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Impressions of the United Verde, UVX and Gladiator Field Trips

<u>United Verde</u> - Bob Rivera, CoCa Mines

CoCa Mines exploration efforts in the Jerome district rely on geophysics (Magnetic IP,VLF, CSMAT) soil gas surveys, Tapeats Sandstone geochemistry, Quarternary gravel studies and four diamond drill holes.

Geophysical studies have identified three anomalies; South A and A, Hopewell and Indian Camp (Slaughterhouse). The south A and A is on Phelps-Dodge ground south of the Haynes shaft. The Hopewell anomaly is located approximately 2000 feet northeast of the Edith shaft directly under a mine dump. The Indian Camp anomaly is located about 8000 feet east of the United Verde pit.

Certain ambiguities exist over the significance of the geophysical anomalies. Survey lines were run over terrane with metal fences, buried pipelines, underground rail and metal buildings. Efforts were made to minimize cultural contamination using questionable gee-whiz hockus-pockus. The Precambrian is overlain by 600-1200 feet of Paleozoic and Tertiary cover, further complicating the geophysical picture.

Mercury soil gas surveys have been run over the Hopewell and Indian Camp geophysical anomalies. Results were inconclusive.

The Tapeats Sandstone was derived from exposed Precambrian rocks. A sampling program was implemented to determine if distribution of trace elements and base metals in the Tapeats sandstone could be used to determine the presence of an undiscovered ore body. Samples were analyzed for Au, Ag, Hg, As, Cu, Pb and Zn.

The study concluded that even though anomalous geochemical values are present in the Tapeats, erratic distribution and lack of paleocurrent indicators failed to identify an area with potential for a buried ore body.

Clast type distribution studies in Quaternary gravels on the downthrown side of the Verde fault were conducted to determine if clasts of Precambrian rocks, especially gossan and jasper showed a systematic distribution eastward from the Valley fault. This might indicate a buried massive sulfide adjacent to the Valley fault. Efforts in this regard failed to show a systematic distribution of clasts. The study concluded that the jasper and gossan found in the gravels were derived from the United Verde massive sulfide body.

As part of the lease agreement with Verde Exploration, CoCa Mines drilled two diamond drill holes in the Indian Camp geophysical anomaly. In addition, CoCa drilled two of their own diamond drill holes. All drill holes failed to intersect massive sulfides. The last drill hole encountered disseminated pyrite in the Hopewell anomaly. Drilling has demanded redrawing of Paul Lindberg's geologic cross sections.

Based on the weakness of the geological data available to CoCa Mines, the expenditure of approximately $800,000(?) and the questionable economic success of an underground copper mine even at grades approaching 10%, one wonders if CoCa Mine's exploration efforts are pointed in the right direction.

<u>United Verde Extension</u> - Don White, Consultant for DMEA

Dickerson Minerals Exploration Advice (DMEA) has leased 2 claims encompassing the "gossan zone" at the top of the UVX ore body. DMEA is concentrating on the auriferous chert (gossan zone) and ignoring the massive sulfide potential. The exploration target is the extension of the "Gold Stope". The Gold Stope produced 35,000 tons of ore averaging 0.4 ounces per ton gold. Cutoff grade at the stope wall varied from 0.1 to 0.2 opt Au.

Underground diamond drilling from the 1100 and 950 levels of the Edith shaft is projected to test the possible extension of gold mineralization southward and down-dip from the Gold Stope. An earlier diamond drill hole, designed to test the updip extension of the Gold Stope, failed to reach the target because of drilling problems.

Gladiator Mine - Ken Larsen, Nor-Quest

Nor-Quest's decision to develop the Gladiator gave me a great deal of insight into the modus operandi of Vancouver-based mining companies.

Geologically, Ken Larsen's interpretation of mineralization in the sulfide iron formation and quartz-calcite ± sulfide veins is broadly similar with my interpretation gleaned from working with Noranda on the Gladiator.

Noranda's sampling of unveined, pyritic iron formation was very discouraging. Gold values rarely exceeded 0.2 ppm. Larsen's contention that ore grade Au mineralization extends a few feet away from the veined area is questionable. The drilling I supervised in 1981 showed that anomalous Au values were always associated with quartz ± calcite veinlets.

The spatial relationship of the latite porphyry dike to the veining is appreciated by the Nor-Quest staff. It is my opinion however, that the dike is the probable heat source associated with the veining event. The dike cuts the Crown King stock and is probably a late magmatic event associated with the 64 my old stock. Other gold-bearing quartz-calcite veins in the area are also associated with Laramide age porphyry dikes.

The source of precious metals is probably the Crown King stock. Another possible source is leaching of gold from the iron formation. The unveined iron formation, however, is very low in gold throughout its strike length. In addition, other gold bearing veins in the area are hosted in the Texas Gulch formation (Crown King, Del Pasco) and in pelitic sediments (Oro Belle). Overall grade is higher in veins hosted in metasedimentary rocks.

The base metals may have been leached from the iron formation. Whole rock analysis of unveined iron formation averaged 1000 ppm Zn, 25 ppm Pb and 130 ppm Cu. The relatively low concentrations may be the result of original low concentrations or depletion as a result of leaching.

Turning to Nor-Quest's chances of success, one is struck by the obviously large sum of money spent on a deposit with reserves of possibly much less than a quarter million tons. Historic production on the Gladiator and the War Eagle veins is estimated at 50,000 tons averaging 0.44 oz/ton Au, 3 oz/ton Ag, 0.35% Cu, 4.5% pb and 15.0% Zn. Current estimates from the George Cross newsletter and Nor-Quest personnel vary from 110,000 tons of 0.58 opt Au to 250,000 tons of 0.5 opt Au. Their method of calculating reserves is particularly interesting. An ex Nor-Quest geologist, who attended that fine institution in Flagstaff, passed on a tale of how Nor-Quest management could make two drill holes indicate 90,000 tons of ore.

The grades reported by Nor-Quest are also suspicious. Sampling I conducted underground in 1981 failed to yield values more than 1 or 2 ppm from the veins. Nor-Quest reports values in excess of 1 opt Au. Jacobs Lab in Tucson and the Iron King Lab in Humboldt are performing Nor-Quest's geochemical work. The best geochem results Noranda obtained was from a 4.5 foot thick massive sulfide vein which contained 0.90 oz/ton Au, 3.73 oz/ton Ag, 2.01% Pb, 6.9% Zn and 0.27% Cu. The massive sulfide was clearly vein related and occurred in a drill hole 2200' feet south of Nor-Quest's workings. Other drill holes 1800 feet to the north and 600 feet to the south of the mineralized drill hole failed to intercept massive sulfide. Based on what the tour was shown by Ken Larsen, it is hard to envision more than 25,000 tons of ore.

In conclusion, the only mining Nor-Quest will do is of it's investors.

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.

AZ B.M. Bull 145 - AZ Ore Deposits

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.

[18] Geologist, Phelps Dodge Corp.

Jerome is about 5,200 feet, and the smelter towns of Clarkdale and Clemenceau are in the valley, about 2,000 feet lower, while the highway to Prescott climbs nearly 2,000 feet higher to cross the Black Hills. The Verde Tunnel and Smelter Railroad connects Jerome with Clarkdale which is on a branch of the Santa Fe.

The Jerome mining district includes an area of about 20 square miles, extending about 8 miles southeasterly along the steep side of the valley from near Jerome, generally between the 4,500- and 6,000-foot elevation contours. This area corresponds approximately with a belt of exposed pre-Cambrian rocks, bounded on the lower side by the great Verde fault and on the upper side by nearly flat-lying Paleozoic beds. The primary mineralization is confined to the pre-Cambrian rocks, which have been sufficiently prospected to delimit roughly the area of persistent scattered mineralization of the district and to show that it does not extend far beyond the exposed area. The southeasterly limit of the district is characterized by the gradual fading out of the scattered mineralization in the exposed belt. A short distance farther south is the Cherry Creek district of small gold veins which lie in a zone paralleling and including the contact of the Bradshaw granite.

Distribution of Ore Mineralization

Within the district practically all the important mineralization occurs on or near boundaries of the intrusive Cleopatra quartz porphyry, two belts of which cross the district. This stronger mineralization does not appear to persist along the contacts beyond the limit of general mineralization, however.

The United Verde ore zone is on the north side of the north porphyry belt. The United Verde Extension (U.V.X.) ore zone is a downthrown fault segment of the same ore zone and shows the same relation to the porphyry. These two segments of the original United Verde ore zone account for over 99 per cent of the total production of the district. The Jerome Verde Mine is in an outlying ore body in the U.V.X. ore zone. The Verde Central ore zone is on the south side of the north porphyry belt. On the same contact, north and east of the Verde Central, the Hull-Cleopatra Dillon tunnel developed several small ore bodies, and several hundred tons were mined.

The Copper Chief-Equator (Iron King) ore zone is on the south side of the south porphyry belt. Small ore bodies, chiefly on the Green Monster property, farther north in the south porphyry belt, yielded perhaps a few hundred tons of ore. Several small veins have been worked for oxidized gold-silver ore. The Shea vein, which is near the Copper Chief, made some production, and the Grand Island Company shipped 100 tons of good ore from a small lens in the Copper Chief flat fault.

Away from the quartz-porphyry belts, two or three of the prospecting companies developed enough ore to supply the stockholders with specimens.

United Verde Ore Zone

Location and development.—The United Verde Mine is west of Jerome. The outcrop of its ore zone was in a notch where the head of Bitter Creek cut into the relatively steep valley slope above the Verde fault (Pl. VIII). The open-pit work has removed most of the top of the ore zone, nearly to the 600-foot level. The collar of No. 3 Shaft, from which the mine levels are measured, was at an altitude of 5,500 feet. The ore zone is thoroughly developed by means of level work and diamond-drill holes to the 3,000-foot level with some work on the 3,300-foot level (altitude 2,200 feet), and a small amount of somewhat deeper diamond drilling. There is extensive stoping to the 2,550- and a little on the 2,700-foot level. Much ore remains in pillars throughout the mine.

On the 1,000-foot level the Hopewell tunnel, with a standard-gauge railroad over a mile in length, connects the mine ore bins with the surface and the railroad to the smelter. The new No. 7 Shaft, not yet in operation, comes to the surface east of the ore zone, on the 300 level bench, near the outcrop of the Verde fault (Pl. IX).

An adit tunnel on the 500-foot level connects the principal working shaft (No. 6) with the main surface plant.

There is work along the Verde fault in the Hermit claim on the 500-, 600-, 700-, and 1,000-foot levels.

Structure and extent.—The United Verde ore zone, as developed in the United Verde Mine, consists of a very irregular pipelike body of massive sulphide, quartz, and mixed sulphide and rock, with a steep north-northwesterly plunge. Quartz predominates on the hanging wall or diorite side of the main sulphide mass, with the mixed material on the footwall or quartz-porphyry side. In plan the mineralized zone ranges from more than 500,000 square feet or about 12 acres to less than 300,000 square feet, with an average near 400,000 square feet. The massive sulphide itself has an average cross section of approximately 250,000 square feet.

The downward trend of the ore zone is determined by a steeply dipping, very irregularly interfingering intrusive contact between rhyolitic quartz porphyry to the south and a series of banded tuffs and sedimentary material ("bedded sediments") to the north. It is located where the average strike of the contact changes from northerly to northeasterly. The more regularly curving contact of the diorite mass, which approximately parallels the rhyolitic porphyry-bedded-sediment contact, forms a clean-cut limit to the northerly or hanging-wall side of the ore zone. On the footwall or quartz-porphyry side the boundary is very irregular and interfingering, largely controlled by the schistosity of the porphyry, the average trend of which is about N. 10 degrees W. with steep easterly to vertical dips (Pl. XII).

In the upper part of the mine an embayment in the diorite and a band of relatively strong schistosity in the quartz porphyry combined to give the ore zone a roughly lenticular cross section, with the longer axis corresponding to the trend of the schistosity (Pl. X).

In the lower levels the more open curve of the diorite, the less intense but more uniform schistosity of the quartz porphyry, the tendency of the schistosity to approach parallelism to the contact, and, no doubt, less irregularity in the original porphyry contact, were jointly responsible for the crescent-shaped outline of the ore zone with the elongation more or less paralleling the diorite and much less interfingering with the porphyry (Pl. XI).

Although other sulphides are present, the copper content of the ore as a rule depends on the abundance of chalcopyrite. Pyrite, generally with appreciable sphalerite, constitutes the sulphide gangue. Black chlorite rock, with some quartz porphyry and quartz, is the predominant rock gangue. About one seventh of the volume of the mineralized zone is commercial copper ore, and a somewhat smaller amount is possible low-grade zinc ore.

Replacement.—As may be inferred from the preceding description of the structural features that control the form of the ore zone, the mineralization is very clearly of the replacement type. Characteristic structures and textures of the replaced rock are commonly preserved by the massive sulphide, and residual shreds of rock or unreplaced quartz phenocrysts are present in many places. Such evidence bearing on the former distribution of rock types in the ore zone aids the unraveling of the complicated history of the mineralization, which in turn serves to explain the occurrence and distribution of the commercial ore.

Sequence of mineralization.—Several definite stages of deposition can be recognized, although the extent to which they represent distinct periods in the sequence, rather than parts of a more or less continuously progressive change, is not clear.

Paragenesis or sequence of mineral deposition, as conventionally determined by the microscopic study of polished surfaces, may prove misleading unless interpreted in the light of detailed study of the occurrence and distribution of the material in place. The correct understanding of the most significant features of a complicated chronology may depend much more upon field study than upon the microscope. Nevertheless the results of microscope work are also essential to a complete understanding.

Microscope work by Benedict,[19] Lindgren,[20] and Hansen,[21] supplies such data.

Two points not made clear by the microscope are significant. First, although breccia filling and replacement of earlier by later sulphides were quantitatively important, rock replacement was most important from beginning to end, so that in a broad way the distribution and structure of any generation of sulphides was primarily controlled by the location of the most accessible unreplaced rock left by preceding generations. Second, the bulk of the black chlorite was formed after deposition of most of the lean pyrite and before most of the chalcopyrite.

The most plausible interpretation of the mineralization is then as follows: The first solutions followed sections of the porphyry contact nearest the diorite and deposited quartz with negligible quantities of pyrite and chalcopyrite and probably specularite. The quartz favored replacement of the bedded sediments but in places left a narrow unreplaced strip against the diorite.

The second period of mineralization deposited pyrite with important quantities of dark red-brown sphalerite or marmatite and a little chalcopyrite, with probably some local quartz as well as intergrown quartz and dolomite similar to that of the sixth period. Microscopic arsenopyrite preceded the pyrite. This period is responsible for the major part of the ore zone, and probably a large part of the possible zinc ore, but no commercial copper ore. Some bedded sediments were replaced, but the pyrite appears to have shown a preference to replacement of the porphyry. For the above reason, or because it was already sealed off by the quartz, the strip of bedded sediments along the diorite remained unreplaced. Microscopic magnetite and a very small amount of specularite following the pyrite were perhaps precursors of the change from sulphide to high-iron chlorite deposition.

The third period represents a definite break in sulphide deposition. Solutions working out from the footwall of the pyrite sulphide mass completely replaced an enormous volume of quartz porphyry and some tongues of the bedded sediments with a nearly black, high-iron variety of chlorite.

In the fourth period were deposited much pure chalcopyrite and considerable chalcopyrite intergrown with nearly black sphalerite or marmatite and in places with galena and probably some pyrite. The chalcopyrite appears to have most readily replaced the black chlorite rock or "black schist." This period was responsible for most of the commercial ore. Numerous tongues and lenses of "black schist" interfingering with the earlier sulphide were completely replaced, material additions were made to the total volume of massive sulphide, and some scattering mineralization formed ore bodies in the schist but very rarely penetrated the quartz porphyry.

The structure that controlled the form of the ore zone in the upper and lower levels is also significant. In the upper levels there was evidently much more interfingering of replaced and unreplaced rock before the chalcopyrite came in, and by further replacement it penetrated deep into the earlier lean sulphides. In the lower levels the earlier sulphide mass was comparatively tight, and for the most part the chalcopyrite was forced to build onto the footwall of the pyrite or spread out into the schist. Probably the greater steepness and regularity of the diorite wall in the lower levels also militated against a more favorable distribution of the early sulphide.

[19] P. C. Benedict, *Geology of Deception Gulch and the Verde Central Mine*, unpublished thesis, Mass. Inst. of Technology, 1923.

[20] Waldemar Lindgren (U.S.G.S. Bull. 782, 1926).

[21] M. G. Hansen, *Microscopical Examination of the United Verde Sulphide Orebody*, unpublished report to United Verde Copper Company, December, 1927.

After the fourth-period mineralization numerous small andesite or fine-grained diorite dikes cut through the ore zone and surrounding rocks along nearly vertical east-west fractures at intervals of 100 to 200 feet or less. These dikes range in thickness from a few inches to 20 feet, although most of them are less than 2½ feet. Such dikes are common throughout the district but nowhere else so abundant. Though somewhat mineralized locally, characteristic differences in the fracturing where they cut high-grade chalcopyrite from that in the lean pyrite are believed to prove them younger than the principal chalcopyrite stage of deposition.

During the fifth period small masses of quartz, in part associated with considerable bornite and probably some other sulphides, were deposited. Microscopic primary chalcocite is intergrown with bornite, and recrystallized black chlorite is an occasional associate.

The sixth and last period was characterized by widespread deposition of intergrown quartz and dolomite or calcite in part associated with chalcopyrite; pyrite; a relatively clear, glassy, pale brown or greenish variety of sphalerite; and tennantite. This mineralization is most conspicuous in the chlorite rock or black schist and probably added materially to the volume of schist ore. The tennantite, predominantly arsenical, contains some antimony and about 40 ounces of silver to the ton, but it rarely affects the silver content of the ore. The same mineral association deposited in fractures in the older quartz and sulphides and in small gash veins in the schist, in places with margins of fibrous serpentine, is the final phase.

Changes with depth.—The ore zone in the U.V.X. Mine probably represents a segment from over 2,000 feet above the top of that exposed in the United Verde Mine. Probably a large part of the chalcocite ore was of fairly good grade before enrichment. As in the highest levels in the United Verde, there was probably a smaller-than-average area of mineralization, with a higher-than-average proportion of chalcopyrite.

In the United Verde Mine the size of the ore zone and the amount of copper ore both vary greatly from level to level. Both increase where the plunge of the ore body is less steep than average.

In a very broad way, the trend is a diminishing one from the top to the bottom of the mine as regards quantity of ore, and from about the halfway point to the bottom as regards the size of the ore zone. The ore zone at the bottom is somewhat larger than the minimum between the halfway point and the surface.

The structural features are no doubt to some extent responsible for the diminishing quantity of ore.

If the lower-level trend of the ore zone and the dip of the east end of the diorite persist, the ore zone may leave the diorite altogether, in which case some scattering of the ore zone, with perhaps discontinuous lenses of massive sulphide, would be expected

This change would probably mean less commercial ore in proportion to the total copper mineralization but might have some favorable aspects. There is a chance for the ore zone to flatten out before it entirely leaves the diorite.

A mineralized zone, with an area of about 10,000 square feet of massive sulphide, quartz, and mineralized schist, encountered on the 3,000-foot level, west of the diorite on the U.V.X., Haynes property, may represent the top of a branch from the main ore zone. If so, the ore zone may become stronger below the junction.

The Haynes-area mineralization includes considerable magnetite and a small amount of pyrrhotite, although otherwise typical of the main ore zone. This may be the precursor of an unfavorable mineralogical change with depth. The mineralization has been remarkably constant for a vertical range of over a mile, from the highest primary mineralization in the U.V.X. Mine to the bottom of the United Verde. Microscopic pyrrhotite in the main ore zone on the 3,000-foot level and more microscopic magnetite and specularite than above, tend to confirm the Haynes showing.

Analyses.—The analyses in Table 3, though not exact averages, give the approximate chemical composition of the material of the primary mineralized area. The last two show the change effected in replacement of quartz porphyry by chlorite.

In addition to the material represented by the analyses, a considerable volume of lean siliceous sulphide and quartz and a smaller amount of mineralized bedded sediments make up the volume of the mineralized zone.

Abundant black chlorite in the ore added greatly to smelting difficulties. In 1927 the concentrating plant was added to the smelter at Clarkdale primarily to eliminate excess black schist from the smelting charge rather than to treat lower grade ore.

Sulphide enrichment.—Although apparently unenriched massive pyrite was in places close under the oxides, it is believed that chalcocite enrichment appreciably affected the chalcopyrite ore as deep as the 500-foot level. Possibly a considerable part of the highest grade ore on the 300-foot level was chalcocite. Detailed records of the early mining are lacking, and pit operations encountered most of the highest grade pillar material as crushed and broken fragments often mixed with old stope fill. Much chalcocite and considerable bornite were present in the most crushed material from the pillars under the 300-, and less extensively under the 400-foot levels. Conditions did not permit even an approximate estimate of the total amount or the mode of occurrence of the chalcocite and bornite encountered in the pit.

Bornite and steely chalcocite were found as lumps and boulders in loose, porous material showing evidence of intense fire action. The time from the first mine fires to the opening of the pit was about thirty years, during much of which the material was extremely hot. The appearance and occurrence of the bornite sug-

TABLE 3.—AVERAGE ANALYSES (PER CENT).

	Cu	Zn	SiO_2	Fe	Al_2O_3	S	CaO	MgO	K_2O	Na_2O	H_2O	CO_2
Lean massive sulphide	0.70	1.33	11.00	35.00	1.39	37.00	2.07					
Zincky massive sulphide	1.16	6.72	11.50	33.00	1.18	38.00	0.78					
Massive sulph. copper ore	4.99	2.40	11.80	31.40	3.50	32.60	1.80					
Siliceous sulph. copper ore	5.44	1.90	37.20	21.40	3.70	21.30	0.64					
Schist copper ore	4.73	0.70	22.90	20.70	12.70	15.40	1.22					
Quartz porphyry copper ore	2.79	0.90	40.10	15.70	12.50	10.80	1.05					
Quartz porphyry	0.02	0.04	72.08	2.21	14.57	0.06	1.98	1.48	2.38	1.26	2.67	1.35
Black schist (chlorite)	0.03	0.26	26.23	15.59	25.99	0.11	0.11	18.16			8.55	0.04

gested that it might have formed in the fire area. Boyd[22] in 1935 concluded that all or nearly all of the bornite and probably much of the chalcocite were formed by fire action. He produced bornite by maintaining chalcopyrite at a temperature of 500 degrees Centigrade in a reducing atmosphere for four to five hours. With further heating some bornite changed to chalcocite. It is thus likely that much of the chalcocite in the pit was not due to original secondary enrichment. Furthermore, the absence in the oxide zone of any such accumulation of quartz as characterized the gossan over the U.V.X. chalcocite, makes it probable that the former chalcocite zone over the United Verde was much weaker than that of the U.V.X., and that enrichment before the pre-Cambrian faulting accounts for this difference.

Sooty chalcocite and covellite, sufficient to affect ore values, were found in crushed material below the 500-foot level. This enrichment was of comparatively recent date and presumably due largely to fire-zone conditions.

A body of disseminated ore in the quartz porphyry adjoining the main ore zone, about 500 feet in vertical extent and containing about 1,000,000 tons of 1.5 per-cent ore, was formed by secondary enrichment of very lean disseminated pyrite. The very small amount of leached capping and the prevalence of traces of oxidized copper mineral throughout indicate this enrichment to be not related to the present erosion cycle.

The distribution of the gold and silver in the open pit and comparison with primary ore at greater depth led to the conclusion that there has been secondary enrichment of both gold and silver. Possibly the precious-metal enrichment also had some relation to artificial stimulation by fire-zone conditions.

Oxide zone.—The gossan of the United Verde ore zone occurred as a blanket about 100 feet in average thickness with the low point slightly below the 160-foot level of the mine. It consisted largely of rather highly colored, soft limonitic material with lenses and boulders of hard iron oxide. At the south end copper carbonate minerals were conspicuous where mineralized black schist interfingers with the quartz porphyry. On the north end massive primary quartz cropped out against the diorite. Lower and to the south of the massive quartz and to some extent along the east side of the gossan, were a few prominent exposures of brecciated, honeycombed quartz. The greater part of the soft gossan was no doubt covered with soil and boulders of the hard limonite.

High-grade gold-silver ore was mined from parts of the soft gossan, and several places showed high concentrations of native silver immediately overlying the sulphides. When mined from the open pit, almost all of the soft gossan proved to be of commercial grade. Portions with relatively low gold-silver were generally high enough in silica to make converter flux.

[22] L. H. Boyd, *Microscopic Examination of Certain Ores from the United Verde Fire Stopes*, unpublished thesis, Colorado School of Mines, December, 1935.

The following analysis (in per cent) is of oxide ore shipped during 1918:

Cu	Fe	Zn	SiO_2	Al_2O_3	S
1.42	31.5	0.2	34.1	5.7	4.2

The Hermit claim has about 230,000 tons of oxidized copper ore, chiefly azurite and malachite with some chrysocolla, copper pitch, and black copper oxide, in basalt and prebasalt gravel in the hanging wall of the fault. The copper was evidently transported from the top of the United Verde ore zone.

U.V.X. Ore Zone

Location and development.—The U.V.X. Mine is below the fault on Bitter Creek where it parallels the lower side of Jerome (Pl. VIII). The collar altitude of the original Daisy shaft is 5,050 feet, and the bottom of the mine is the 1,900-foot level at 3,200 feet altitude. Some diamond-drill work has been done in the ore zone below the 1,900-foot level, and the outlying area, formerly Jerome Verde property, is explored most extensively on the 1,400- and 1,700-foot levels. The Josephine tunnel, with a standard-gauge railroad 2¼ miles long, connects the shaft ore bins with the surface.

Structure and extent.—The Daisy shaft passed through the fault into the pre-Cambrian rocks at 4,600 feet altitude, whereas the main shafts are in younger rocks to about 4,300 feet altitude.

The top of the ore zone ranges from a little above the 700-foot level to a little below the 800 level, with 500 to 700 feet of overlying younger rocks. Although a wedge of Paleozoic formations overlies part of the ore zone, most of it was exposed by a deep Tertiary canyon so that prebasalt gravel rests directly on the gossan (Pl. XIV).

The ore zone on the 800-foot level, near the top of the pre-Cambrian (Pl. IX), is of about the same size or a little larger than the top of the United Verde ore zone.

The form and trend of the U.V.X. ore zone has been controlled primarily by the greenstone-quartz porphyry contact and to a less degree by the margin of the diorite. The general east-west trend of the interfingering porphyry contact and the local schistosity parallel to that trend account for the direction of the long axis of the main ore body.

As shown on the 1,300-foot-level map (Pl. XIII), the main ore body, with maximum east-west length of about 500 feet and width of about 200 feet, constitutes the most important part of the ore zone. From the main ore body bands of mineralization extend northwesterly around the northeast side of the diorite and penetrate re-entrants in the diorite. In the upper part of the ore zone the northeast diorite contact dips northeast and the southeast contact dips generally southeast; the re-entrants are to some extent southeasterly plunging troughs in the diorite. Small vein-like tongues with a northwesterly plunge extend south and east of the main ore body along shear zones related to the interfingering of porphyry and greenstone.

In the lower part of the ore zone, the southeast or south side of the diorite has a northerly dip and the east part a westerly dip that corresponds with dips in the United Verde. The ore zone which consists of lenses of massive sulphide joined by weaker mineralization plunges northward. The pinching out of the main lens of massive sulphides below the 1,600-foot level, at an altitude of about 3,450 feet, forms a sag in the footwall of the ore zone entirely comparable to the footwall structure in the United Verde Mine. The deeper sulphide lenses are generally closer to the diorite, though also related to the porphyry-greenstone contact. Unlike the United Verde Mine, the U.V.X. Mine contains much fine-grained, schistose marginal diorite, some of which has been mineralized. The apparent penetration of the diorite by massive sulphide, however, is partly due to faulting.

Faulting.—From near the pre-Cambrian surface to below the 1,900-foot level the U.V.X. ore zone is progressively cut off by the Verde fault.

The possibility of pre-Cambrian postmineral faulting was always given due consideration but not regarded seriously until work in the U.V.X. Mine proved the complete cutoff of the ore zone by the fault and began to suggest that there was no footwall continuation. The predominant trend of striations and rolls in the fault indicates a direction of movement not more than 10 to 20 degrees southeast of the dip. This direction, with the measurable vertical component, pointed to the position of the footwall segment, although the evidence was not deemed conclusive enough to justify definitely limiting prospecting along the fault. Exploratory work by 1926 made it fairly certain that there was no segment of the ore zone under the fault and established the corollary of pre-Cambrian displacement. By projecting all geologic data on fault-plane sections, the writer showed conclusively in 1928 that the opposite sides of the fault could not be made to match by reversing the Tertiary movement, regardless of assumptions as to lateral movement. This fact established the former continuity of the United Verde and U.V.X. ore deposits beyond reasonable doubt. Projecting the United Verde ore zone and the plane of the fault to an intersection above the outcrop gives a vertical displacement of about 4,000 feet, or possibly anywhere between 3,500 and 4,500 feet. Projecting the base of the Paleozoic rocks to the plane of the fault from opposite sides gives 1,600 feet for the Tertiary vertical displacement, which is probably exact within 50 feet. Hence the pre-Cambrian displacement was 2,400 feet plus or minus 500 feet. These figures check with Ransome's interpretation.[23]

In general nearly 90 per cent of the Tertiary Verde fault movement is connected along the Verde fault, a single plane with heavy gouge sometimes referred to as the main footwall break. The remainder of the Tertiary and possibly some of the pre-Cam-

[23] F. L. Ransome, *Ore Deposits of the Southwest* (16th Int. Geol. Cong., 1932), Guidebook 14, pp. 20-21 and Pl. 4.

brian movement is distributed over a braided system of small hanging-wall breaks that are extremely difficult to map accurately and may have considerably affected the structural details of the sulphide masses.

Due to several much stronger hanging-wall branches farther north and up the dip of the fault, the footwall strand under the small sulphide body mined from the United Verde 600-foot level represents only about half of the total Tertiary displacement.

Sulphide zone.—The top of the sulphides of the main ore body is about 50 feet below the 1,200-foot level. Over the most important vein ore body, it is near the 1,100-foot level. Small sulphide masses in the quartz and some sulphide in the southeast veins range from altitudes of 4,300 to 4,400 feet, with a few fairly close to the pre-Cambrian surface.

Although primary quartz and residual pyrite are present, the primary mineralization is masked by intense secondary enrichment throughout much of the mine. There was enough primary material in the deeper parts of the mine, however, to permit comparison with the United Verde deposit.

The hard, dense, lean pyrite with microscopic quartz, which is conspicuous in the United Verde ore zone, is scarce in the U.V.X. ore zone, which contains a greater abundance of quartz-carbonate gangue. Most of the minerals of the United Verde deposit are present in the U.V.X., and all of the primary material in the U.V.X. deposit can be duplicated in the United Verde deposit. The black chlorite rock or "black schist," with the characteristic interfingering pattern, is extensively developed by replacement of quartz porphyry and siliceous greenstone in the vicinity of the main U.V.X. ore body. Farther north it replaces less siliceous greenstone and minor quantities of schistose diorite as well as quartz porphyry.

The sequence of mineralization appears to have been similar to that in the United Verde Mine.

The typical lean primary sulphide in the U.V.X. Mine consisted of pyrite with minor quantities of sphalerite and chalcopyrite (2 to 4 per cent zinc and ½ to 1½ per cent copper), in places banded, with admixture of quartz carbonate, and cut by numerous quartz-carbonate veinlets.

The lower part of at least one of the smaller ore bodies was very good, clean, primary chalcopyrite ore. Some and perhaps much of the slightly enriched ore owed its value to primary chalcopyrite. The proportion of chalcopyrite in the primary material does not differ greatly from that in the United Verde Mine.

The study of polished sections by Lindgren[24] and Schwartz[25] indicates the quantitative importance of pyrite replacement, and

[24] Waldemar Lindgren, *Ore Deposits of the Jerome and Bradshaw Mountains Quadrangles, Arizona* (U.S.G.S. Bull. 782, 1926), pp. 54-97.

[25] G. M. Schwartz, "Oxidized Copper Ores of U.V.X. Mine," *Econ. Geol*, XXXIII (January, 1938), pp. 21-33.

Lindgren[26] has expressed the view that there never was much chalcopyrite in the ore. The writer believes that chalcopyrite replacement was most important in portions of the high-grade chalcocite ore. If this is true, proportion of primary chalcopyrite in the U.V.X. deposit corresponds to a better-than-average section of the United Verde deposit.

Sulphide enrichment.—The intensity and extent of the secondary enrichment in the U.V.X. Mine formed an almost unique deposit of chalcocite that places the mine in the front rank of high-grade copper mines. Outside of the main ore body the principal lenticular veinlike body was a small bonanza in itself, and numerous smaller bodies helped to swell the high-grade total.

The decrease of chalcocite with depth, the general scarcity of chalcopyrite or sphalerite where chalcocite was most abundant, and the intense kaolinic alteration of the wall rocks, varying with the abundance of chalcocite, conclusively indicate formation by the process of secondary enrichment, which is also confirmed by microscopic evidence.

The evidence only shows that all but a very little of the chalcocite was formed before the deposit was covered by the Paleozoic sediments. Since then, except for a fleeting instant in geologic time, after the precipitous prebasalt canyon barely cut into the top of the gossan, the deposit has been continuously buried. A minute quantity of sooty chalcocite and covellite has been formed by underground-water circulation since the faulting. The basal Tapeats sandstone is not believed to be older than middle Cambrian, and important secondary enrichment could have taken place in early Cambrian time. The same reasoning applies to the date of the earlier postmineral faulting; but evidence from comparison with the United Verde deposit indicates that the greater part of the U.V.X. enrichment preceded that faulting; and minor deformation, thrust faulting, and probable interrelation of the intrusive rocks point to a not very late pre-Cambrian age for the primary mineralization and make it most probable that the age of the enrichment was truly pre-Cambrian.

Oxide zone.—The bottom limit of the oxide zone in the U.V.X. Mine is extremely variable, ranging from an altitude of about 3,850 feet over the main ore body to more than 4,400 feet at the tops of some of the smaller sulphide bodies. Above the 1,200-foot level, however, dense fine-grained primary quartz, much of which carries very little sulphide, becomes more and more predominant. Within the quartz were a number of irregular lenses of high-grade quartz-chalcocite ore, some of very limited vertical extent. In the higher bodies malachite, locally with a little cuprite, was conspicuous but generally unimportant.

The gossan or capping over the main ore body is extremely siliceous and includes much massive quartz which in part shows repeated brecciation and recementation, but in part is difficult to distinguish from the undisturbed primary quartz. Somewhat

[26] Waldemar Lindgren, unpublished report of U.V.X. Mine, August, 1926.

cavernous, hard quartz breccia with considerable limonitic material is more abundant than the cleaner quartz. Soft limonitic material, comparable to most of the United Verde gossan, occurs only very locally, although predominant close to the top of the sulphides, with much native copper in places. The vertical extent of the gossan ranges from 450 to 500 feet. Some of the smaller quartzy ore bodies were capped with 40 to 50 feet of relatively irony gossan, but in a few places the chalcocite merged into massive quartz with no obvious leaching or slumping.

The veinlike tongues extending south and east from the main ore bodies, not terminated by weaker mineralization, were overlain by 50 to 100 feet of thoroughly leached, kaolinized rock with more or less limonitic material. The vertical range of the ore bodies was from near the 1,300-foot level to a few floors above the 800-foot level. Oxidized copper minerals which were prevalent throughout, in some of the higher parts accounted for over half the copper content and entirely masked the finely divided chalcocite. All the more common oxidized copper minerals were present, with malachite, chrysocolla, and azurite most abundant. In the deeper parts sulphides with some small stringers and lenses of massive chalcocite and bornite were generally more conspicuous.

Such partially oxidized copper ore yielded nearly one eighth of the production of the mine, whereas ore with all the copper in oxide minerals, mined from the prebasalt gravel or conglomerate in the northwest part of the mine amounted to about 2 per cent. The conglomerate ore was formed at a comparatively recent date by ground water carrying copper presumably from the top of the United Verde ore zone and is similar to ore developed by the United Verde along the fault.

Unlike the United Verde gossan, even the soft limonitic material was rarely commercial gold-silver ore in the U.V.X., although some high-grade native silver ore occurred above the chalcocite of the main ore body.

The "gold stope" ore body was a tabular veinlike body along the diorite contact, bottoming in a trough in the diorite, and in part limited by massive quartz. The typical ore was fine-grained friable quartz sand with almost no residual iron oxide. The maximum length was about 350 feet, the width from 5 to 20 feet, and the vertical extent nearly 200 feet. It extended above and below the 950 level from an elevation of about 4,060 feet to about 4,250 feet. It may have averaged $10 per ton in gold, with some relatively high-grade sections. Evidently, the local conditions were exceptionally favorable to concentration of gold.

Copper Chief-Iron King Ore Zone

Location and development.—The Copper Chief and Iron King or Equator mines are 3½ miles south-southeast from Jerome (Pl. VIII). The two mines are separated by a property boundary that divides the ore zone, with the Copper Chief to the west and

the Iron King to the east. The collar of the Copper Chief shaft was within the principal gossan area at an altitude of about 5,750 feet. On the bottom level, about 350 feet lower, an adit tunnel connects the shaft with the surface 850 feet to the south. There was fairly extensive stoping of oxide ore from the 240-foot level to the surface on the Copper Chief side of the property line. Mill holing of ore and waste fill has formed a considerable pit at the surface corresponding to the original extent of the gossan. All the Copper Chief work above the 240-foot level is inaccessible. On the 300-foot level are some stopes in massive sulphide.

The Iron King Mine was worked through an adit from the east about 80 feet above the Copper Chief adit, with a length of about 500 feet from the portal to the property line. Stoping extends from about 15 feet below the tunnel to about 70 feet above, with several raises, winzes, and sublevels.

Structure and extent.—The Copper Chief-Iron King ore zone extends for about 800 feet along a vertical premineral fault contact that trends about N. 80 degrees E. between quartz porphyry on the north and banded greenstone tuff on the south. It has been formed very largely by replacement of the greenstone; the quartz porphyry makes a fairly regular, nearly vertical north wall. West of the property line the deposit has the form of the west half of a fairly regular lens, with the south side somewhat ragged due to the influence of the low-angle northerly dip of the greenstone banding. The surface gossan was about 60 feet wide near the property line and extended about 250 feet west. The deposit has a somewhat smaller horizontal area at the top of the massive sulphide, about 240 feet down, and bottoms on the banding of the greenstone at about 320 feet.

Near the property line the top of the gossan plunges to the east, leaving on the surface only a narrow streak that follows the contact down to a mass of gossan at the portal of the Iron King tunnel and a few less-definite streaks along the trend of the south side. In the Iron King end the south or footwall side of the ore zone is more completely controlled by the rock banding so that vertical sections tend to have an unsymmetrical inverted crescent form, with the bottom progressively thinner eastward until it pinches out.

At or near the bottom the porphyry contact leaves the steep fault and continues with a relatively flat north or northwesterly dip. No downward continuation of the mineralization has been found other than a very small chimney or pluglike mass of lean sulphide, about 600 square feet in area, which trends vertically downward in the greenstone.

Copper Chief fault.—The Copper Chief fault, which has a very flat west to northwesterly dip, cuts through the Iron King tunnel near the portal, passes under the ore zone, and shows on the Copper Chief tunnel level. It can be traced on the surface for about ¼ mile to the north and ¾ mile to the southwest from the Iron King portal (Pl. VIII). A rather extensive diamond drilling campaign was based on the possibility of the fault having cut the ore zone and someone's opinion that the fault represented a large overthrust from the northwest. At a later date the Iron King winzes were unwatered and the small chimney of massive sulphide rediscovered on the 100-foot sublevel. A small amount of work to improve the exposure of the fault brought to light evidence of grooving and drag and gave a nearly exact measure of the amount and direction of the fault displacement. This indicated a horizontal throw of a little over 300 feet in a direction more nearly east than southeast. The negative result of the exploratory work indicated by this determination made it fairly certain that there was no displacement of the bottom of the main sulphide lens.

Sulphide zone.—Although there is much less fine-grained jaspery quartz, and black chlorite is conspicuously absent; the general character of the sulphide mineralization has enough in common with that in the United Verde to indicate a close relationship. Any type of sulphide aggregate in the Copper Chief-Iron King ore zone is duplicated somewhere in the United Verde.

Sulphide enrichment was limited on the Copper Chief side to a 2- to 4-foot layer where sooty chalcocite and covellite merged downward into crumbly pyrite and upward into oxidized material, in places with some concentration of copper and lead carbonate, and to a similar but generally thinner layer on the Iron King side. Some of this material was high in silver.

Probably about half of the sulphide in the ore zone was ore. Nearly all of it was in the Iron King end, from which about 30,000 tons were smelted. The Copper Chief shipped a few hundred tons of sulphide ore when there was a good copper market, and more recently lessees have shipped about 6,000 tons of low-grade sulphide to the U.V.X. company for flux.

Oxide zone.—The oxide ore mined by the Copper Chief and Equator companies was very similar to the soft limonitic gossan of the United Verde, although the average lead content was no doubt somewhat higher. The few thousand tons of lower grade oxide left in the Iron King by the Equator Company and now being taken out by a lessee are decidedly less irony and considerably higher in lead.

Verde Central Ore Zone

Location and development.—The Verde Central Mine is south of Walnut Gulch near the Jerome-Prescott highway and about 4,000 feet south of the United Verde Mine.

The collar of the main shaft is at an altitude of about 5,500 feet. The bottom level is the 1,900 foot at an altitude of 3,594 feet. In addition to the development of the productive area, there is extensive exploratory work to the south on both the 100- and 1,000-foot levels and a long crosscut to the west on the 1,450-foot level.

Structure and extent.—The Verde Central ore zone, like the United Verde and U.V.X. zones, is where the contact of the quartz porphyry is extraordinarily irregular or interfingering, although

on the footwall instead of the hanging wall of the porphyry mass. The exceptionally long tongue of porphyry extending south from above the Verde Central and the change in the average trend of the contact are probably most significant. The Verde Central was a "blind" prospect because the plunge of the interfingering contact zone brought the mineralization into the workings below the surface. The surface showing of irony gossan, altered black schist, and quartz with some oxidized copper minerals, around the end of the porphyry tongue on top of the hill to the south at an altitude of about 5,850 feet, undoubtedly is the outcrop of the Verde Central ore zone (Pl. IX).

There are two types of ore in the mine. One on the contact extending south from near the shaft is patchy mineralization in black schist. This has produced an ore body which extended from above the 800- to below the 1,000-foot level, with a length of about 200 feet and a mean width of about 9 feet.

The other type, the one responsible for most of the Verde Central ore, consists of a tabular, veinlike body of quartz, pyrite, and chalcopyrite in varying proportions, which though irregular in detail and varying in width from 5 to 30 or 40 feet, is essentially continuous for a maximum length of over 1,000 feet on the 1,000-foot level. It begins to show near the top of the mine, and is still fairly strong at the bottom. Although there is much less chalcopyrite than quartz or pyrite, its distribution is such that bodies of good size and an average copper content of nearly 3 per cent can be mined. Below the 600-foot level, ore of this character made up a fair proportion of the vein. Mining more selectively to produce higher grade ore would be very difficult, however.

It required abnormally high copper prices to enable the Verde Central to enter production, and the net profit on the copper produced plus any additional profit that may result from the developed ore remaining in the mine, must fall far short of returning the cost of the exploratory work.

Sequence of mineralization—Three stages of deposition—quartz, pyrite, and chalcopyrite—or four, if the black chlorite be included, correspond to the principal periods of deposition in the United Verde deposit. A vertical channel pattern of the ore shoots in the vein points to a definite separation between the pyrite and the chalcopyrite periods, although there is not much indication of the black chlorite solutions having followed the main pyrite channels as might be expected from comparison with the United Verde. For the most part, the black chlorite appears to have worked out from the porphyry contacts. What appears to be an abnormally low precious-metal content may be a function of the scarcity or absence of the other sulphides common as minor constituents of the United Verde deposit.

Supergene, secondary sulphides and oxide zone minerals are of negligible interest or importance in the Verde Central ore bodies, although a few burro loads of carbonate ore and chalcocite were found associated with the outcrop of the ore zone.

Shea Ore Zone

Location and development.—The Shea Mine is about 1,500 feet south of the Copper Chief outcrop. The shaft follows a south-dipping vein for 1,220 feet at an average dip of 42 degrees, attaining a vertical depth of 825 feet. The lower tunnel level, which reaches the surface about 1,300 feet east of the shaft, has almost 3,000 feet of drifts. The total of all the level work is about 7,000 feet.

Structure and extent.—Though replacement was no doubt a factor, the Shea vein is a clean-cut quartz vein that follows a premineral fault of a probable throw of more than 100 feet. The vein can be traced for about 1,200 feet east from the portal of the main adit, making the known length over 3,400 feet. The most westerly 650 feet of the adit level drift is on a different fracture. The surface exposure ends less than 200 feet west of the shaft where blanketed by the flat Copper Chief overthrust fault. Farther west the vein is weak immediately under the fault, and the fissure has not been positively identified on the surface west of the flat fault outcrop. In the most westerly part of the mine and from some distance west of the tunnel portal to the east limit of exposure, the quartz is lenticular and discontinuous. It may not average more than a foot in thickness throughout the mine, although the maximum in the vicinity of the ore shoot exceeds 5 feet.

The vein is for the most part within a large area of the dark, moderately fine-grained dioritic rock which has been called the Shea diabase. Near the shaft, it cuts across the north-south granite-porphyry dike belt.

The flat fault has been explored from the mine workings near the surface and drifted on for short distances from two deeper points, one about 500 and one about 1,200 feet west of the outcrop. This latter indicates an average dip of only 13 degrees for the flat fault.

Mineralization.—A large part of the vein consists of coarsely crystalline white quartz with sparsely scattered pyrite and only a few spots or bunches of very coarse intergrown ankerite or siderite and pyrite, usually with some chalcopyrite. Locally, there is also a little arsenopyrite and some tetrahedrite. The tetrahedrite (or freibergite) carries 600 ounces or more of silver per ton. It contains only a little arsenic. Where the sulphide mineralization is strongest and the tetrahedrite most abundant, the vein has a banded structure due to variation in the abundance of the minerals. Near the ore shoot there was a very little galena, which, at least in part, occurred in quartz veinlets cutting the older quartz; it may belong to a distinctly later period, possibly related to the barite found in the flat fault.

In one locality only did the mineralization justify mining. This was from about 300 to 400 feet west of the shaft on the 300-foot level up to where the vein was cut off by the flat fault. Near the top, native silver was associated with the tetrahedrite. About $65,000 worth of silver, copper, and gold was obtained from 1,200 to 1,300 tons of sorted shipping ore. Eighty per cent of the value was silver.

From near the Iron King tunnel to near the Shea shaft a quartz vein in the Copper Chief flat fault has largely replaced the gouge. This vein, which is several feet in maximum thickness, is similar to the Shea vein, although entirely barren quartz predominates to an even greater extent. Farther southwest only small stringers of quartz occur in the fault except at one spot, near the Grand Island shaft, where a short, thick lens produced over 100 tons of high-grade copper-gold ore. There was relatively little tetrahedrite, and the pyrite carried the gold.

Work in the flat fault vein more or less over the Shea ore shoot exposed a mass of at least several tons of barite in the flat vein and perhaps partly in the bent-over top of the Shea vein. The barite, which was not definitely associated with any other vein material, appeared to be younger.

Origin of Primary Mineralization

Conclusive evidence shows that practically all the Jerome district mineralization was replacement of pre-existing material by solutions. General knowledge of metalliferous ore deposits makes it practically certain that the source of the ore-bearing solutions was related to igneous rocks or igneous magma reservoirs. The particular igneous rock or inferred magma reservoir to which the ore solutions are related is speculative.

The location of the Jerome district with respect to the main mass of the Bradshaw granite and granitic material to the north and northwest makes the Bradshaw granite magma a very plausible deep-seated source for the solutions so far as location in space is concerned. It is reasonable to suppose that its magma may have been in an actively molten condition over a long period of time.

There is little reason to doubt that the vein mineralization of the district represents a late manifestation of the same mineralization that formed the massive sulphide bodies. The time location of the north-south granite-porphyry dikes between the vein formation and the earlier mineralization, together with the probable close affiliations of these dikes to the Bradshaw granite, indicates that the district mineralization was not widely separated in time from the intrusion of the granite.

Either the United Verde diorite or the Cleopatra quartz porphyry may very plausibly have been early differentiation products of the known Bradshaw granite. The diorite is similar to diorite closely associated with the granite in the quadrangle to the south.[27]

As the last important intrusive preceding the mineralization and because of its conspicuous association with the ore zone in the United Verde and U.V.X. mines, the United Verde diorite deserves

[27] T. A. Jaggar, Jr., and C. Palache, *U.S.G.S. Geol. Atlas*, Bradshaw Mountains Folio (No. 126), 1905.

first consideration. Otherwise there is little to suggest any genetic association. Away from the main ore zone the mineralization shows remarkably little tendency to favor diorite contacts. On the other hand, association of mineralization with the Cleopatra quartz porphyry is so widespread and conspicuous that it appears fairly certain that the association is more than a purely structural one, and in the main ore zone itself the evidence indicates that the first mineralizing solutions followed the porphyry contact more than the diorite contact.

The diorite does not occur very extensively in the district or surrounding area. The quartz porphyry is much more extensive, but probably its occurrence is largely within a radius of 5 miles from the center of the district.

It appears most probable that the ore-bearing solutions and the Cleopatra quartz porphyry had a common deep-seated origin in the Bradshaw granite magma.

General Geology

State of knowledge.—An article published by Provot[28] in 1916 correctly interprets the broader geological features of the district.

Reber's[29] 1920 paper was the result of more detailed study and observation. Dr. Lingren's[30] description, resulting from field work in 1922, is much more comprehensive and involves some corrections as well as important additions to the earlier papers.

Rickard's[31] early description of the U.V.X. Mine and Benedict and Fearing's[32] paper on the Verde Central Mine are of special local significance.

Even Dr. Lindgren's excellent and comprehensive description is subject to numerous minor corrections, as well as some very significant additions, in the light of all the information available to date. Hansen's[33] article outlines the most important of these additions.

It may never be possible to interpret some of the more obscure pre-Cambrian relationships with absolute certainty. Further detailed field work and much additional petrographic study are required. From a strictly practical viewpoint, however, the information now available is fairly adequate.

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[28] F. A. Provot, "A Geological Reconnaissance of the Jerome District" (Arizona), Abs., *E.&M.J.*, CXXV (1916), 1028.

[29] L. E. Reber, Jr., "The Geology and Ore Deposits of the Jerome District" (Arizona), 1920, *T.A.I.M.E.*, LXVI (1922), 3-26.

[30] Waldemar Lindgren, *Ore Deposits of the Jerome and Bradshaw Mountains Quadrangles, Arizona* (U.S.G.S. Bull. 782, 1926), pp. 54-97.

[31] T. A. Rickard, "The Story of the U.V.X. Bonanza," *M. and S. P.*, CXVI (1918), No. 1, 9-17; No. 2, 47-52.

[32] J. L. Fearing, Jr., and P. C. Benedict, *Geology of the Verde Central Mine* (E. & M. J. Press, April 11, 1925), CXIX, 609-11.

[33] M. G. Hansen, "Geology and Ore Deposits of the United Verde Mine," *Mining Congress Journal*, XVI (April, 1930), No. 4, 306-10.

The following chronological outline, though necessarily in part somewhat speculative and subject to some valid differences of opinion, summarizes what is believed to be the best interpretation now possible.

Chronological Outline of Geologic History

Pre-Cambrian.—1. Outpouring of a series of lava flows of widely varying composition, with some interbedded volcanic ash (tuff) and sedimentary material. Formation name, "Greenstone."

South end of district believed oldest because of prevalence of north to northwesterly dips throughout the district.

2. Outpouring of a great series predominantly of rhyolite lava flows and volcanic agglomerates of remarkably uniform composition, characterized by microscopic or very small visible quartz phenocrysts. Included with "Greenstone" on Plate VIII.

Because of the prevalently green color of the fresh rock and the difficulty often experienced in identifying the metamorphic material, the noncommital term, "greenstone," has been used for formations "1," "2," and "5," as well as "4" when not considered separately. It is also sometimes applied to material lacking the distinctive banding in "3." On the areal map, Plate VIII, "4" is shown separately.

3. Deposition of a series of volcanic tuffs and sedimentary material, for the most part distinctly bedded; at least some of the bedding is due to deposition in water. Formation name "Bedded Sediments." There were probably some contemporaneous lava flows.

In Haynes Gulch, north of the United Verde Mine, which is the type locality, there are some beds in which clastic sedimentary material undoubtedly predominates and one or two horizons showing well-rounded pebbles up to 1 inch in diameter. There is also at least one horizon containing from ½ to 2 feet of very typical "Lake Superior banded jaspilite or iron formation," which is much more extensively developed, in what is presumably the same horizon, south of the Yaeger Mine on the west side of the Black Hills.

3a. Period of regional deformation and folding with development of schistosity.

4. Intrusion of hornblende syenite, older diorite, and "Shea diabase."

The "older diorite," and hornblende syenite are not distinguished from the greenstone on the areal map (Pl. VIII).

5. Outpouring of a series of siliceous lava flows, first rhyolite, then predominantly dacite.

In addition to the large area shown on the map (Pl. VIII), small areas of this rhyolite occur as far north as the Copper Chief Mine.

5a. Some regional deformation.

6. Intrusion of Cleopatra quartz porphyry as a large continuous mass crossing the north end of the district, approximately on the greenstone-bedded sediments contact and a number of very ir-

regular intrusions forming a discontinuous belt crossing the south end of the district.

The area where porphyry predominates is shown as though it were a continuous belt (Pl. VIII).

The Cleopatra quartz porphyry is a rhyolite porphyry not very unlike the older rhyolites in composition. Its intrusive character and the distinctive appearance due to the prevalence of abundant large quartz phenocrysts as well as apparent significance in relation to the mineralization justify the distinctive name.

Ransome[34] has questioned the intrusive character of the north belt of porphyry. It is believed that evidence in the United Verde Mine indicating the intrusion of the bedded sediments by the porphyry is adequately conclusive in itself. It is fairly certain that all the greenstone along the south contact is surface volcanic material, and the nature of the contact is such that at least one of the rocks must be intrusive. The absence of any abrupt changes within the porphyry mass suggesting flow boundaries is also significant.

6a. Period of deformation, with somewhat local development of schistosity, and perhaps development of anticlinal structure more or less corresponding to area of general district mineralization.

The degree of schistosity in the porphyry varies greatly although most of it within the district is more or less schistose while such as known to the east of the mineralized area is relatively massive. This, as well as the prevalent N. 10 to 20 degrees W. trend of the schistosity in the northerly part of the district, is not inconsistent with the anticlinal structure suggested by the trend of several of the contacts and boundaries, but the prevalent east-west schistosity farther to the south is difficult to reconcile.

7. Intrusion of United Verde diorite.

8. General replacement deposition of fine-grained "jaspery quartz" by mineralizing solutions.

9. Somewhat widespread deposition of pyrite followed by less widespread deposition of brown sphalerite and probably more or less localized deposition of quartz carbonate.

10. Fairly widespread deposition of high-iron black chlorite.

11. Deposition of chalcopyrite with more or less pyrite followed by black sphalerite and galena locally.

12. Intrusion of numerous small andesite dikes, with prevalent east-west trend.

The composition of these dikes is very similar to that of the United Verde diorite.

13. Deposition of quartz followed by less widespread deposition of bornite.

14. Fairly widespread deposition of quartz, carbonate with a small amount of pyrite, and less widespread deposition of chalcopyrite, in part associated with light-colored sphalerite and very local tennantite.

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[34] F. L. Ransome, unpublished report on United Verde Extension Mine.

15. Intrusion of Bradshaw granite.

This is hypothetical, although suggested by inferred relationship of north-south dikes.

16. Intrusion of granite-porphyry dikes along generally north-south dike zone.

These dikes are known only along a single rather definite belt or zone which has only been traced about 4 miles south of the Shea Mine but no doubt continues much farther. The actual trend is a little east of north to north of the Copper Chief Mine where it curves to a little north of east and then pinches out close to the Verde fault. Both microscopically and to the naked eye the rock from the larger dikes appears identical with a phase of the Bradshaw granite occurring to the southeast except for the absence of biotite and the local occurrence of hornblende phenocrysts.

17. Formation of quartz veins, typically with more or less coarsely intergrown ankerite, pyrite, chalcopyrite, tetrahedrite, and other minor constituents.

These veins generally follow premineral faults or other fractures, with a more or less east-west trend.

17a. Copper Chief thrust fault movement and perhaps also nearly horizontal movement on faults near Verde Central and very small thrusts in United Verde Mine.

18. Formation of additional quartz veins, more or less similar to 17.

19. Deposition of barite in the Shea Mine.

This, the only barite known in the district, may be younger than pre-Cambrian.

20. Extensive erosion with development of oxide and chalcocite zones in sulphide deposits.

21. Gentle submergence and deposition of youngest pre-Cambrian sedimentary formations.

This is purely by inference from the most probable age of mineralization.

21a. Gentle uplift followed by great faulting, with movement on the order of 2,400 feet vertical displacement along the Verde fault, which cut off and shifted the upper portion of the United Verde ore chimney to the northeast as well as downward.

22. Perhaps some pre-Cambrian erosion and further secondary enrichment of sulphide deposits.

Paleozoic.—1. Continued erosion and gradual submergence with perhaps some further secondary enrichment of sulphide deposits.

2. Deposition of great thickness of Paleozoic sediments interrupted by periods of uplift and erosion without perceptible tilting, initiated by the deposition of the basal Tapeats sandstone in Middle Cambrian time.

Mesozoic.—Either continuous erosion or some submergence and deposition of Mesozoic sediments which were later entirely removed.

Tertiary.—1. Continued erosion with gentle tilting so that Paleozoic sediments were completely removed from the Bradshaw Mountain area to the south, but a maximum thickness of nearly 1,000 feet was left close to Jerome and progressively greater thicknesses farther north.

1a. Development of early Tertiary Verde Valley with deep gulches near Jerome, one of which slightly penetrated the pre-Cambrian formations and partially exposed the top of the U.V.X. downfaulted segment of the Verde ore zone.

2. Interruption of drainage and filling of gulches with prebasalt gravels.

3. Outpouring of series of basalt flows, which totaled over 800 feet in thickness, with some interflow weathering and erosion.

4. Tertiary faulting. Development of the Tertiary Verde fault belt and gradual lowering of the Verde Valley area with contemporaneous filling of the valley with the Verde lake beds to a thickness of over 2,000 feet and contemporaneous gravel deposition from the fault scarps merging into the lake beds. Also some further outpouring of basalt during the lake-bed deposition.

Movement of the main Verde fault added to the separation of the two segments of the Verde ore zone and erosion of the fault scarp exposed the top of the United Verde segment to very active attack, resulting in the destruction of most of the pre-existing oxide and chalcocite zones. The redeposition of copper dissolved from the outcrop, in oxidized form in the limestone and in bouldery gravel in gulches below the fault, resulted in the formation of the Dundee deposit and the carbonate veins in U.V.X. ground near the Columbia shaft.

Quaternary.—Rejuvenation of drainage leading to present erosion cycle. Final draining of Verde Lake, dissection of lake beds, and more intense erosion of steep slope due to fault belt. Further erosion of top of United Verde ore zone and deposition of oxidized copper in basalt and prebasalt gravels in and along Verde fault and appreciable sooty chalcocite enrichment in U.V.X. ore zone. This secondary copper deposition was perhaps initiated during the preceding period.

Significant Dates in Human History

United Verde Mine and Jerome District.—

1875. Discovery of showings by U.S. Army scouts.
1876. Location of first mining claims.
1880-85. Working of United Verde gossan for silver.
1883. Operation of first copper smelter.
1888. Completion of railroad from Ashfork to Prescott. Supplies hauled 28 miles from Granite, near Prescott.
1889. Purchase of United Verde Mine by William A. Clark.
1894. First mine fire on 300 level of United Verde Mine. Completion of narrow-gauge railroad to Jerome.
1900. Start of fairly active prospecting of district.
1904-5. Operation of Equator Mining Company smelter in south end of district.

1914. Completion of standard-gauge railroad to Clarkdale.
1914-20. Very active prospecting throughout district.
1915. Removal of United Verde smelting operations from above the mine to new plant at Clarkdale.
1916. Copper Chief 125-ton cyanide mill in operation. Finally closed down in 1923.
1918. Beginning of United Verde open-pit operation.
1920. Completion of standard-gauge railroad to Jerome.
1921. Completion of direct highway from Jerome to Prescott.
1924-27. Series of large "coyote" blasts in open-pit stripping.
1927. Addition of flotation concentrator to Clarkdale plant.
1929. January—Verde Central 350-ton flotation mill in operation. Closed in 1930. July—Cave-in of upper levels of United Verde Mine. United Verde peak copper production—142,290,000 pounds of copper from 1,737,000 tons of ore, for year.
1931. Purchase of Verde Central property by United Verde.
1935. Purchase of United Verde property by Phelps Dodge Corporation.
1938. United Verde open-pit work nearing completion.

United Verde Extension.—

About 1900. Verde Queen smelter treating carbonate ore from near Columbia shaft. (Later U.V.X. property.)
1900. Location of Little Daisy fraction by J. J. Fisher, the first U.V.X. claim.
1902. Organization of U.V.X. Company.
1912. Reorganization of U.V.X. Company by J. S. Douglas and G. E. Tener.
1914. First important ore discovery in U.V.X. Mine.
1915. Discovery of main ore body.
1917. U.V.X. peak copper production—63,243,000 pounds of copper from 115,064 tons, for year. First production from Jerome Verde, main top ore body (mined out in 1920).
1918. Completion of U.V.X. smelter at Clemenceau.
1929. U.V.X. peak tonnage production—59,127,000 pounds of copper from 358,650 tons of ore, for year.
1930. Addition of 200-ton flotation mill to plant at Clemenceau.
1937. January—U.V.X. smelter permanently closed.
1938. May—U.V.X. Mine permanently closed.

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