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# Early Proterozoic volcanogenic massive sulfide ore deposits, Jerome, Arizona, USA

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## ABSTRACT

**Rocks of Early Proterozoic age host volcanogenic massive sulfide ore deposits in the Verde mining district of central Arizona at Jerome. Mining lasted from 1883-1953 with a production of 33,655,430 metric tons of ore. Selective mining of high-grade copper ore from the United Verde massive sulfide deposit, from outcrop to a depth of 1372 meters, produced 88.5% of district tonnage. The blind supergene-enriched United Verde Extension (UVX) deposit produced 10.5% of district tonnage from 1915-1938. Small production also came from the Verde Central, Copper Chief and Cliff deposits but all mines are now inactive. By 1970 exploration geologists adopted the volcanogenic model for ore-deposit genesis that replaced the obsolete "selective replacement" model. Well-preserved "black smoker" sulfide columns have been recovered from the United Verde massive sulfide deposit that are virtually identical to modern counterparts. Two ore horizons occur within the volcanic succession that host volcanogenic ores. The older Verde Central ore horizon lies at the apex of Deception Rhyolite along cauldron fractures; the much larger United Verde ore horizon lies at the stratigraphic top of the overlying, submarine-emplaced Lower Cleopatra Rhyolite extrusion. Deep-water massive sulfide deposits accumulated above Mg-chlorite footwall alteration zones that formed at hydrothermal sea-floor vents along cauldron fractures. Sulfides are dominated by pyrite, chalcopyrite and sphalerite with associated gold and silver content. The sulfide system is capped by proximal jasper and flanked by thin, distal, sulfide-chert exhalite. Immediately overlying the United Verde ore horizon is unaltered, post-ore Upper Cleopatra Rhyolite with a $^{207}Pb/^{206}Pb$ age of 1738.5 ± 0.5 Ma. Other post-ore rocks include Upper Sequence rhyolite domes, volcaniclastic sediments, turbidites, mafic flows, jasper beds, banded-iron formation and a diorite sill. NNW trending $F_1$ folds and near east-west $F_2$ "cross folds" are ubiquitous in local Precambrian rocks and affect all volcanic, sedimentary and intrusive units equally. Paleozoic sedimentary rocks lie unconformably on top of deeply eroded Precambrian basement rocks. High-angle reverse faulting associated with the Laramide uplift 70-75 Ma, accompanied by a low-angle décollement fault and gravity slide, partially exposed the UVX deposit during Tertiary time. Erosion of a deep channel directly over the UVX deposit allowed for substantial supergene enrichment of the Precambrian deposit during Tertiary time. Following the Laramide Orogeny, northeast-directed stream flow unroofed the Precambrian basement rocks of the Bradshaw Highlands to the southwest and removed much of the Paleozoic sedimentary cover over the Jerome sulfide deposits. Tertiary conglomerates and 10-15 Ma Hickey Basalt were deposited onto the unconformity prior to basin and range extensional faulting 8-10 Ma when the Verde graben was formed. Fault-scarp erosion exposed the rocks of the Jerome area in relatively recent time.**

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## PREVIOUS STUDIES OF JEROME AREA GEOLOGY

Throughout the period of active mining in the Verde mining district at Jerome, Arizona (southwestern USA), most geologists believed that the Proterozoic massive sulfide ore deposits were formed by selective replacement of pre-existing Precambrian host rocks. Hydrothermal activity associated with intrusive quartz porphyry was believed to be the causative agent. A complex theory of fault offsets had also been invoked to account for the physical position and Precambrian supergene enrichment of the United Verde Extension (UVX) ore deposit (Ransome, 1933). Although there were a few skeptics, it was widely believed that the rich UVX ore deposit was the faulted-off apex of the adjacent United Verde massive sulfide body that lay to the west of the fault. Even though these concepts are no longer held to be valid, there is an excellent description of district geology and history of mining up through the mid 1950s in an informative U.S. Geological Survey Professional Paper (Anderson and Creasey, 1958).

Since the 1970s, the Jerome area massive sulfide deposits are known to be volcanogenic in origin and hosted within a series of rhyolite extrusive rocks as part of the stratigraphic succession. Field evidence for the volcanogenic model is widespread in the district. One noteworthy example is the presence of "black smoker" sulfide columns extracted from the United Verde massive sulfide deposit (Fig. 1). Despite their age, they are almost identical in mineralogy and structure to specimens dredged off the modern deep-sea floor. One investigator still held to the replacement ore model well after the volcanogenic model was recognized by most geologists (Norman, 1977).

Detailed geological and structural mapping, new exploration drilling, underground examination, and exhaustive correlation studies over the past several decades have clarified the relationship and geologic history between the two major ore deposits at Jerome. The large United Verde massive sulfide lies on the west-facing limb of the Jerome anticlinorium, and the smaller UVX deposit lies on its east-facing limb (Fig. 2). While the blind UVX deposit had been discovered using the "faulted-off apex of the United Verde body" theory, its discovery was a matter of serendipity and very good luck. Each deposit has its own Mg-chlorite footwall alteration and jasper caprock. The UVX deposit barely touches the plane of the Verde fault tangentially and is not cut by the fault. The two deposits are separate and occur on sub-parallel cauldron fracture zones, now folded onto opposite limbs of a north-northwest plunging anticlinorium. No evidence has been found for a Precambrian age of Verde fault movement, as invoked in the 1930s by Ransome. Verde fault activity first began in Late Cretaceous time.

A number of articles that incorporate the volcanogenic genetic model have been published (Anderson and Nash, 1972; Lindberg and Jacobson, 1974; Handverger, 1975). Later publications stress the volcanogenic model as well as the complex structural history and mineralogy of the district (Lindberg, 1983, 1986a, 1986b, 1986c, 1989; White, 1986; Lindberg and Gustin, 1987; Gustin, 1988; Slack, et al. 2007). Nomenclature of 1972 and older USGS rock formations (Anderson and Creasey, 1958; Anderson and Nash, 1972) are incompatible with the volcanogenic model and the relationship between ore and host rocks as presented in this paper. For example, the USGS reclassification from quartz porphyry intrusive to rhyolite extrusive places the Cleopatra Rhyolite as a member wholly contained within the Deception Rhyolite formation. Descriptions since the 1980s restrict the classification of Deception Rhyolite to that formation which lies below the hydrothermally altered Lower Cleopatra Rhyolite and its associated massive sulfide deposits. The Cleopatra is considered distinct enough to be classified as a formation in its own right. Post-ore unaltered rocks of the Upper Cleopatra Rhyolite and Upper Succession rhyolite blister domes and flow breccias lie above the mineralized rocks and are also considered as separate formations.

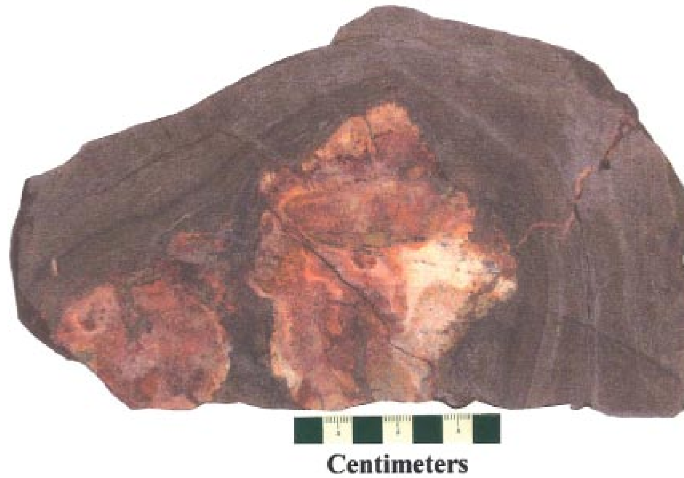


Figure 1. Cross-sectional slab of a "black smoker" sulfide specimen collected in 1989 by Pat MacGeehan and Paul Lindberg from the western wall of the United Verde open pit at the 500 (foot) level of the massive sulfide deposit. Outer bands of the sulfide column are mainly composed of pyrite, marcasite, and sphalerite that formed as sulfides precipitated above a submarine vent site, probably at a depth of at least 3000 feet (900 m). Sulfides grew inward from the outer shell before the hydrothermal vent was choked off and the core was filled by end-stage silica with minor chalcopyrite. This is one of a number of in-situ, vertically packed columns found near the stratigraphic top of the massive sulfide body. The same delicate syngenetic features are found at modern sea-floor hydrothermal vent sites observed and recovered by submersible vehicles. Similar black-smoker columns probably existed in deeper portions of the United Verde massive sulfide body but were recrystallized and destroyed by the replacement of chalcopyrite as hydrothermal fluids attacked the base of the growing sulfide body. The age of this well-preserved Early Proterozoic specimen is ~1738 Ma.

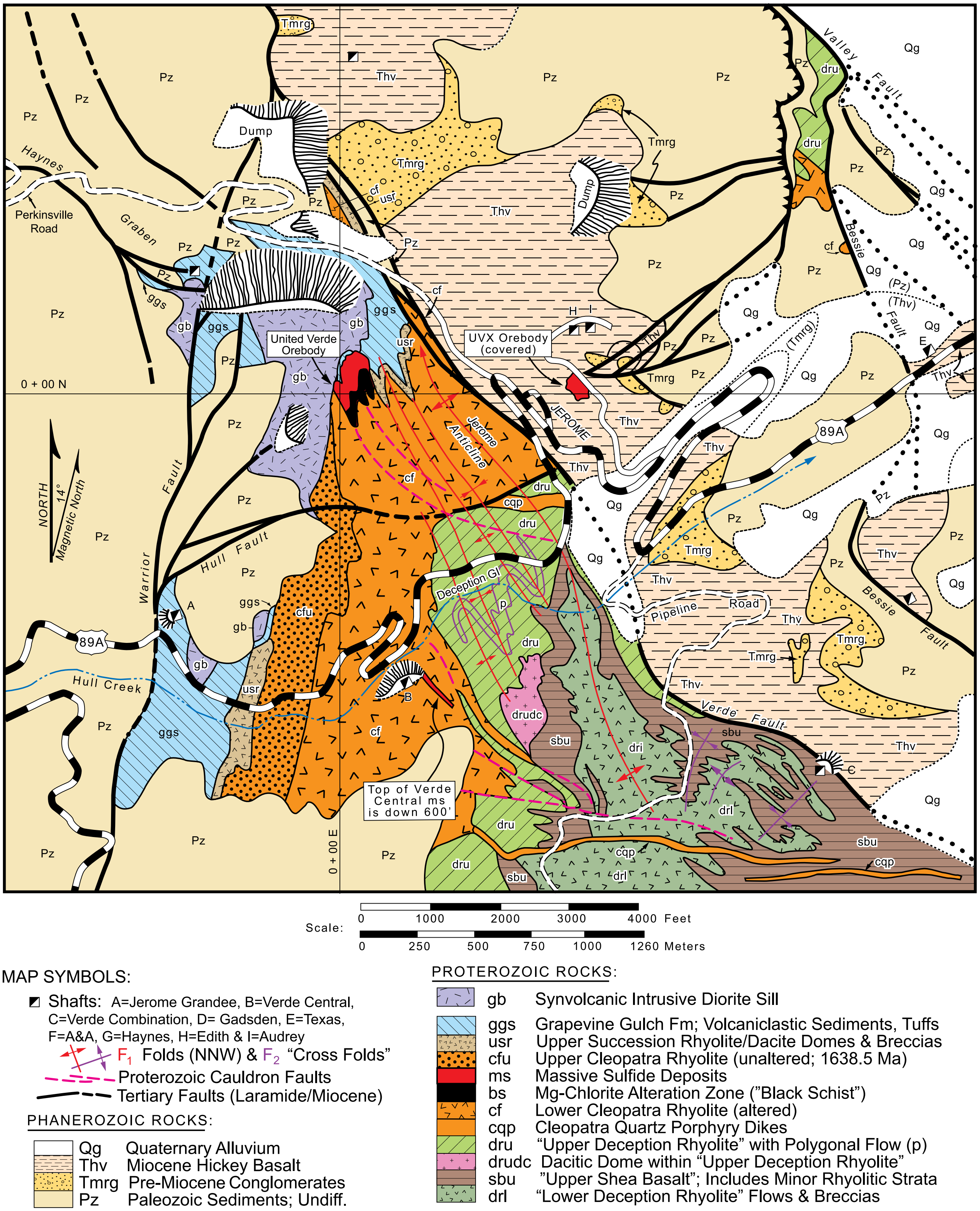


Figure 2. Simplified geologic map of the Jerome area, Verde district, Yavapai County, Arizona (modified from Lindberg, 1986a). Post-1971 detailed contact mapping modifies the interpretation and nomenclature of Anderson and Creasey (1958) and Anderson and Nash (1972). Current informal district usage is given below.

## GEOLOGY

### Precambrian geology

Precambrian volcanic rocks of Early Proterozoic age are exposed in a north-northwestward narrowing outcrop zone along the eastern flank of Mingus Mountain in central Arizona (Fig. 2). They are unconformably overlain by Paleozoic sedimentary rocks and Miocene basalt flows to the west and are down-dropped (and hidden beneath Phanerozoic cover rocks) to the north and northeast along basin and range faults associated with the formation of the Verde graben at 8-10 Ma. The portion of the Jerome volcanic pile that contains massive sulfide ore deposits displays an overall rake to the NNW with the oldest portion of the stratigraphic sequence exposed in the Copper Chief mine area ~6 km to the SSE of Jerome (south of the area of Figure 2). At that location locally pillowed Shea Basalt flows and hyaloclastites are conformably overlain by a northward thickening accumulation of rhyolite lavas and flow breccias. A palinspastic reconstruction of the Jerome volcanic pile shows that the Copper Chief mine area lies close to the southern boundary of a northward thickening Jerome volcanic pile that is dominated by rhyolite extrusive rocks.

In Deception Gulch (Fig. 2), immediately southwest of Jerome along Highway 89A, the bold canyon outcrops are composed of fold-thickened flows, flow breccias, and sills of non-porphyritic Deception Rhyolite in the core of the Jerome anticlinorium. The cauldron-fractured apex of the Deception Rhyolite is the site of the small Verde Central massive sulfide that was being developed shortly before ore production ended in 1929 at the start of the Great Depression. Deception Rhyolite and the Verde Central massive sulfide deposit were buried by a gigantic submarine eruption of porphyritic Lower Cleopatra Rhyolite soon after the sulfide deposit had been formed. Deception Rhyolite is cut by quartz porphyry dikes that fed the overlying voluminous, submarine-extruded Lower Cleopatra Rhyolite that forms the host rock for the United Verde, UVX, Copper Chief and Cliff massive sulfide ore deposits. The Cleopatra contains abundant and conspicuous 2-4 mm quartz phenocrysts. Widespread sericite alteration, localized Mg-chlorite alteration along cauldron fractures, and massive sulfide mineralization located above hydrothermal vent sites of the Lower Cleopatra Rhyolite distinguishes it from the unaltered Upper Cleopatra Rhyolite. Prior to alteration, the Lower and Upper Cleopatra Rhyolite appear to have been identical and to have come from the same magma chamber (Gustin, 1988). The massive sulfide event horizon occurs between the two formations. The late Charles Meyer characterized the sulfide ore-forming horizon as occurring between altered Lower Sequence rocks and unaltered Upper Sequence rocks, an ideal guide for mineral exploration (private company reports).

Unaltered Upper Cleopatra Rhyolite flow rock has a $^{207}Pb/^{206}Pb$ age date of 1738.5 ±0.5 Ma (Slack et al., 2007) and it conformably overlies the United Verde ore horizon. This provides a date immediately following the sulfide forming event and the deposition of jasper caprock and distal sulfide-chert exhalite beds. Post-ore rocks also include small rhyolite blister domes and breccias that are overlain by Grapevine Gulch formation that is composed of volcaniclastic sediments and submarine turbidite beds. A large intrusive diorite sill preferentially intruded into the Grapevine Gulch formation in post-ore time. The boundary of the diorite sill lies just above the plunging surface of the United Verde sulfide body from surface to the bottom of the mine. Near its lowest level the diorite sill cut into the massive sulfide body at one point and dilated a small portion of west-facing ore to the western sill margin, thus forming the small Haynes ore body. The diorite sill also converted some of the red jasper caprock to white quartz.

Deposition of the oldest rocks of the Jerome volcanic pile may have begun well before ~1800 Ma, with the main massive sulfide deposits at Jerome being formed immediately before 1738.5 ±0.5 Ma (Slack et al., 2007). Subsequent burial of the sulfide horizon by new cycles of volcanism and associated volcaniclastic sediments must have lasted for several more millions of years prior to crustal accretion of the island-arc complex against the North American continent.

**Precambrian structural geology.** Horizontally-directed compression generated $F_1$ folds in the Verde district, with axial planes trending north-northwest and dips ranging from 78º NE at Jerome to as gentle as 30º NE in the Copper Chief and Cliff mine areas to the south of Jerome (Fig. 2). $F_2$ "cross folds" trend nearly east-west across the undulating regional $F_1$ fold crests, resulting in fold interference that generated "Christmas tree" and "egg crate" map patterns throughout the entire Jerome volcanic pile. In the northern portion of the district, the NNW-plunging Jerome anticlinorium is defined by the Cleopatra Rhyolite and intensely folded Deception Rhyolite that resides in the core of the fold. The United Verde massive sulfide deposit plunges ~60º NNW from surface outcrop to a depth of 1370 m along the western limb of the anticlinorium. The full amplitude of the combined $F_1$ and $F_2$ folds in the immediate Jerome area probably exceeds 1800 m. By ~1700 Ma the entire Early Proterozoic succession in central Arizona had been laterally compressed into folds with the crust thickened by major vertical extension and development of $F_2$ "cross folds".

Folding and mountain building culminated in regional granitic intrusions. Granodiorite of the Cherry batholith intruded the area ~16 km to the south of Jerome but its dike offshoots extend to the north-northeast from the main batholith only as far north as the Copper Chief and Cliff mines. In that area the dikes have been thrust offset to the east by a relatively flat, west-dipping fault of Precambrian age known as the Flat fault. Its upper plate contains the decapitated Copper Chief and Cliff massive sulfide ore deposits and their theoretical lower plate counterparts have yet to be discovered. The plane of the Flat fault is occupied by quartz, siderite and local silver mineralization at the small Shea vein mine. Further north, the Flat fault is bounded by the near east-west Cliff fault whose right-lateral vertical fault plane is occupied by a small silver-bearing quartz vein. These exotic, late Precambrian age, vein deposits suggest that metal values may have been scavenged from buried sulfide deposits laying at depth off to the west.

Despite the belief that there was a Precambrian age of movement on the Verde fault (Ransome, 1933), exhaustive correlation studies of UVX and United Verde mine records, underground mapping and exploration drilling have failed to disclose evidence for such an offset. Modern structural interpretation shows conclusive evidence that there were two ages of movement on the Verde fault. High-angle reverse movement took place during the Laramide Orogeny at about 70-75 Ma and normal faulting occurred 8-10 Ma.

## ECONOMIC GEOLOGY

### Mining

High-grade footwall stockwork veins of chalcopyrite, devoid of pyrite and sphalerite, constitute “black schist ore” that was mined from the United Verde deposit (Fig. 3). On some mine levels, 50% of the ore came from the black schist ore in the footwall with the rest coming from the basal portion of the massive sulfide. Overall, the pyrite-matrix massive sulfide displays a distinct vertical mineral zoning, with its base being dominated by replacement chalcopyrite of the original syngenetic body, now containing diminished sphalerite. The central portion of the massive sulfide body, largely unmined, contains extensive pyrite-sphalerite-chalcopyrite mineralization that often retains primary syngenetic features. Bedded sulfides and rare black-smoker sulfide columns can be found near the stratigraphic upper portion of the sulfide body. The stratigraphic top of the body is composed of siliceous sulfides, a mixture of silica and pyrite with a low content of sphalerite and minimal chalcopyrite. Precious metal values generally increase upward within the deposit. Historic production from the United Verde mine extracted only copper-rich ore from the stratigraphic base of the deposit and only 5-10% of the 150-200 million ton massive sulfide body was mined. Zinc, copper and precious metal values constitute a significant mineral reserve in the deposit.

### Mineral production

Overall, the Verde mining district produced 33,655,430 metric tons of massive sulfide ore that yielded an astonishing 1,644,300 metric tons of copper. Only high-grade copper ores were mined, especially from the large United Verde deposit. Byproduct metal production of copper-ore smelting was 44,156,870 kg zinc, 314,450 kg lead, 1,579,999 oz Au and 57,313,000 oz silver (Lindberg, 1989). Most of the known ore deposits in the Verde district were mined out, but the huge United Verde deposit has a substantial un-mined reserve of Zn-Cu-Au-Ag ore.

### Model for volcanogenic massive sulfide and exhalite genesis

The United Verde and UVX massive sulfide ore deposits at Jerome were deposited directly onto the sea floor immediately following the submarine extrusion of cauldron-fractured Lower Cleopatra Rhyolite. Massive sulfide mounds were deposited above deep-water hydrothermal vents that issued from linear, sub-parallel cauldron fractures that broke the surface of the rhyolite extrusion. While the rock was still extremely hot, seawater cells developed and circulated over a wide area of adjacent sub-seafloor rocks before venting through seafloor fractures as superheated hydrothermal fluid. Several cubic kilometers of Lower Cleopatra Rhyolite had its feldspar altered to sericite and its normative copper and zinc values severely depleted. Intense magnesium metasomatism converted rhyolite minerals into Mg-chlorite, called black schist, within the tabular cores of cauldron fractures where fluid flow was concentrated. Hydrothermal fluid that vented onto the sea floor was a mixture of seawater from the circulating side-wall cells and primary magmatic fluids that contained iron, sulfur, copper, zinc, silver, gold and trace elements.

Syngenetic sulfide precipitation took place immediately above the vent sites, presumably assisted by the same bacterial activity as found in modern sea-floor analogies. The initial sulfide composition is presumed to have been dominated by pyrite, sphalerite and chalcopyrite, with a complete absence of pyrrhotite. As the sulfide mounds grew in size on the sea bed, the continued flow of hydrothermal fluid that passed through the earlier-formed sulfide layers generated replacement textures, whereby much of the original sphalerite was replaced by chalcopyrite. (This is the primary reason why mine geologists originally believed that the entire ore system was the result of replacement.) Over time the stratigraphic base of the massive sulfide mound became progressively enriched in copper as zinc and precious metals were re-dissolved and re-precipitated at higher stratigraphic layers in the sulfide mound. Proximal sulfide deposition above the vent site was accompanied by simultaneous chemical deposition of thin layers of distal chert exhalite that contains layered beds of pyrite and sphalerite and anomalous precious-metal values. Copper minerals are totally absent in the distal chert exhalite beds.

As the volcanic heat engine created by the massive extrusion cooled down, hydrothermal fluid flow from the vent sites diminished and sulfur-bearing minerals ceased to be deposited. Late-stage fluids, rich in silica and iron, issued from the hydrothermal vents and deposited a jasper caprock on top of the sulfide body. That, in turn was buried by thin layers of Upper Sequence rhyolite crystal tuffs, Upper Cleopatra Rhyolite tuff, and a thick layer of volcaniclastic sediments of the Grapevine Gulch formation. The latest fluids that issued from the submarine volcanic edifice traveled some distance from the vent site and precipitated banded iron formation in deep-water basins. The youngest exposed portion of the Jerome volcanic pile contains the diorite sill that was preferentially intruded into the Grapevine Gulch volcaniclastic sedimentary package.

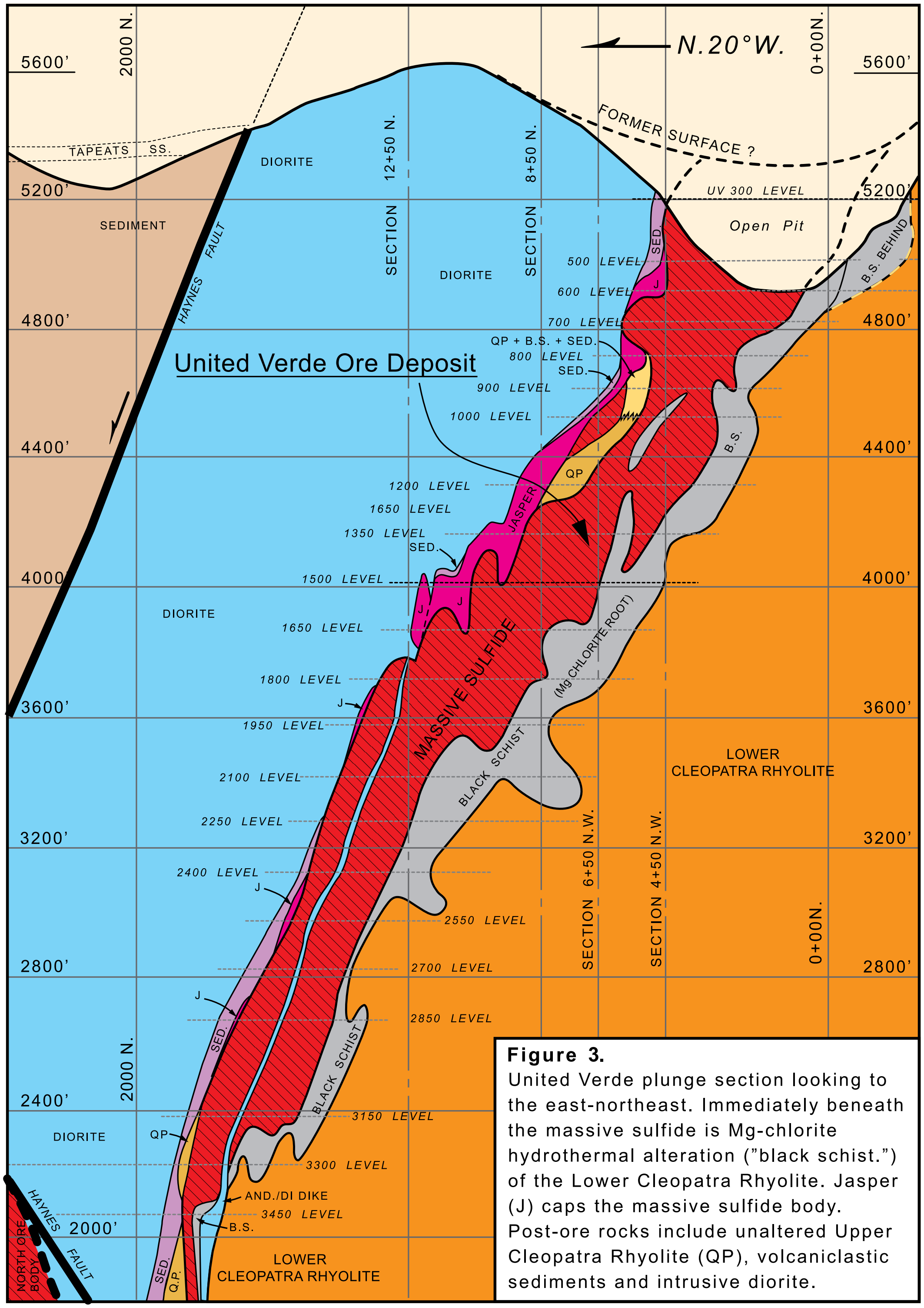


**Figure 3.** United Verde plunge section looking to the east-northeast. Immediately beneath the massive sulfide is Mg-chlorite hydrothermal alteration ("black schist.") of the Lower Cleopatra Rhyolite. Jasper (J) caps the massive sulfide body. Post-ore rocks include unaltered Upper Cleopatra Rhyolite (QP), volcaniclastic sediments and intrusive diorite.

## Supergene enrichment of Precambrian-age sulfide deposits

Exploration drilling in the Jerome area indicates that the average depth of pre-Paleozoic weathering beneath the Tapeats Sandstone is 60 m or less. Only the topmost portion of the plunging United Verde massive sulfide body would have been oxidized to produce an underlying supergene-enriched sulfide blanket during Precambrian time. Some of the earliest mine workings in the discovery area would have contained ores enriched by supergene processes in Precambrian time. Deeper down, a limited volume of high-grade supergene chalcocite and bornite was recovered from the 300 level bench (91 m below discovery) during open-pit excavation. Some of this enrichment zone would have been formed over the last few million years as the deposit was being exposed by modern erosion. On United Verde mine levels deeper than the 300 level, the sulfide content of the deposit has remained unchanged from its depositional composition because of isolation from oxidizing near-surface groundwater.

The UVX deposit, on the other hand, was changed radically by the supergene enrichment processes. Very much like the adjacent United Verde deposit, a portion of the UVX sulfides that lay beneath the Great Unconformity must have had a small amount of Precambrian age supergene-enriched ore. Following the Laramide Uplift about 70-75 Ma, however, there were significant differences in the fault relationship and erosion of the two deposits that lay on opposite limbs of the Jerome anticlinorium (Figs. 4, 5). During all of Tertiary time the UVX massive sulfide deposit was subjected to preferential supergene-enrichment while the United Verde deposit remained unchanged. The reason for this difference is described below.

## PHANEROZOIC GEOLOGIC HISTORY

### Paleozoic sedimentary rocks

Following the period of Early Proterozoic folding, mountain building activity and intrusive events, the Precambrian basement rocks of central Arizona were subjected to a prolonged period of erosion. At the beginning of the Paleozoic Era, Tapeats Sandstone was deposited onto a nearly flat unconformity surface. The type section for the Tapeats Sandstone in the Grand Canyon to the north is clearly Cambrian in age, but its deposition in the Jerome area may be somewhat younger. Overlying the Tapeats Sandstone is a 6.7 m thick marly shale called Chino Valley formation that may be the stratigraphic equivalent of the Bright Angel Shale of the Grand Canyon. It has been mapped at several outcrop locations and cut in drill holes and it maintains a constant thickness. That formation, in turn, is conformably overlain by Martin Dolomite of Devonian age, as determined by its fossil content. Still higher is Mississippian Redwall Limestone that is locally quarried for the manufacture of cement. Further to the north are remnants of Permian Supai Sandstone. All of the Paleozoic sedimentary rocks display a low dip to the northeast as part of the Laramide age Verde monocline and have been truncated by erosion to the southwest following Laramide uplift. Paleozoic rocks are found above the Great Unconformity to the west of Jerome on Woodchute Mountain and are down-dropped along Miocene graben faults to the east of Jerome.

### Phanerozoic structural history and supergene-enrichment of the UVX deposit

Some remarkable structural events took place in the Jerome area following uplift of the region during the Laramide Orogeny at ~70-75 Ma. Rocks in the Jerome area were raised to their modern elevation during the Laramide Uplift with Paleozoic sediments dipping gently off to the northeast as part of the Verde monocline. At the time of uplift, many high-angle reverse faults were developed throughout the Verde Valley region. On the western side of the Verde Valley these include the ancestral phase of the Verde, Bessie, Valley and many other un-named faults in the cement-quarry area near Clarkdale. On the eastern side of the Verde Valley are the ancestral high-angle reverse phase of the Cathedral and Oak Creek faults. The ancestral Verde fault at Jerome displays an uplift of its northeastern side of about 100 m. Tilted Paleozoic strata on the northeast side of the high-angle reverse fault decoupled along the water-saturated Chino Valley formation that conformably overlies the Tapeats Sandstone. The Chino Valley formation acted as a lubricated gravity-slide plane with the overlying Paleozoic strata sliding to the northeast for about 100 m. The toe of the mile-long gravity-slide block ramped up onto the high-angle reverse-fault buttress of the Bessie fault ~1.6 km below Jerome where it is exquisitely exposed in outcrop. As a result, the décollement fault generated a physical gap, or "pullaway", along the plane of the Ancestral Verde fault that lay directly above the UVX massive sulfide deposit. Over the next 60 million years regional erosion bared the Precambrian basement rocks to the southwest of Jerome and carried the gravels northeastward across the Jerome-Sedona area and onto the Colorado Plateau where they were deposited as Rim Gravels. At Jerome that period of Tertiary erosion cut a 140-meter-deep channel through the Paleozoic cover and into Precambrian basement at the top of the UVX ore deposit.

The deep erosion channel above the UVX deposit was ultimately back-filled with conglomerate that contains boulders of Paleozoic rocks derived from the west and abundant Precambrian cobbles similar to the rock types found in the Lynx Lake area south of Prescott, many kilometers to the southwest of Jerome. Throughout Tertiary time, groundwater was able to deepen the oxidation zone over the UVX deposit to more than 150 m. The erosion channel along the fault plane allowed surface water to penetrate deep into the fractured ore body and create the bonanza-grade supergene enrichment of the ore deposit. While this window of erosion occurred over the UVX during Tertiary time, the adjacent United Verde body remained sealed beneath its Paleozoic rock cover to the west of the fault plane.

### Miocene basalt eruption and Verde graben development

Miocene age Hickey Basalt was erupted between 15-10 Ma and buried the Tertiary conglomerates. These would be contemporaneous with the deposition of the House Mountain basalt further to the northeast at Sedona before extensional faulting generated the Verde graben and the Mogollon Rim escarpment. The modern normal phase of offset along the Verde, Bessie, Valley, Cathedral Rock and Oak Creek faults took place ~8-10 Ma during graben formation. Drill records and interpretation of gravity measurements indicate that portions of the graben dropped more ~1900 m in the core of the Verde Valley.

Fig. 4.

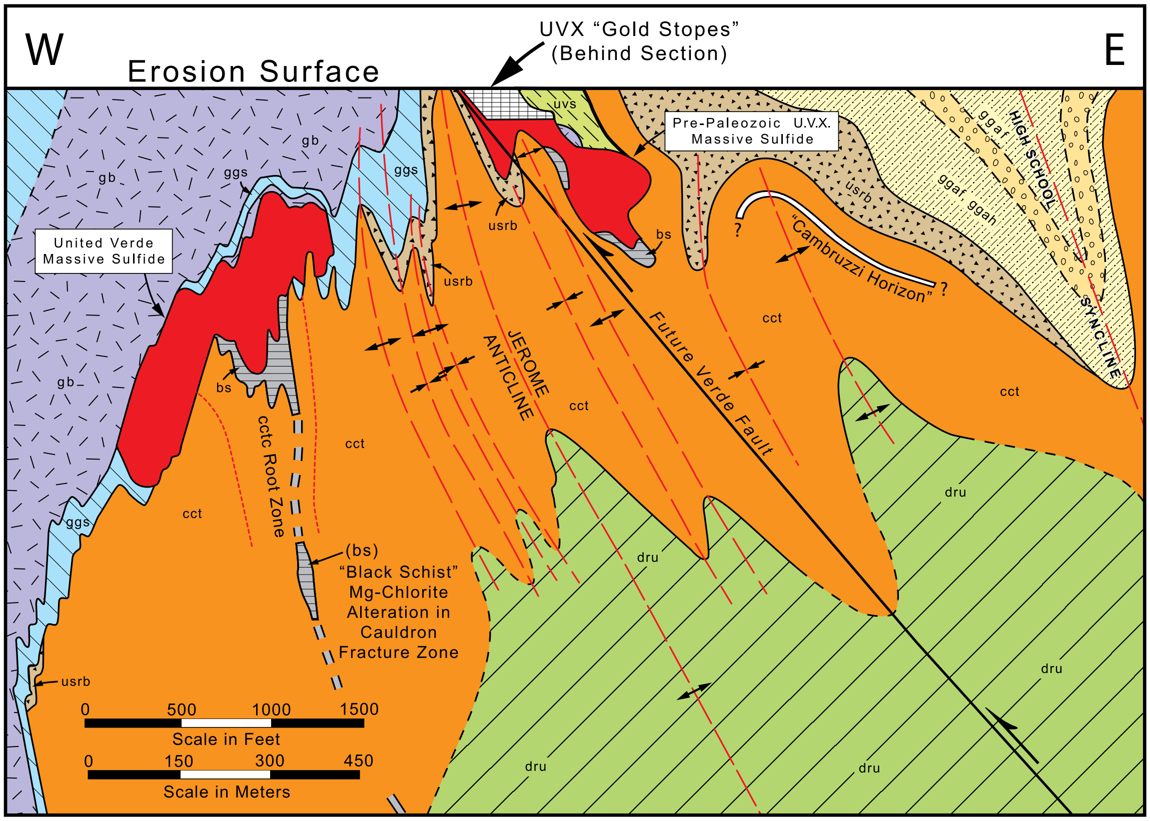
W
E
Erosion Surface
UVX "Gold Stopes" (Behind Section)
uvs
Pre-Paleozoic U.V.X. Massive Sulfide
United Verde Massive Sulfide
"Cambruzzi Horizon"
HIGH SCHOOL SYNCLINE
JEROME ANTICLINE
Future Verde Fault
cctc Root Zone
(bs) "Black Schist" Mg-Chlorite Alteration in Cauldron Fracture Zone
gb
ggs
usrb
bs
cct
dru
ggaf ggah
0 500 1000 1500
Scale in Feet
0 150 300 450
Scale in Meters

Fig. 5.

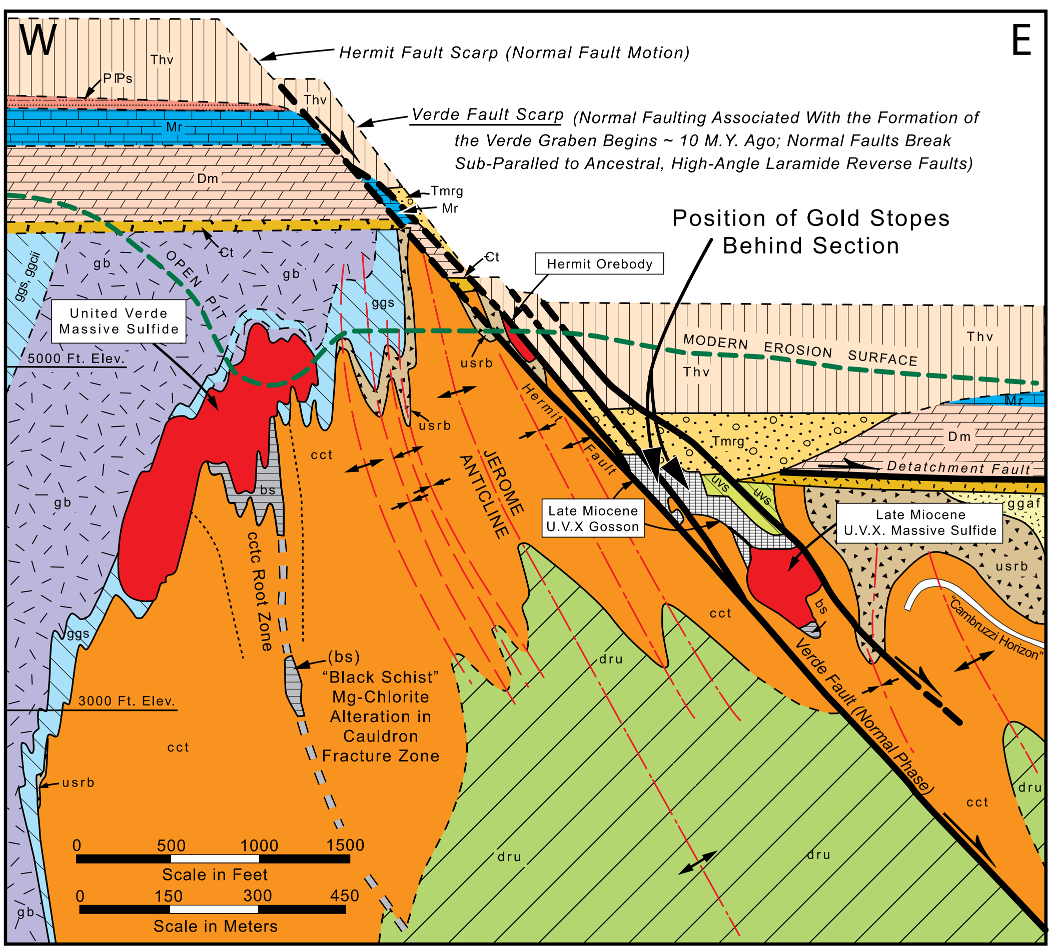
W
E
Thv
PPs
Mr
Dm
Hermit Fault Scarp (Normal Fault Motion)
Verde Fault Scarp (Normal Faulting Associated With the Formation of the Verde Graben Begins ~ 10 M.Y. Ago; Normal Faults Break Sub-Paralled to Ancestral, High-Angle Laramide Reverse Faults)
Tmrg
Ct
Position of Gold Stopes Behind Section
Hermit Orebody
OPEN PIT
United Verde Massive Sulfide
MODERN EROSION SURFACE
5000 Ft. Elev.
3000 Ft. Elev.
Hermit Fault
Detachment Fault
JEROME ANTICLINE
Late Miocene U.V.X Gosson
Late Miocene U.V.X. Massive Sulfide
"Cambruzzi Horizon"
Verde Fault (Normal Phase)
cctc Root Zone
(bs) "Black Schist" Mg-Chlorite Alteration in Cauldron Fracture Zone
ggs, ggcil
gb
ggs
usrb
bs
uvs
ggaf
cct
dru
0 500 1000 1500
Scale in Feet
0 150 300 450
Scale in Meters

Figure 4 (left, upper). East-west section looking north through the United Verde and UVX massive sulfide deposits showing the $F_1$ folds and erosion surface that existed at the close of Precambrian time. The folds plunge into the plane of the section at about 60°. $F_2$ "cross folds" formed at right angles as the result of differential vertical extension of the $F_1$ folding event. All folding was probably complete by about 1700 Ma and the once mountainous terrain was eroded until the onset of deposition of Paleozoic sediments that began at about 500 Ma. A thick succession of Paleozoic, and possibly some Mesozoic, sediments later covered this erosion surface. The two massive sulfide deposits lie on opposite-facing limbs of the central Jerome anticline that is known from subsequent mine records and subsurface drilling. Each of the deposits is believed to lie on sub-parallel cauldron fractures with its own alteration zone. Both of these massive sulfide deposits must have had a Precambrian-age supergene ore blanket lying beneath an oxidized zone that did not exceed ~165 feet (~50 m) in depth. As shown in Figure 5, the modern depth of the oxidation zone and resulting supergene enrichment of the UVX deposit is now about three times deeper due to Tertiary events.

Figure 5 (left, lower). Same cross-section orientation as shown in Figure 4 but showing modern disposition of rock units in the Jerome area. Paleozoic sediments cover the eroded Precambrian surface. During Laramide orogenesis at ~70-75 Ma, the entire region was uplifted to its present elevation with an initial high-angle reverse-fault phase of movement on the ancestral Verde fault. Tilted Paleozoic strata on the east side of the Verde fault decoupled along the thin Chino Valley marl lying between the Cambrian Tapeats Sandstone and the overlying Devonian Martin Dolomite. A "pullaway" was created along the fault scarp and subsequent Tertiary erosion carved a deep erosion channel directly above the exposed UVX gossan. As a result, the UVX supergene enrichment blanket was deepened during Tertiary time. Hickey Basalt lava flows covered the Tertiary erosion surface between 15 and 10 Ma. Normal faulting on the Verde fault and other valley faults to the east took place during the formation of the Verde graben at about 8-10 Ma. Modern erosion exposed the United Verde deposit while the UVX deposit remained buried until its discovery in 1914.

## MODERN EROSION AND ORE DISCOVERY

Modern erosion of the fault scarps in relatively recent geologic time exposed the United Verde massive sulfide body and its gossan cap. The Spanish explorer Espejo found prehistoric pits, dug for colorful pigments, at the site when he and his Hopi guides visited the future site of Jerome on May 8, 1585. Serious mining of the United Verde ore deposit began about 1893 and lasted until 1953. It was not until a decade of dedicated underground exploration, almost ending in failure, that the blind UVX ore deposit was discovered in December, 1914. It produced bonanza grade copper ore from 1915 until its exhaustion in 1938. During the 1980s and 1990s a small amount of gold ore was mined under contract from the Gold Stope of the UVX mine and used for high-value smelter flux (White, 1986). The gold-bearing siliceous sinter deposit was apparently deposited as a separate seafloor siliceous sinter in close proximity to the main UVX massive sulfide body but deposited near the end of sulfide deposition.

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