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PRECAMBRIAN GEOLOGY AND ORE DEPOSITS OF THE PECOS MINE, SAN MIGUEL COUNTY, NEW MEXICO

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INTRODUCTION

Stimulated, in large part, by Giles' (1974) re-interpretation of the ore bodies at the Pecos mine as volcanogenic massive sulfide deposits, several workers have re-examined and re-mapped Precambrian rocks in much of the southern Sangre de Cristo Mountains. This mapping has delineated an extensive volcanic and sedimentary terrane, mainly in the headwater area of the Pecos River, that is known as the Pecos greenstone belt (Robertson and Moench, this guidebook). Riesmeyer (1978) discusses the Precambrian volcanic and sedimentary geology, and the ore deposits of the Pecos mine area in more detail than the present summary.

GENERAL GEOLOGIC SETTING

Precambrian igneous and metamorphic rocks are exposed over a continuous distance of almost 5 km along the easterly-trending lower canyon of Willow Creek (fig. 1). Paleozoic sedimentary rocks unconformably overlie an erosion surface developed on Precambrian basement that dips 7-12° to the southwest. From oldest to youngest, the Paleozoic section along

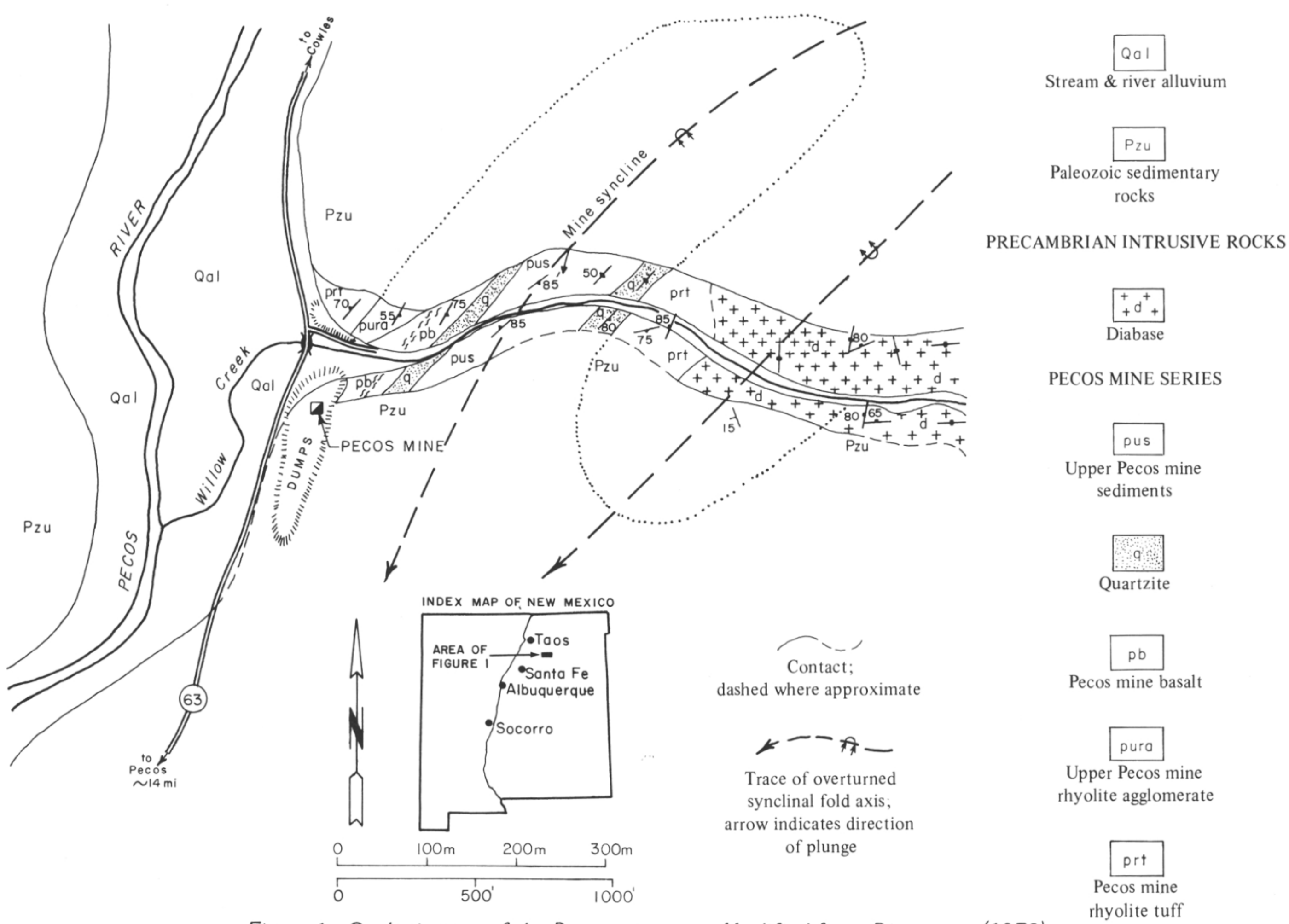

Figure 1. Geologic map of the Pecos mine area. Modified from Riesmeyer (1978).

Willow Creek consists of: (1) pre-Mississippian Del Padre Sandstone; (2) pre-Mississippian Espiritu Santo Formation; (3) Mississippian Tererro Formation; (4) Pennsylvanian La Pasada Formation; and (5) Pennsylvanian Alamitos Formation. Detailed stratigraphic descriptions of these Paleozoic units are given in Miller and others (1963).

Precambrian metavolcanic and metasedimentary rocks of the Willow Creek area, hereafter informally called the Pecos mine series, are part of a regional assemblage of subaqueous volcanic and volcaniclastic rocks, cherty iron formation, and immature sediments that has been called the Pecos greenstone belt. A regional stratigraphic column for the entire greenstone belt has not been worked out, so that the exact stratigraphic position of the Pecos mine series is not known. Lithologies and rock relations within the series, however, suggest that these rocks represent the waning stages of volcanism, and therefore, may be placed tentatively in the upper part of the Pecos greenstone succession.

PRECAMBRIAN GEOLOGY

General Statement

Stratified Precambrian rocks of the Pecos mine series exposed along Willow Creek have been folded tightly into a series of synclines and anticlines that trend northeast and have wavelengths of roughly 330 m (fig. 1). The syncline containing the Pecos orebodies hereafter is termed the Mine syncline.

The metavolcanic and metasedimentary succession is summarized in Table 1. The estimated maximum thickness in Willow Creek is greater than 420 m. In the Mine syncline, where lower Pecos mine rhyolite is not exposed and upper Pecos mine sediments do not display their maximum thickness, the section is about 190 m thick.

Pecos mine series rocks are cut by four varieties of Precambrian intrusive rocks. From west to east along Willow Creek, the intrusives are diabase, dacite, granodiorite and granite. The radiometric ages of these rocks are not known, but mineralogic and textural features and field relations indicate that the granodiorite, dacite and diabase are pre- or syn-metamorphic, whereas the granite is post-metamorphic. Only the diabase intrudes the Mine syncline, and the following detailed descriptions are limited to this single intrusive variety.

Pecos Mine Series Stratigraphy

Lower Pecos mine rhyolite

Lower Pecos mine rhyolite is not exposed in the Mine syncline, but probably exceeds 90 m in thickness along Willow Creek. It is a dense, siliceous, weakly porphyritic rock, with scattered quartz and plagioclase phenocrysts in a microcrystalline, devitrified (?) matrix of quartz, subordinate plagioclase and minor K-feldspar and biotite. Small, lozenge-shaped patches of quartz and sericite may represent recrystallized pumice fragments. Two major textural varieties are present: a light pink, flow-banded, distinctly porphyritic unit, and a grayish, massive, slightly porphyritic unit.

Pecos mine rhyolite tuff

Peocs mine rhyolite tuff ranges in thickness from 15 m in middle Willow Creek to more than 60 m in the Mine syncline, and conformably overlies lower Pecos mine rhyolite. It is a white, granular, fine-grained quartz-sericite phyllite, with scattered, highly distorted quartz "eyes." In the vicinity of the Pecos mine, this unit contains horizons of abundant, angular to rounded patches of quartz and sericite ± chlorite that may represent relict pumice fragments or lapilli. In addition, much silica has been introduced to this unit in the immediate mine area, producing abundant, thin, irregular lenses of grayish-white quartz that parallel foliation. The uppermost several meters of Pecos mine rhyolite tuff are chloritized locally.

Upper Pecos mine rhyolite

On the west limb of the Mine syncline, upper Pecos mine rhyolite is represented by a small lens of silicified and brecciated rhyolite agglomerate. Along middle Willow Creek, the unit is a dense, pinkish-gray, structureless, vaguely porphyritic rock with no evidence of included lithic or pumiceous fragments. In Davis Creek, about 2 km to the south, the unit is an aphanitic, grayish-white, sparingly porphyritic rock containing abundant ash-sized fragments of devitrified glass that appear to have nucleated about individual phenocrysts of quartz, plagioclase or potash feldspar.

Upper Pecos mine rhyolite agglomerate marks the ore horizon at the Pecos mine, although the agglomerate does not extend very far into the subsurface, and the closest ore body is

Table 1. Precambrian Stratified Rocks of the Pecos Mine Series

Unit	Character	Thickness (m)
Upper Pecos Mine Sediments	Variable mixture of impure quartzite, fine-grained, well-layered siltstone, and medium-grained, typically massive immature sandstone	70 – 100+
Pecos Mine Basalt	Aphanitic, olive-green, highly altered basalt; minor cherty horizons toward base	15+
Upper Pecos Mine Rhyolite	Agglomeratic in Mine syncline; elsewhere, tuffaceous to massive, grayish-white to pinkish-gray, fine-grained to aphanitic	0 – 45
Pecos Mine Rhyolite Tuff	White, fine-grained granular phyllite with scattered quartz "eyes"; locally contains abundant pumice lapilli	15 – 60
Lower Pecos Mine Rhyolite	Light pink, flow-banded, porphyritic; to grayish, massive, slightly porphyritic	90 – 200+

roughly 9 to 15 m below present ground level. At depth, the ore horizon is represented by massive to tuffaceous rhyolite (quartz-sericite schist), similar to upper Pecos mine rhyolite exposed along middle Willow Creek and in Davis Creek.

The rhyolite agglomerate has the shape of a small lens or dome, standing more-or-less on edge, its northeastern half concealed by Paleozoic sediments. On the north side of Willow Creek at its widest exposure, the dome is approximately 45 m thick. Ninety meters along strike toward the southwest, the unit is barely 1 m thick. The agglomerate lens may represent only a part of the flanking breccias around a larger dome, now eroded.

The agglomerate is composed of sub-angular to rounded fragments of rhyolite in a highly silicified and weakly chloritized aphanitic rhyolitic matrix. The fragments (as much as 30 to 40 percent of the rock) range in size from less than 0.5 cm to more than 30 cm in diameter. Smaller fragments tend to be sub-angular, whereas larger fragments display a crackled rind, suggestive of rapid cooling, possibly as bombs. The matrix, typically flow-banded and spherulitic, is composed primarily of aphanitic quartz with minor sericite, biotite and chlorite. The entire agglomerate dome is intensely fractured; the fractures are filled by chalcedony, aphanitic grayish-green rhyolite or a fine-grained mixture of chlorite, biotite and quartz. These chlorite-biotite-quartz zones form anastomosing vein lets, stringers and pipe-like bodies as much as 1 m in diameter and are characterized by concentrations of gold, zinc and copper. Irregular pods of massive dark green to black chlorite, up to several meters long, are scattered through the upper part of the dome, and contain concentrations of copper. The dome also contains a number of small (less than 1 m long) pods or lenses of highly contorted, banded ferruginous chert, and a few relatively undeformed lenses of quartz-chlorite rock that most likely represent small accumulations of clastic sediment. Several thin (15-20 cm) dikes of basalt cut the dome and are probably feeders for the overlying Pecos mine basalt.

Pecos mine basalt

Pecos mine basalt is a local flow exposed only in the west limb of the Mine syncline where it conformably overlies upper Pecos mine rhyolite agglomerate. The basalt was originally about 15 m thick. The dominant lithology is a dark olive-green, massive, structureless, aphanitic rock that is closely jointed, highly chloritized, extensively veined by carbonate and deeply weathered. Contained within, and concentrated toward the bottom, are bands and pods, as much as 1 m thick, of red and white, banded, ferruginous chert. The chert is highly contorted; irregular balls of chert may be the result of subaqueous extrusion and flowage of lava over unconsolidated sea-floor cherts.

Upper Pecos mine sediments

Upper Pecos mine sediments conformably overlie Pecos mine rhyolite tuff, and locally in the west limb of the Mine syncline, Pecos mine basalt. The sediments are at least 100 m thick where they crop out along middle Willow Creek, but only the lower 70 m are exposed in the Mine syncline. Three major lithologic varieties are recognized in this unit: (1) fine-grained, generally well layered siltstone; (2) vaguely bedded, impure quartzite; and (3) medium-grained, poorly bedded to massive immature sandstone.

Quartzite is the lowermost sedimentary unit in the Mine syncline where it is 23 m thick. The quartzite is greenish-gray and bedded (crossbedded locally), and contains abundant chlorite, sericite, biotite, magnetite, and less commonly, garnet. Medium-grained, poorly bedded to massive sediments overlie the quartzite in the core of the Mine syncline. These grayish-green to apple-green, highly siliceous rocks consist of quartz, chlorite, sericite and biotite. Angular to sub-angular fragments of fine-grained quartz and sericite are 1-6 mm in length and make up as much as 20-30 percent of the rock. They are interpreted as relict lithic fragments. Lens-shaped features, 0.5 to 2 m long, with upward-fining quartz grains may be scour-and-fill structures. Upper Pecos mine sediments contain anomalous concentrations of copper and zinc, especially in the Mine syncline.

Intrusive Diabase

A large body of diabase, approximately 400 m thick, intrudes the east limb of the Mine syncline where it cuts out the lower Pecos mine rhyolite. The diabase, metamorphosed to a greenish-black, fine- to medium-grained, generally nonfoliated amphibolite, is composed of hornblende, plagioclase and minor biotite. It is distinguished from metabasalt by its coarser grain size, nonfoliated appearance and relict diabasic texture. Diabase lenses interspersed with the massive sulfide ore possibly are related to the intrusive diabase.

Structure and Metamorphism

The structural grain of Precambrian rocks exposed along Willow Creek is approximately N45E, and is defined by moderately to well developed foliation in most of the stratified succession. Foliation is commonly sub-parallel to bedding or layering. Fold axes and fault traces generally follow this northeasterly trend.

The Pecos mine ore bodies lie in the west limb of an isoclinal, closed syncline (the Mine syncline) that plunges steeply to the southwest and is overturned slightly to the east (fig. 1). Another plunging syncline, slightly overturned to the east, is exposed along middle Willow Creek. The intervening anticline apparently has been obliterated by intrusive masses of diabase and dacite.

No significant faults have been recognized in the Mine syncline, although several faults displaying vertical displacements of less than 50 m cut the stratified succession along middle Willow Creek.

All Precambrian rocks in the Willow Creek area, with the exception of the intrusive granite exposed along the upper part of Willow Creek, have undergone regional low-grade, greenschist metamorphism.

ORE DEPOSITS

History

The Pecos ore body was discovered in 1881 by a prospector from Kansas named Case. A. H. Cowles tried to develop the property in the mid-1880's, but was forced to abandon the task when it became clear that the complex zinc-lead-copper ores were not amenable to treatment by then-available methods. Sporadic development work continued until 1916, when an extensive effort by the Goodrich-Lockhart Company succeeded in blocking out large tonnages of zinc-lead ore. According to Harley (1940), the period of greatest development began in 1925 when the American Metal Company of New Mexico took an option on the property. A program of development and construction was begun which cost about two million dollars, blocked out one million tons of ore, and saw a mine plant, mill and 19-km-long aerial tramway completed by 1927.

From 1927 through 1939, the mine produced more than 2 x 106 M.T. of ore that averaged 10.6% zinc, 3.3% lead, 0.5% copper, 87 gm/M.T. silver, and 3.1 gm/M.T. gold (Harley, 1940). Labor and water problems, and bad ground at depth contributed to the mine's shut-down in late May, 1939.

Ore Body Geometry

The following descriptions rely on Stott (1931), Krieger (1932) and Harley (1940). The ore at the Pecos mine was concentrated mainly in two, strata-bound, lens-shaped bodies, the Katydid and the Evangeline, each of which is an aggregate of smaller sulfide lenses. The two major ore lenses strike northeast and are sub-parallel southwest of the main shaft over a strike length of over 250 m. Near the main shaft, the two lenses begin to converge, their projected intersection at a point some 212 m farther to the northeast. The lenses dip steeply to the northwest in the upper levels of the mine, become vertical around the 600 level, and with increasing depth, dip toward the southeast at progressively shallower angles. The ore bodies plunge 50 to 55 degrees to the southwest. Neither ore lens reached the present surface, although the northeasternmost portions of the Evangeline came within 9 to 15 m of the Precambrian-Paleozoic unconformity beneath the north wall of Willow Creek Canyon. The lenses varied from about a meter to almost 15 meters in thickness. The larger, eastern (Evangeline) lens was mined along a strike length of over 600 m.

The ore lenses and associated volcanic host rocks have undergone extensive post-mineralization deformation that includes, in crude chronologic order: (1) intrusion of numerous, discontinuous diabase sheets; (2) folding, with the development of a pronounced axial-plane foliation; and (3) shearing, roughly parallel to foliation. The shearing has, in many instances, broken off and isolated individual blocks of diabase within the ore horizons, severely disrupting their original shapes.

Host Rock Relations

The Pecos mine massive sulfide lenses are related spatially to silicic volcanic rocks. Krieger (1932) and Harley (1940) indicate that the host rocks for the ore lenses are quartz-sericite and quartz-chlorite schists. Judging from published petrographic descriptions, the quartz-sericite schist is most likely a metarhyolite, stratigraphically equivalent to upper Pecos mine rhyolite. Mine records, as well as samples collected from the dumps, show that this rock type hosts a relatively minor percentage of the sulfide mineralization, mainly in the form of disseminated pyrite. According to published reports, quartz-chlorite schist hosts most of the massive sulfide ore. The bulk of the sulfide mineralization, at least in the dump samples, is associated clearly with quartz-chlorite schist that contains substantial amounts of actinolite. This quartz-chlorite-actinolite schist may be hydrothermally altered and metamorphosed silicic volcanic rock, probably correlative with upper Pecos mine rhyolite. Published descriptions indicate that the ore lenses are concordant with foliation and compositional layering of the enclosing rocks.

Mineralogy

Ore at the Pecos mine consists of sphalerite (both normal and iron-rich or marmatitic varieties), galena and chalcopyrite, mixed with pyrite, and accompanied by small amounts of silver and gold. Silver is associated closely with galena (Krieger, 1932, p. 463). Gold appears to be associated with late-stage quartz and chalcopyrite veins. Pyrrhotite occurs sparingly; bornite, magnetite and hematite are rare. Supergene minerals are exceedingly rare. Gangue minerals include quartz, chlorite, actinolite, sericite and tourmaline. Polished sections and slabs have no sulfide-silicate replacement textures. Metamorphic textures (plastic flowage of sulfide minerals, annealing, microfolding, etc.), however, are common, and indicate that the ore was involved in at least the last regional metamorphic event.

Ore Types

Ore from the Pecos mine can be classified into three major categories: (1) massive sulfide ore, (2) low-grade ore, and (3) stringer ore. Published descriptions and mine records are deficient on this subject, so the following paragraphs refer almost entirely to material collected from the dumps.

Massive sulfide ore

This variety is defined commonly as ore consisting of at least 50 percent sulfides by volume (Sangster and Scott, 1976). Massive sulfide ore at the Pecos mine may be subdivided into three distinct textural types: (1) massive, structureless ore; (2) banded ore; and (3) breccia ore.

Massive, structurelss ore may consist exclusively of sphalerite, marmatite or pyrite, or a combination of these minerals in varying proportions. Massive marmatite ore is the most common ore type and is commonly fine-grained (1 mm or less), with a granoblastic texture, and may contain up to 50 volume-percent small, subhedral to rounded pyrite grains disseminated through the matrix. Patches or lenses of galena and/or chalcopyrite occur sparingly.

Banded ore is less common than structureless ore, and generally contains more gangue material. Three mineralogic varieties are recognized: (1) banded pyrite ore, plus gangue and minor chalcopyrite; (2) banded marmatite-pyrite ore, plus gangue and minor amounts of chalcopyrite and galena; and (3) banded pyrite-marmatite-gangue ore, plus minor chalcopyrite and galena. Banded ore displays several structures that are suggestive of sedimentary deposition: (1) size grading; (2) regular ordering of band mineralogy, i.e., pyrite-rich, overlain by marmatite-rich, overlain by gangue-rich, representing a density grading with the densest pyrite (SG = 5.02) at the base, less dense marmatite (SG = 3.9) in the middle, and least dense silicate gangue (SG — 3.0) at the top; and (3) a type of bedding disruption in which bands of quartz-chlorite-actinolite gangue appear to have been partially scraped up, deformed and folded by adjacent, mainly undeformed sulfide-rich bands. These structures resemble flow rolls and rip-ups caused by pre-consolidation slumpage or flowage of mechanically unstable material.

Breccia ore is the least common variety of massive sulfide ore at the Pecos mine. It consists of angular to subangular fragments of slightly pyritized and chloritized quartz-sericite schist (metarhyolite) up to 6 cm across and smaller amber sphalerite fragments in a matrix of fine-grained to aphanitic, brownish-black marmatite that contains abundant 1 to 2 mm subhedral pyrite grains.

Lowgrade ore

Low-grade ore is defined as strata-bound ore containing less than 50 percent sulfide minerals by volume. This variety may be subdivided into two types: (1) massive, structureless ore, characterized by disseminated pyrite, marmatite and lesser amounts of chalcopyrite, in a fine-grained groundmass of actinolite, quartz and chlorite; and (2) banded ore, containing thin (up to 0.5 cm) galena-rich horizons, with or without marmatite and pyrite, in a quartz-chlorite ± actinolite schist.

Stringer ore

Stringer ore contains substantially less than 50 volume-percent sulfides, and may be only marginally economic. It consists of veinlets and stringers of quartz and chalcopyrite, generally accompanied by tourmaline, and lesser amounts of pyrite, pyrrhotite and amber sphalerite, that are commonly discordant with the foliation of the enclosing quartz-chlorite-actinolite schist.

Alteration Associated with Ore

Alteration associated with the ore bodies consists of silicification and chloritization, and appears to be limited to the footwall side of the massive sulfide lenses. A few ore samples from the dumps contain visible secondary carbonate. Stott (1931) and Harley (1940) indicate that silicification is common in the "shear zone" that hosts the ore. Intense silicification is also apparent in the upper Pecos mine rhyolite agglomerate and underlying Pecos mine rhyolite tuff. Chlorite-biotite-quartz pipes cut the rhyolite agglomerate and represent irregularly cylindrical zones of intensely chloritized rhyolite. Similar alteration is developed locally in the upper part of the Pecos mine rhyolite tuff. The assemblage quartz-chlorite-actinolite biotite occurs only in the immediate vicinity of the massive sulfide lenses, and may represent a slightly more Ca-rich variety of the chloritized silicic volcanic rocks.

Genesis

Prior to 1974, sulfide ores at the Pecos mine were interpreted as hydrothermal replacement bodies, deposited by late-stage fluids emanating from the Precambrian Embudo granite (Harley, 1940; Krieger, 1932; Stott, 1931). Giles (1974) suggested that the Pecos ores might be volcanogenic massive sulfide deposits. Our work confirms this hypothesis.

The concordant, strata-bound nature of the sulfide lenses, the primary sedimentary structures in the ore, the widespread occurrence of copper and zinc anomalies at or near a single stratigraphic horizon within the Pecos mine series, and the apparent lack of significant alteration in hanging-wall rocks point to the syngenetic deposition of sulfides as an integral part of the formation of the volcanic and sedimentary rocks.

The zinc-lead-copper ores at the Pecos mine are volcanogenic massive sulfide deposits, closely related in time and space to subaqueous silicic volcanism that occurred during the early middle Proterozoic in northern New Mexico. The sulfides accumulated at or near the volcanic rock/seawater interface during the waning stages of silicic volcanism, most likely deposited from hot saline brines that flowed through channelways, now marked by chlorite alteration pipes, in and around a rhyolite agglomerate dome. The ore occupies a position marginal to the dome and is intercalated with a pile of silicic volcanics that forms the tuffaceous apron of the dome. The present stratigraphic separation of the two major ore lenses may be due to later folding and metamorphism. It seems more likely, however, that the separation is the result of small silicic eruptions between the times of the two major outpourings of metal-rich brines; these eruptions produced a barren rhyolite screen between the two sulfide bodies.

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