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SANDSTONE COPPER DEPOSITS OF THE NACIMIENTO REGION, NEW MEXICO

by

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SUMMARY

Copper sulfides and copper-iron sulfides have partly replaced or are closely associated with carbonaceous fossil plant material in sandstones and arkoses ranging in age from Pennsylvanian to Triassic in the Nacimiento region of north-central New Mexico. Primary sulfide minerals, chalcocite, covellite, bornite, chalcopyrite, and pyrite, were probably deposited from ground-water solutions; mineralization occurred where there was a favorable reducing environment provided by fermentation of carbonaceous material. Small amounts of native silver occur with the sulfides.

The sulfide minerals were partly oxidized later, and copper in the form of malachite, chrysocolla, and azurite was disseminated in the adjacent host rock, forming irregular halos around the mineralized fossil plant material.

Deposition of the sulfides probably occurred principally during Triassic time. Major faults post-date deposition of the sulfide minerals and can be expected to offset some of the mineralized bodies.

Large-scale deposition of the sulfide minerals occurred at fossil logjams within paleochannels. Orientations of cross-bedding and fossil logs can be used to determine the trends of the paleochannels. These trends should be followed in subsurface exploration.

INTRODUCTION

This report is a generalized summary based upon detailed studies by us (Kaufman and others, 1972; Woodward and others, 1974). Locations of most of the mineralized areas are shown on a series of geologic maps at 1:24,000 scale published by the New Mexico State Bureau of Mines and Mineral Resources (Woodward and others, 1972, 1973a, 1973b, 1973c).

Previous reconnaissance reports by Newberry (1876), Cazin (1880), Jenks (1899), Lindgren and others (1910), and Fischer (1937) covered some of the deposits described here. A circular by Soulé (1956) shows assay results and claim maps of these deposits. Elston (1967) summarized the mineral resources of several counties in central New Mexico, including the principal mines noted in this report.

The area covered by this report produced over 7,500,000 pounds of copper and about 75,000 ounces of silver between 1881 and 1960 (Elston, 1967, p. 26), with most of the production coming from the San Miguel mine (Fig. 1, loc. 1) prior to 1900 (Lindgren and others, 1910). From 1900 until the middle 1960s production was sporadic and minor, the Eureka and San Miguel mines (Fig. 1, lots. 1 and 2) being the main producers (Elston, 1967). An extensive exploration program that centered around the Eureka and the Nacimiento mines (Fig. 1, lots. 2 and 3) was undertaken by Earth Resources Company in the late 1960s. In 1971 the Nacimiento mine (formerly Copper Glance-Cuprite mine) went into production with reserves estimated to be 9.6 million tons at 0.71% copper (Mining Record, October 22, 1969).

HOST ROCKS

The mines and prospects in this report are sandstone-type deposits. They have been called "red-bed" copper deposits (Emmons, 1905), but actually the host rocks are white to buff. Strata above and below the host rocks, however, are typical red beds. Mineralization occurs in beds ranging in age from Pennsylvanian to Triassic (Fig. 2).

The Madera Formation (Pennsylvanian) is comprised of gray limestone, arkosic limestone, arkose, orthoquartzite, and red to gray shale. This unit is locally missing in the central Sierra Nacimiento where the Permian rocks rest unconformably upon the Precambrian.

The oldest Permian unit is the Abo Forrriation, which is about 150 to 750 feet thick and consists of reddish-brown mudstone with thick, lenticular interbeds of reddish-brown to greenish-gray arkosic sandstone. Minor amounts of nonfossiliferous, dense, gray limestone occur near the base of the Abo.

The Abo Formation is overlain by the Yeso Formation, which is 0 to 300 feet thick and is composed of reddish-orange and orange buff, well-rounded, well-sorted, fine- to very fine-grained, quartzose sandstone. A few dense, gray limestone beds are present in the upper part of this formation in the southern part of the area covered by this report. A disconformity at the top of the Permian cuts stratigraphically lower northward in this area so that the Yeso thins northward and is absent about 1 mile north of the Nacimiento mine.

In the southern part of Sierra Nacimiento the Glorieta Sandstone and the Bernal Formation (Permian) are present, but near the San Miguel mine and northward they are missing. The Glorieta consists of up to 50 feet of whitish sandstone and the Bernal is composed of as much as 65 feet of reddish-brown sandstone.

The Agua Zarca Sandstone Member of the Chinle Formation (Triassic) consists of white to buff, fine- to very coarse-grained, thick-bedded, quartzose sandstone. It ranges from 80 to 200 feet in thickness and forms a steep cliff between the bench-forming redbeds above and below. The unmineralized rock contains 90-95% quartz, 2-5% fresh feldspar, 1-5% chert, 1-2% magnetite, up to 1% muscovite, and trace amounts of zircon, tourmaline, chlorite, and biotite. The original clasts are angular to well-rounded, but minor overgrowth on quartz

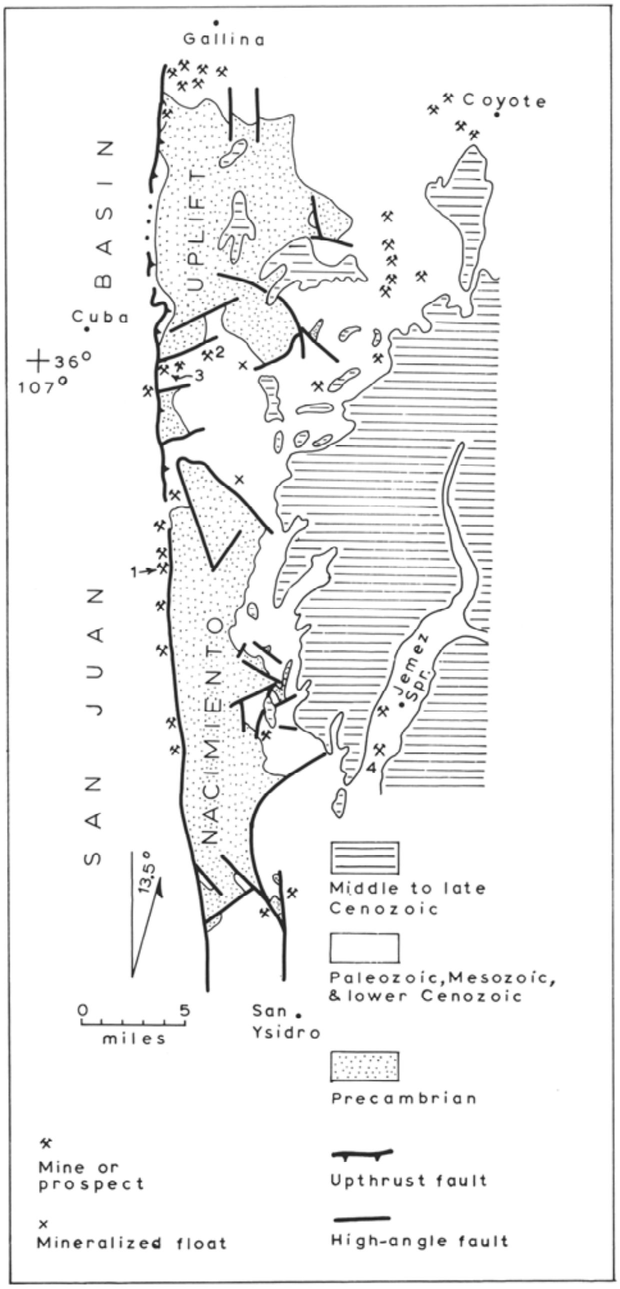

Figure 1. Generalized geologic map showing sandstone copper deposits of Nacimiento region, New Mexico. Numbered localities are: 1, San Miguel mine; 2, Eureka mine; 3, Nacimiento mine; 4, Spanish Queen mine.

grains has modified the grain outlines. Most of the sandstone is friable, as cementation is weak and has occurred mainly by quartz overgrowth and by deposition of interstitial microcrystalline quartz. Background copper content of the Agua Zarca away from mineralized areas is 10 to 150 parts per million (Table 2).

Lenticular channel deposits within the Agua Zarca Sandstone Member are widespread and are characterized by cross-bedded conglomerate and conglomeratic sandstone beds containing fossil wood fragments, clay galls, and well-rounded pebbles and cobbles of metaquartzite up to 5.0 inches in diameter. The individual channels are mostly 2-6 feet thick and 20-50 feet wide, but locally, the channels form complexes that are up to 40 feet in thickness and 280 feet in width.

The Salitral Shale Member of the Chinle Formation rests conformably on the Agua Zarca and consists of about 300 feet of maroon shale with subordinate gray shale, green shale, and very coarse-grained, green to light gray, calcareous sandstone. Zones of carbonaceous shale are common in the Salitral Shale.

Above the Salitral Shale Member lies the Poleo Sandstone Member of the Chinle Formation. It ranges in thickness from 0 to 135 feet, with rapid stratigraphic changes in thickness along strike. This member thins southward and is absent in the vicinity of the San Miguel mine. The Poleo consists of greenish, very fine- to coarse-grained, thick-bedded, micaceous sandstone that commonly contains carbonaceous fossil plant material. A few beds of lenticular, dense, light gray, elastic limestone are present at most localities. Subordinate green and

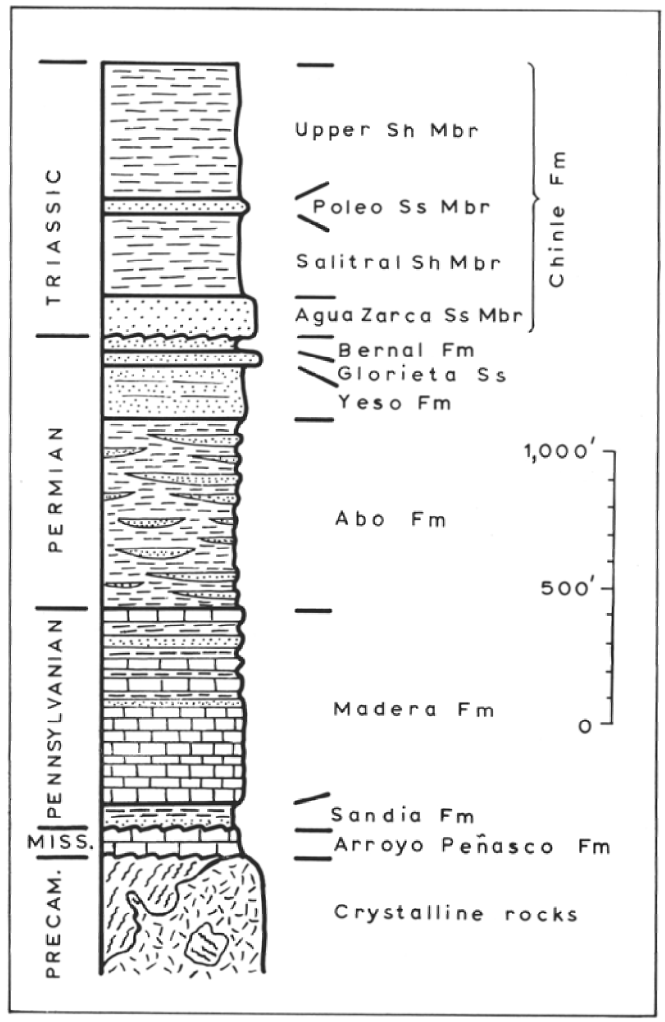

Figure 2. Columnar section of Precambrian through Triassic rocks of Sierra Nacimiento, New Mexico. Sandstone copper deposits occur in Madera Formation, Abo Formation, and Agua Zarca Sandstone Member of Chinle Formation.

reddish-maroon shale occur within the Poleo Sandstone Member.

The youngest member of the Chinle Formation in this area is the Upper Shale Member which is composed of 460 to 600 feet of reddish shale with minor amounts of green and maroon shale, red siltstone and sandstone, and gray, clastic limestone.

MINERALIZATION

Copper sulfides, copper-iron sulfides, and iron sulfide occur as replacements of and surrounding carbonaceous fossil plant material. Native silver is associated with the sulfides. Malachite, azurite, and chrysocolla occur in the interstices of the clastic host rocks and along fracture surfaces, forming irregular halos surrounding the organic material and the sulfides. Minor cuprite, native copper, antlerite, and spangolite are locally present at the Nacimiento mine.

Carbonaceous fossil plant material occurs as branches and trunks of trees, as rounded nodules of fossil wood up to 5 cm across, and as thin films of unidentified plant material along bedding surfaces. Branches and trunks are most abundant in Agua Zarca paleochannels that are commonly filled with pebble- and cobble-conglomerate.

The most abundant ore minerals are chalcocite and malachite; subordinate bornite and chrysocolla, and minor amounts of covellite, azurite, and chalcopyrite are present. Polished sections of mineralized fossil wood from the Eureka, San Miguel, and Nacimiento mines contain (by volume percent) an average of approximately 81% chalcocite, 11% bornite, 2% covellite, 5% pyrite, and trace amounts of chalcopyrite. Pyrite is most abundant in nodules of fossil wood from the San Miguel mine (up to 10%) and is absent in some specimens from the Nacimiento and Eureka mines.

Bornite has selectively replaced cell walls and chalcocite has replaced the centers of cells in the fossil wood. Pyrite, where present, also occurs in the centers of cells and has been partly replaced by chalcocite. The paragenetic sequence cannot be established firmly, but the suggested order of deposition (from oldest to youngest) is pyrite, bornite, chalcocite, and covellite. Any younger mineral may be seen to replace any older mineral in the sequence. The position of chalcopyrite in the sequence is not clear.

Analyses of mineralized fossil wood from the Eureka, Nacimiento, and San Miguel mines show that copper ranges from 38.9% to 65.8% and silver ranges from 5.6 to 6.8 ounces per ton (Table 1). Mineralized fossil wood constitutes a small percentage of total rock volume at these localities; however, it contributes significantly to the average grade of ore in these deposits. Samples of clastic host rocks containing interstitial copper carbonates and silicate were assayed and show a maximum of 4.7% copper and 0.088 ounce of silver per ton.

	Cu (%)	Ag (oz/ton)
Eureka mine	38.9	6.4
San Miguel mine	43.0	6.8
Nacimiento mine	65.8	5.6

Table 1. Atomic absorption spectrophotometric analyses for copper and silver contained in mineralized fossil wood from Eureka, San Miguel, and Nacimiento mines. J. W. Husler analyst.

The following descriptions of the mineralized areas are discussed in stratigraphic order from oldest to youngest (Fig. 2) and include those in the Madera Formation, the Abo Formation, and the Agua Zarca Sandstone Member of the Chinle Formation.

Madera Formation

Mineralization in the Madera Formation occurs in siltstone and in coarse-grained arkose and consists of minor disseminated malachite. The observed areas of mineralization do not appear to be of commercial value; however, they are important in showing the geographic distribution of copper mineralization. As malachite is usually the only copper mineral present, mineralization in the Madera is probably the result of leaching of copper minerals from the Abo Formation and(or) the Agua Zarca Sandstone Member in the same general area.

Abo Formation

There are numerous prospects and two areas of mineralized float that were observed in the Abo. Most of the mineralized beds consist of tan, coarse-grained arkose or feldspathic sandstone, or rarely conglomerate.

The exposed mineralized areas at most of these localities consist of stratigraphically thin zones that are laterally discontinuous. Carbonaceous material is sparse and so are sulfides; malachite, azurite, and chrysocolla are by far the most abundant cupriferous minerals and are present in the interstices of the host rocks. Silicified beds up to 6 inches thick and minor amounts of barite are present in the Abo near some of the mineralized areas.

The larger deposits include one of the prospects near Gallina and the Spanish Queen mine near Jemez Springs (Fig. 1, loc. 4). The latter produced about 19,200 pounds of copper between 1928 and 1937 (Elston, 1967, p. 24). The prospect near Gallina is somewhat different than the other Abo localities insofar as the mineralized horizon is conglomeratic, with quartzite pebbles and cobbles exposed in lenticular channels that can be traced for several hundred feet along strike.

Exploration efforts for copper in the Abo Formation should be directed along paleochannel (and paleocurrent) trends in search for large accumulations of carbonaceous trash which may be mineralized. It should be kept in mind that host arkoses in the Abo are lenticular and discontinuous and therefore the chance of finding large copper deposits in this unit in the Nacimiento area is probably low.

Agua Zarca Sandstone Member

The Agua Zarca Sandstone Member contains the largest of the known copper deposits in the region covered by this report.

The mines and prospects in the Agua Zarca near Eureka Mesa (Fig. 1, locs. 2, 3) have been called the Copper Cities group by Soulé (1956) and include the Eureka mine, the Nacimiento mine and two prospects. Triassic and older rocks are exposed near Eureka and Blue Bird Mesas, and as a result of uplift, the Agua Zarca is folded and faulted, with the attitudes of bedding ranging from flat-lying to very steeply dipping. The major deposits are described below.

Eureka Mine

The Eureka mine is on the south side of Eureka Mesa, where the Agua Zarca is approximately 140 feet thick and dips gently to the southwest. The mine is in the base of the Agua Zarca, and the ore has been mined by means of surface and underground workings. A detailed mine map is available in the publication by Woodward and others (1974).

Ore mineralization is confined principally to a lenticular channel approximately 280 feet wide and a maximum of 40 feet thick, which is composed of intercalated, cross-bedded, quartz-pebble conglomerate and cross-bedded, quartzose sandstone. High-angle, festoon and planar cross-bed sets up to 5 feet thick and fossil wood fragments up to 1 foot in diameter and 5 feet long are numerous within the channel. The conglomerate contains more carbonaceous material and is also more porous and permeable than the adjacent sandstone, which is usually barren. Clay galls are common throughout the channel, and clay beds up to 2 feet thick are present as overbank deposits in the north part of the mine.

Elston (1967) reported that cross-bedding shows that the current direction was toward the southwest and a detailed paleocurrent study confirms this trend (Kaufman, 1971).

Nacimiento Mine

A description of the Nacimiento mine is given by Talbott (1974) in this Guidebook.

San Miguel Mine

The San Miguel mine occurs west of the range-marginal fault which is nearly vertical here. Two west-trending faults about 800 feet apart apparently bound most of the mineralized area. The ore body has been offset by both of these faults. Mineralized Agua Zarca is present a few feet north of the northern fault which has left-lateral separation. The fault to the south is mostly covered by pediment gravel that obscures the structural relations. The strata bounded by these three faults form a structural terrace, with most of the present workings in the gently dipping part. Details of the structure are given by Woodward and others (1974).

Lindgren and others (1910) reported that five or six drifts, ranging from 300 to 800 feet long, were driven along strike. These drifts are all inaccessible and no underground maps are available. Dozer trenches and dumps developed during the 1950s and 1960s have obscured most of the older workings.

A paleochannel complex is present here, but is not as obvious as that at the Eureka mine. Cross-bed data and other primary sedimentary structures suggest that the current direction was nearly due west.

ORIGIN

Carbonaceous material in permeable zones appears to have been the most important factor in controlling mineralization. Primary copper sulfide minerals were deposited in the presence of carbonaceous material which created the reducing environment necessary for precipitation of copper from solution; some of the copper sulfides probably replaced pyrite that had been precipitated in the presence of carbonaceous material. Although some of the copper sulfides appear to have replaced pyrite, it is unlikely that all of the copper was deposited in this manner as pyrite is not present in many specimens. Regardless of whether pyrite was replaced by copper sulfides or the cop per sulfides directly replaced the carbonaceous material, the presence of the carbonaceous material ultimately was essential in localizing deposition of the ore. The sulfide minerals were partly oxidized later, resulting in disseminations of malachite, azurite, and chrysocolla in the adjacent sandstone and conglomerate.

The following hypotheses concerning the time and processes of mineralization have been considered by geologists working in this area: 1) the sulfide ore minerals were deposited by ground water moving through permeable zones, either during, shortly after, or possibly long after deposition of the sediments, 2) hydrothermal solutions passed upward along faults and mineralized favorable adjacent sedimentary rocks. These two hypotheses have totally different and very important implications for exploration. According to the first hypothesis the mineralized areas need not be directly or even remotely associated with faults, whereas the second hypothesis implies that faults are critical in the localization of the ore deposits.

The lack of sulfide mineralization and hydrothermal alteration along the faults or other conduits indicates that the copper-bearing solutions were not derived from nearby hydrothermal sources. There is no apparent relation between faults and mineralized zones as would be expected if the copper minerals were deposited by solutions moving through faults. The strata-bound nature of these deposits and their wide geographic distribution favor deposition from ground water.

Copper mineralization has not been observed in rocks younger than the Agua Zarca Sandstone Member. The Poleo Sandstone Member commonly contains permeable, carbonaceous zones, but there is no reported mineralization. (Soule (1956) incorrectly reported that the host rock for some of the ore deposits discussed here was the Poleo Sandstone Member of the Chinle Formation.)

Therefore, primary sulfide ore deposition in the Agua Zarca Sandstone Member occurred after deposition of the host rock, but prior to deep burial and probably prior to deposition of the Poleo Sandstone Member. Well-preserved cellular structure in the mineralized fossil logs suggests that replacement by sulfides occurred prior to deep burial that could have crushed the wood cells.

Several possible models that could account for the ultimate source of the copper-bearing solutions include: 1) an older deposit leached by ground water; 2) hydrothermal solutions introduced into the paleohydrologic system from outside the study area; 3) copper derived by leaching of large volumes of rock containing low abundances of the metal.

We favor a model that involves deriving the copper from an older deposit, or deposits, from the Uncompahgre highland to the north during the time of deposition of the Agua Zarca Sandstone Member. The highland supplied the elastic components of the Agua Zarca (Stewart and others, 1972, p. 94) and, in an area about 35 miles northeast of the Eureka mine, Gabelman and Brown (1955) have reported detrital chalcocite in the Agua Zarca in a paleochannel. Primary copper deposits occur in the Precambrian of the Brazos uplift of northern New Mexico (Bingler, 1968), an area which comprised part of the Uncompahgre highland in Triassic time. This model is similar to a tectonic-climatic model proposed by Strakhov (1970) to account for the genesis of sandstone copper deposits whereby copper sulfides are leached from an actively dissected highland that lies in a moist climatic zone where relatively low pH hydrologic conditions exist. The copper is carried in solution by water draining into an arid intermontane basin where relatively high pH hydrologic conditions occur. Deposition of copper minerals occurs as a result of either a local or a regional pH and(or) Eh change. The association of ores of copper with coarse-grained elastic rocks appears to be related to changes in pH of water in streams moving from humid to arid environments (Strakhov, 1970, p. 71-81). Mineralization in the Agua Zarca and Abo appears to be related to lowering of Eh conditions in and around accumulations of carbonaceous material as a result of fermentation. In this environment sulfate-reducing bacteria probably were also active in lowering the Eh. Reduction of copper and iron in solution resulted in precipitation of copper sulfides and copper-iron sulfides. It seems likely that in many cases the copper was deposited and later leached, perhaps several times, en route to its present location.

Other possibilities concerning the ultimate source of the copper are discussed below. However, they seem to have less in their favor than the model proposed above.

It is unlikely that the copper was derived from Precambrian rocks in the Nacimiento area because these rocks were buried by the Permian Abo Formation during the time that the Agua Zarca Sandstone Member was being deposited. Also, the Precambrian rocks are low in metal content (Table 2).

The Mogollon highland to the south was the source area for the sediments composing the shale members of the Chinle Formation in the Nacimiento region (Stewart and others, 1972). Much of the clay in these units is of volcanic origin, which suggests that leaching of copper from the shales is a possibility. Also, hydrothermal solutions may have entered the paleohydrologic system and moved northward from the Mogollon highland in the direction of sediment transport. The fact that the Poleo Sandstone Member contains permeable, carbonaceous zones, and is enclosed by the Chinle shales, but has not been mineralized, detracts from this hypothesis.

Sample	Cu ppm	Ag ppm	Pb ppm	Zn ppm
Cretaceous black shale	20	0.40	<40	80
Cretaceous black shale	10	1.20	<40	30
Jurassic mudstone	80	1.80	90	52
Jurassic mudstone	<10	0.20	<20	20
Triassic, Upper Shale	10	1.20	40	30
Triassic, Upper Shale	40	1.20	<40	55
Triassic, Salitral Shale	290	0.80	60	40
Triassic Salitral Shale	50	1.00	<40	20
Triassic, Salitral Shale	5	2.80	<40	10
Triassic, Salitral Shale	6	0.40	<40	20
Triassic, Agua Zarca	10	<0.20	<20	72
Triassic, Agua Zarca	12	<0.20	<20	94
Triassic, Agua Zarca	150	<0.20	<20	52
Triassic, Agua Zarca	10	<0.20	<20	60
Triassic, Agua Zarca	12	0.20	<20	46
Permian sandstone	8	0.40	<40	25
Permian arkose	46	0.58	25	40
Permian shale	<10	1.40	<20	54
Precambrian quartz monzonite	14	0.79	<20	84
Precambrian quartz diorite	24	1.40	<20	110
Precambrian granite	62	0.20	<20	52
Precambrian mafic dike	124	0.20	70	144

Table 2. Atomic absorption spectrophotometric analyses of unmineralized rocks from Sierra Nacimiento showing background values of copper, silver, lead, and zinc. J. W. Husler analyst.

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