeeding paper on the geology of the Bisbee district discloses new discoveries or modifies former ideas. This condensed account summarizes the well-established facts and presents some observations not previously recorded. A bibliography is given on page 41.

ROCKS

The columnar section (Pls. III and V) gives the essential information regarding the sedimentary rocks. It will be observed that the igneous rocks are represented as having been intruded: (1) granite in pre-Cambrian, (2) granite porphyry in pre-Cretaceous, and (3) andesite in post-Cretaceous time. This section shows also the idealized relationship of the pre-Cretaceous granite porphyry to the ore occurrences in the various formations.

GEOLOGIC HISTORY OF THE MULE MOUNTAINS

The schistosity of the pre-Cambrian Pinal schist was initiated before intrusion of the granite shown in the northwest corner of Plate VII. Accompanying this intrusion was some mineralization of which only roots of no economic importance remain.

The area was eroded to a peneplain and later sank below the sea. The Cambrian Bolsa quartzite was laid down with profound unconformity upon the schist.

The Abrigo limestone, also of Cambrian age, followed the Bolsa quartzite.

Ordovician, Silurian, and lower and middle Devonian rocks are lacking in this section of Arizona. The upper Devonian is represented by the shaly to rather pure Martin limestone. A bed of quartzite 8 to 10 feet thick is used locally as a marker between the Cambrian and upper Devonian.

From upper Devonian to early Permian time there was almost continuous deposition of limestone, followed by regional uplift, erosion, intrusion of the granite porphyry, and ore deposition. The Dividend fault, with a throw of 2,000 to 5,000 feet, followed the intrusion. Erosion subsequently stripped almost all of the Paleozoic rocks from the northeast or upthrown side of this fault, exposing the Pinal schist and the intrusive granite porphyry.

An unconformity, Triassic and Jurassic in age, exists between the Carboniferous and Cretaceous. The Cretaceous consists of a great thickness of sandstone and limestone, the upper portion of which has been eroded.

During the Laramide revolution at the end of Cretaceous or early Tertiary time old fissures and faults were reopened and new ones formed. At this time weak siliceous veins were formed, and considerable tilting of the Cretaceous and other formations in the district occurred.

STRUCTURAL FEATURES

In the Bisbee Folio, Ransome recognized seven structural blocks or tracts (Pl. VI). Of these, six will be discussed briefly because of geologic interest, and the Copper Queen block will be given greater consideration because of its geologic and economic importance.

The blocks have been named: (1) Bisbee block, (2) Escabrosa block, (3) Naco block, (4) Copper Queen block, (5) Gold Hill block, (6) Glance block, and (7) Cretaceous tract.

Broadly considered, the Bisbee, Escabrosa, Naco, and Copper Queen blocks are essentially masses of pre-Cretaceous rocks, bounded wholly or in part by faults of post-Carboniferous but pre-Cretaceous age. The Escabrosa block has been dropped 2,000 to 2,500 feet with reference to the Bisbee block, whereas the Naco block has been dropped about the same amount with reference to the Escabrosa block.

The Bisbee block is composed of Paleozoic beds, pre-Paleozoic metamorphic rocks, and two intrusive bodies. The Escabrosa block has only Paleozoic rocks exposed. The limestone of the Naco Hills in the Naco block is Permian or upper Carboniferous in age.

The Copper Queen block, comprising part of a canoe-shaped syncline of Paleozoic beds, is downthrown with reference to the Bisbee block but less so than the Escabrosa block.

The Gold Hill and Glance blocks are Paleozoic and younger beds, which have been thrust toward each other from the southwest and east, respectively, over the beds of the Cretaceous Bisbee group.

The Cretaceous tract is less a definite fault block than an area of little disturbance.

COPPER QUEEN BLOCK

The Copper Queen block is bounded by the Dividend, Quarry and Bisbee West faults, and by the Black Gap fault which is east of the Campbell fault and not shown on Plate VII.

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[15] Paper obtained for, and originally presented at, the regional meeting of the A.I.M.&M.E. held at Tucson, Arizona, November 1-5, 1938.

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Structure.—Within this area are at least twenty fault zones, with an average strike of N. 15 to 30 degrees E. Most of them dip steeply westward, although some, particularly in the west end, dip eastward.

Crossing these fault zones are two systems of faults approximately parallel to the Dividend and Bisbee West faults. Other fracture zones either radiate from, or are concentric with, Sacramento Hill. Underground workings show radiating fault zones that contain ore where intersected by northeast fractures.

The Oliver and Dividend faults, which are cut and offset by several faults, are apparently among the oldest in the district.

The important fault zones from west to east are the Hedberg, Escacado, Czar-Shattuck, Ella, Crescent, Alhambra, Tuscarora, Dallas, Junction, Mexican Canyon, and Campbell.

Faults and fault zones, as here considered, are 100 feet in maximum width but are represented on the map by a line.

Practically all of the exposed fracture zones are traceable by the silica, manganese, iron oxides, and sparse copper glance or copper carbonate mineralization that occurs intermittently along them. Such mineralization has been followed from outcrops to underlying ore. The Glance conglomerate covers a large part of the area between the Campbell fault and the Black Gap fault to the east. Hence the pre-Cretaceous fracture zones in this area lack surface expression except where they weakly appear in the Glance conglomerate as possible upward extensions of reopened zones in the underlying Paleozoic rocks. Consequently the search for fracture zones must often be carried on underground.

Geologic history of the Copper Queen block.—After Carboniferous and before Cretaceous time erosion cut down the upper Carboniferous strata into a very irregular land surface. During this interval the area underwent doming, followed by explosive intrusion of a chimney-shaped mass of granite porphyry. The porphyry found its way also along breaks and leafed the strata apart. Probably at the same time the adjacent fault blocks settled, generally complicating the fault pattern. The main porphyry mass is surrounded by a rubble, known as the contact breccia, which consists of a mixture of all of the pre-Cretaceous rocks in the district. The contact breccia surrounds the granite porphyry of Sacramento Hill except where penetrated by dikes of the granite porphyry. The contact breccia ranges from several feet to more than 500 feet in width and is present in depth where granite porphyry masses had previously been presumed to exist.

Mineralizing solutions that came after the intrusion invaded the fracture zones in the limestone and also followed porphyry dikes and sills. Depositions of copper and iron sulphides as replacement of the limestone took place. Several waves of solution of varying mineral content, strength, and intensity must have occurred to produce the mineral zones which, though obscure, appear to be superimposed on one another. Lead and zinc sulphides are common but of very minor importance. Lead carbonate ore, however, mined in the west end of the camp, amounted to an appreciable tonnage.

The chemical composition of limestone is of slight importance compared to its physical character in determining replacement. Thoroughly broken rock along fissure zones, intersecting break zones or in embayments of the granite porphyry, was most readily replaceable. This may account to some extent for the abrupt contact between the sulphide and the limestone.

Ore replaces large and small limestone blocks and aggregates in the contact breccia.

The granite porphyry stock and the contact breccia were intensely silicified, pyritized, and sericitized. Oxidation and secondary enrichment of the mineralized granite porphyry produced a siliceous, iron-bearing gossan underlain by secondarily enriched, low-grade ore bodies.

After considerable erosion the Dividend fault, with a displacement of 2,000 to 5,000 feet, truncated the porphyry chimney. The granite porphyry of Sacramento Hill, on the south side of the Dividend fault, has gossan with low-grade ore bodies below, whereas the granite of Copper King Hill north of the Dividend fault has no gossan or ore bodies. On the north side of the fault erosion has kept pace with oxidation, and iron sulphide, with very small amounts of copper sulphide, occurs near the surface. The contact breccia around this section is composed entirely of schist. Additional evidence of the truncation by the Dividend fault is the presence of schist against the north side of the fault on the 1,800-foot level of the Sacramento shaft. Mule Pass Gulch was developed along the Dividend fault because of the weakness of the rocks.

Erosion stripped practically all of the Paleozoic rocks and any ore they may have contained from the north or upthrown side of the Dividend fault in pre-Cretaceous time.

In Cretaceous time a great thickness of sedimentary rocks was laid down, and when these rocks were tilted in late Cretaceous or early Tertiary time old breaks were opened and new ones were formed along which mineralizing solutions deposited what is known as Bisbee Queen silica. This silica replaced the basal fragments of limestone in the Glance conglomerate and also formed narrow veins in the overlying Cretaceous formations. This quartz is slightly gold bearing in places and contains sparse galena, sphalerite, and chalcopyrite, which are of no economic value. Some gulches contain small areas of gold placer from this silica.

The granite porphyry, of pre-Cretaceous age and undoubtedly of deep-seated origin, is believed to be chimneylike in the schist and to spread more widely in the fractured Paleozoic rocks.

Evidence of the Age of Ore Mineralization

It has been stated in several articles that because the ore mineralization in Cananea, Mexico, south of Bisbee, and in Tombstone, Arizona, is of late Cretaceous or early Tertiary age, it is reasonable to assume that the Bisbee mineralization was of that age. Proofs were offered, particularly the asserted absence of altered porphyry boulders of the Sacramento Hill type in the Cretaceous Glance conglomerate. The absence of porphyry boulders in this formation at its contact with the porphyry would argue for an intrusive contact, whereas the reverse condition would indicate an erosional contact.

The base of the Glance conglomerate, however, does contain porphyry boulders and fragments of siliceous, ferruginous gossan of the Sacramento Hill type. A short distance above this basal layer are layers of conglomerate that contain quartzite and schist. One of the best exposures showing this relation is near Sacramento Hill at the site of the old ice plant. As the Dividend fault truncates the granite porphyry but does not displace the Cretaceous, the ore must therefore be pre-Cretaceous. Underground openings on the contact of the Naco limestone (Carboniferous) and the Glance conglomerate show fragments of typical outcrop material, containing iron oxides, silica, copper carbonates, and manganese in the pre-Cretaceous detrital material which was followed to their source, an old outcrop in the Naco limestone.

Dr. Ransome's original statement that the age of mineralization was pre-Cretaceous is undoubtedly true.

Silica Outcrops

Silica outcrops of two types are easily distinguished. On the surface in the western part of the district and underground in other parts of the district, the type known as silica breccia occurs. It is of pre-Cretaceous age and commonly crops out above ore. It is dense, fine grained, slightly iron stained, intensely brecciated, and cemented by silica. It occurs mostly either in the upper or in the lower Escabrosa (Mississippian) where zones of chert occur in the limestone. When the rocks were broken the chert horizons underwent intense shattering. Following the channels thus created, the mineralizing solutions not only cemented the limestone and chert fragments, making silica breccia, but in some places dissolved and removed the limestone surrounding the chert. In several places the thickness of the Escabrosa has been reduced by as much as 200 feet from its original 700 feet by this process. In several places the silica breccia itself was repeatedly shattered and recemented by silica.

The Bisbee Queen type of silica is of yellow to cream color and has an open, boxworklike structure with drusy surfaces. It occurs either on the contact between the Naco limestone and the Glance conglomerate, where it replaces the pre-Cretaceous limestone detrital material, or in veins in the Cretaceous formations. Several attempts to find ore in connection with the Bisbee Queen type of silica, which is of post-Cretaceous age, have failed. Nowhere does this silica penetrate for more than 100 feet below the old Naco limestone surface.

Ore Zones

The horizontal projection of ore bodies shows the ore zones in striking manner. As long as mining was near the Sacramento Hill porphyry stock, the zones were not clearly evident. The first to develop was along the Czar fault, a zone about 100 feet wide which contains ore intermittently along one or several breaks. Granite porphyry, as dikes and sills connected with the Sacramento Hill mass, is present in this zone.

The Southwest area ore zone is practically free of the influence of the granite porphyry. The ore is mostly in the Martin (Devonian) limestone and clusters about a siliceous core which crops out as silica breccia and manganese on the surface. This siliceous core, which is porous due to leaching, contained most of the lead carbonate ores that were mined from the district. The iron and possibly some copper were leached out of this silica core, which later collapsed. The lead, altering in place, remained in the silica. In this silica also the gold was both mechanically and chemically concentrated during leaching. Where shelves of contact material occurred between the silica and the limestone, variable thicknesses of silica resting on this contact were minable for gold.

The silica core may have resulted from complete leaching of siliceous pyrite which is commonly associated with ore bodies in all parts of the district. The oxidation slumping above the ore body as well as around its sides suggests this possibility.

The Shattuck ore zone, composed of four or five parallel fault zones, is as wide as it is long and is closely confined to the trough made by the Shattuck and Wolverine granite-porphyry dikes. This trough plunges northeast, and its bottom becomes a sill. Ore is found in and below the trough and also on the north side of the part designated as the Shattuck dike. The ore bodies were found in Shattuck and Copper Queen ground. In depth this trough becomes a dike which connects with the granite porphyry of Sacramento Hill.

The Cole-Oliver ore zone is made up of four or five parallel fault zones of considerable extent. Near Sacramento Hill the ore is associated with dikes and sills of granite porphyry. In the southern end the ore bodies are considerably elongated and dip at a low angle northward. In general the ore replaces limestone where rather strong but narrow fracture zones cut the limestone beds at right angles. The solutions evidently could not penetrate very far into the unbroken limestone and deposited their load in the narrow open channels.

The Junction-Briggs ore trend is composed of numerous fractures and fracture zones and, from the standpoint of mineralization, is next to the widest and strongest in the district. Its southern end also terminates in veinlike bodies of the type already described. In the north its ore is associated with granite porphyry.

The Campbell fault zone is being developed. At its north end the Denn Mine has found some ore bodies near the granite porphyry. Southward, mineralization that terminates in the Sorrel Horse ore-body area has been found along it.

The strongest, most important productive ore zone formed a semicircle around the granite-porphyry stock of Sacramento Hill and occurred both in the limestone and the contact breccia. This area was so thoroughly broken up prior to mineralization that the solutions deposited a major portion of their load here.

Ore Bodies

The first discovery of copper ore in the district was in the old open cut on the hillside above the Bisbee Post Office. Except at the White Tailed Deer Mine, it was the only copper ore outcrop in the district. The ore here was malachite and azurite, which for many years was the only kind of ore found or mined. As work progressed downward and southeastward, secondarily enriched sulphides and finally primary sulphides of minable grade were found.

It is clear from a horizontal projection that the ore bodies of the district are arranged in a semicircle around Sacramento Hill and also radiate outward from this center. The trend of ore which extends from northwest to southeast transverses the more steeply dipping limestones, hence the ore is found in higher formations in the southeast than in the northwestern part of the district.

Although some ore has been found in all of the Paleozoic limestones, certain beds in certain sections of the district contain more ore than those above or below them. Thus, in the Junction-Campbell area, in the eastern end of the camp, the Escabrosa (Carboniferous) limestone is favored, while in the Czar-Holbrook area on the western end of the district, the Martin (Devonian) was host to most of the ore. Between these areas, in the Gardner-Sacramento area, the Devonian and lower Escabrosa limestone are considered the most favorable rocks.

To the south, in the Don Luis area, the upper 150 feet of the Abrigo (Cambrian) is a particularly favorable formation. In the Denn Mine considerable ore was mined and discovered in the lower Naco limestone, although the major portion of it was in the Escabrosa limestone. Exploration in this area is not complete.

A commonly accepted idea about the replacement ore bodies in the limestone is that they are tabular, wider than they are high. The idea originated at a time when mining was done mostly in the western portion of the camp. Here the statement seems to apply until one considers that oxidation and erosion shrank and cut down the height of some of the ore bodies of this area. Southeastward it becomes more and more evident that the height of the important ore bodies is at least as great as their length or width, and in the extreme eastern ore area, height is generally greater than length or width. There are, of course, numerous small, rather tabular ore bodies in the district.

Oxidation progresses in intensity from southeast to northwest.

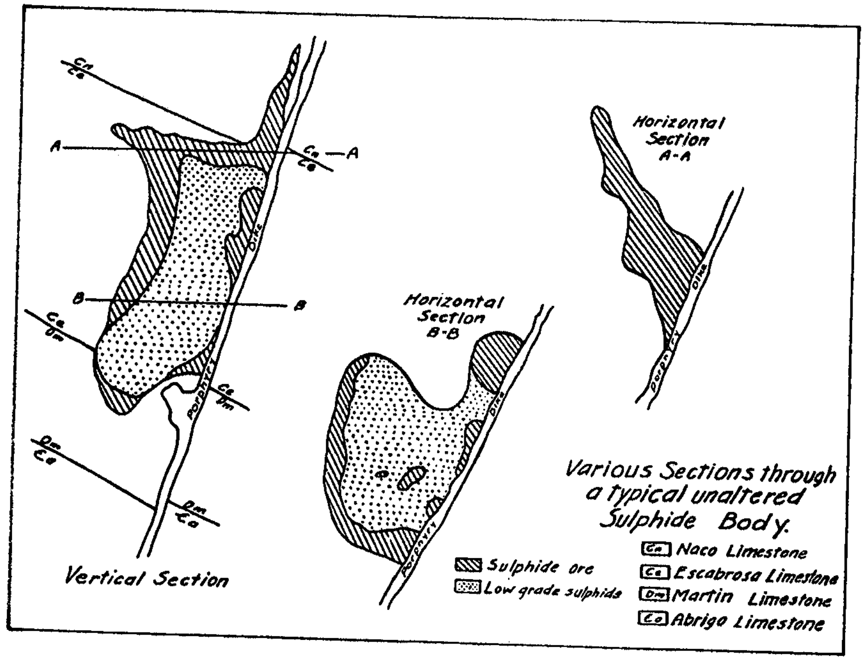

Figure 5.—Various sections through a typical unaltered sulphide ore body, Bisbee.

In small portions of the Campbell area, however, oxidation has penetrated as deep as the 2,300 level.

Ideal vertical and horizontal sections of an unaltered ore body are given in Figure 5. Practically all of the ore bodies of the district have, or had, a central core of somewhat siliceous pyrite containing small amounts of copper around which sulphides of copper and iron occurred. Oxidation and alteration obscure this relation, particularly in the northwestern part of the camp.

The pyrite core may be coarse or fine grained. In the latter case the pyrite is commonly shattered and becomes ore because of the deposition of small veinlets of copper sulphides in the breaks and cracks.

Hematite and specularite are commonly associated with the ore along its contact with the limestone. Magnetite is intimately mixed with the pyrite and chalcopyrite in certain areas.

Contact metamorphic minerals are scarce, even close to Sacramento Hill, and are practically absent at short distances from it. Characteristically there is an abrupt, clear-cut contact between the sulphide and the limestone in areas where there has been little or no oxidation. The only change discernible in most places is marbleization of the limestone. In the northwestern end of the camp where oxidation has been intense, the limestone surrounding the original ore bodies has been thoroughly saturated with the products of sulphide oxidation.

In the process of replacement the grain structure, bedding, and the included unreplaced chert lenses of the limestone are frequently beautifully preserved in the resulting sulphide.

Porphyry Ore Bodies

There is a fairly large mineralized area within the stock of Sacramento Hill. Ore in the western section of this area has been removed by steam-shovel and glory-hole mining. That in the eastern section is being mined by block caving. These ore bodies are secondarily enriched by chalcocite and are partly in the porphyry mass of Sacramento Hill and partly in the contact breccia around it. The protore contains less than 0.50 per cent copper. The stock of Sacramento Hill was highly silicified, sericitized, and pyritized, and the small amounts of chalcopyrite and bornite in the protore are responsible for the copper of the secondary enrichment. The great irregularity of the contact between the gossan and the secondarily enriched zone is worthy of note.

The porphyry on the north side of Mule Pass Gulch is not nearly so pyritized or silicified as the part in which the porphyry ore bodies occur, no secondary enrichment has taken place, and drilling found no mineralization of economic value.

Ore Guides

The ore guides in limestone may be summarized as follows:

Manganese oxides as outcrops or along fracture zones can be used as ore guides. The ore associated with them may be below or to one side of the occurrence.

Silica breccia and hematite, or both, are usually closer to ore than manganese. To get to the ore, usually found in connection with them, it is necessary to prospect down the fracture zones or the replaced bedding along which they occur.

Limonitic gossans and calcite-filled cracks in the limestone over oxidized slumped ore bodies are direct guides and point down to the possible ore.

As the calcite-filled cracks and slumping are due to either the oxidation of a sulphide ore body, pyrite body, or a solution cave, ore is not present under all of them.

Caves encountered underground are near guides, because the difference between a solution cave and a slump cave can generally be recognized.

Boxwork siderite is the result of the acid solutions which are formed when a sulphide ore body is being oxidized. The iron sulphates reacting with the limestone form siderite and gypsum. The gypsum is usually carried off in solution. The siderite forming below the sulphide which is being altered points upward as a guide. Since, however, the same solutions may come from a mass of pyrite or from a sulphide ore body, ore may or may not be present.

Granite-porphyry dikes and sills are guides to ore. By following them on both sides ore may be encountered in embayments.

Fracture zones, where they are rather steep and dip more or less normally to the bedding, are well worth following if they are at all mineralized.

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Jerome District[17]

By Louis E. Reber, Jr.[18]

Location and Extent

The United Verde and United Verde Extension, the chief mines of the Jerome or Verde mining district, are at Jerome, in Yavapai County, in north-central Arizona. Jerome is on the northeasterly slope of the Black Hills, facing across the broad Verde Valley to the northern Arizona plateau escarpment. The mean altitude of

[17] Paper prepared for, and originally presented at, the regional meeting of the A.I.M.&M.E. held at Tucson, Arizona, November 1-5, 1938.

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