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GEOLOGY AND MINERAL DEPOSITS OF THE SEDIMENTARY-COPPER DEPOSITS IN THE SCHOLLE MINING DISTRICT, SOCORRO, TORRANCE AND VALENCIA COUNTIES, NEW MEXICO

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ABSTRACT—Small, uneconomic, stratabound sedimentary-copper deposits at the Scholle mining district are restricted predominantly to the lower member of the Abo Formation, with minor occurrences in the upper member of the Bursum Formation and the Meseta Blanca Sandstone Member of the Yezo Formation. Spanish settlers likely mined copper from the district sometime after the founding of the Abo and other Salinas missions in the area in 1629. Sedimentary-copper deposits were rediscovered by modern prospectors in the Scholle district as early as 1902, but production did not begin until 1915. From 1915 to 1961, 15,037 short tons of ore were produced and yielded 1,122,468 lbs Cu, 8,147 oz Ag, and 426 lbs Pb. Copper and uranium minerals in the Abo Formation occur: (1) as disseminations within bleached arkose, limestone-pebble conglomerate and siltstone; (2) along bedding planes and fractures at or near sandstone-shale, sandstone-siltstone and sandstone-limestone contacts; (3) as replacements of wood and other organic materials; and (4) as replacements of clay or calcite cement within the host sandstone. Copper and other metals were probably transported in low-temperature brine solutions through permeable sediments and along bedding planes and faults shortly after burial. Oxidizing waters could have leached copper and other metals from at least three sources: (1) clay minerals and detrital mineral grains and rock fragments within the red-bed sequences, (2) Proterozoic rocks enriched in these metals, and (3) Proterozoic base-metal deposits. Most sedimentary-copper deposits in the Scholle district, as elsewhere in New Mexico, are too low grade, low tonnage, and far from existing copper mills for current development of copper. However, increases in copper and silver prices have sporadically renewed interest in some of the larger deposits, such as in the Scholle district.

INTRODUCTION

Stratabound sedimentary-copper deposits containing copper, silver, and locally lead, zinc, uranium, vanadium, and molybdenum occur throughout New Mexico (Fig. 1). These deposits also have been called *red-bed* or *sandstone* or *sediment-hosted* copper deposits by previous workers (Soulé, 1956; Phillips, 1960; Cox and Singer, 1986; Kirkham, 1989). The U.S. Geological Survey now calls these deposits a red-bed type of sediment-hosted stratabound copper deposits (Hayes et al., 2015). These deposits typically occur in bleached gray, pink, green, or tan sandstone, siltstone, shale, and limestone within or marginal to typical thick red-bed sequences. In New Mexico, the red, brown, purple, or yellow sedimentary host rocks were deposited in fluvial, deltaic or marginal-marine environments of Pennsylvanian, Permian, or Triassic age. One of the largest producing districts containing sedimentary-copper deposits in New Mexico is the Scholle mining district (also known as the Abo or Carocito district), found in the southern Manzano Mountains at the junction of Socorro, Torrance and Valencia Counties, where copper minerals are found in the Permian Abo Formation and minor occurrences in the underlying Pennsylvanian-Permian Bursum and overlying Permian Yezo formations.

The purposes of this report are (1) to summarize the previous work and mining history of the Scholle district, (2) to describe the geology, geochemistry, and mineral deposits, and (3) to summarize the mineral resource potential of the district.

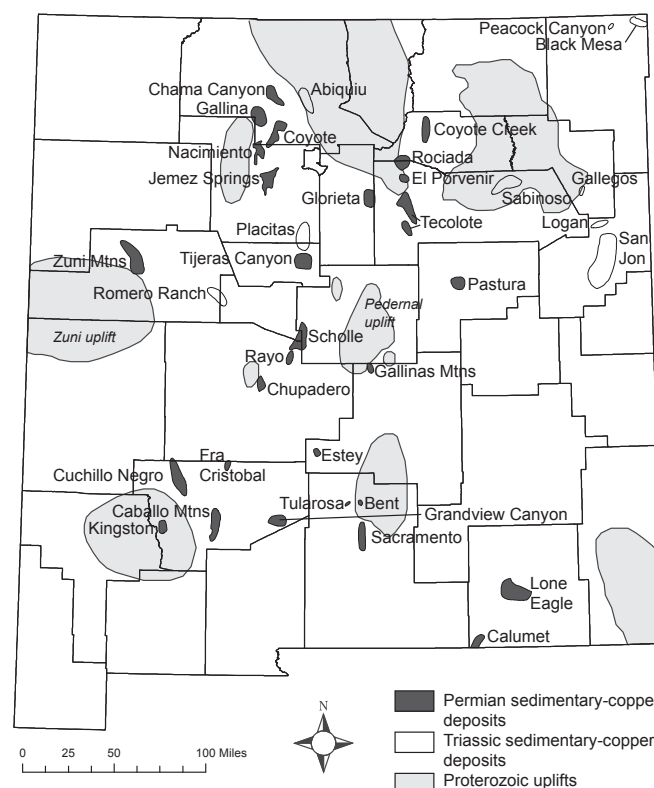


FIGURE 1. Permian and Triassic stratabound sedimentary-copper deposits in New Mexico. Proterozoic uplifts, exposed during deposition of the Permian Abo Formation, are from Kues and Giles (2003).

Data used in this report have been compiled from a literature review, field examination, and New Mexico Bureau of Geology and Mineral Resources (NMBGMR) unpublished data. Published and unpublished data on existing mines and prospects within the Scholle district were inventoried and compiled in the New Mexico Mines Database (Appendix 1). The mines and prospects in this report are described in the New Mexico Mines Database (McLemore et al., 2002, 2005a, b) and are identified by a unique mine identification number (Mine ID), beginning with NM (for example NMTO0054). This information is provided in order to properly locate the mines, occurrences, and deposits; the New Mexico Mines Database is constantly being updated and locations of mines not in McLemore et al. (2002) can be obtained by request using the Mine ID number.

MINING HISTORY AND PREVIOUS WORK

Spanish settlers likely mined copper from the Scholle mining district sometime after the founding of the Abo and other Salinas missions in the area in 1629 (Parker, 1947). Sedimen-

tary-copper deposits were rediscovered by modern prospectors in the Scholle district as early as 1902 (Emmons, 1905; McLemore, 1984), but production did not begin until 1915 (Table 1). In 1916, approximately \$700 worth of radium was produced from this district (U.S. Bureau of Mines unpubl. files, 1949; McLemore, 1984). W.A. Thomas discovered copper at the Pioneer mine (or Hannie; NMTO0027) in 1949, which was later claimed by G.G. Farman in 1951 (Collins and Nye, 1957). In the 1950s, mining claims were filed for uranium and found associated with the copper-bearing sandstones by D.A. Voyles, D.B. Voyles and D. Lammel. Chapman and Wood (1954) leased the claims and performed shallow drilling for uranium about 1954. Fisher, Gore, Anglin, and Green drilled at the Copper Girl mine (NMTO0024). In 1957, the U.S. Atomic Energy Commission (AEC) drilled near the Pioneer mine (Collins and Nye, 1957). Despite the increased exploration in the 1950s and 1960s for uranium, there was no uranium production from the district.

Production statistics for the Scholle district are in Table 1. All of the known deposits (Fig. 2) are found at or near the sur-

TABLE 1. Estimated and reported production from the Scholle mining district, Socorro, Torrance, and Valencia Counties, New Mexico (from U.S. Geological Survey, 1902-1927; U.S. Bureau of Mines Mineral Yearbooks, 1927-1990; McLemore, 1984; NMBGMR unpubl. files) — no reported production. Note that in 1938, 47 short tons of ore containing 4,700 lbs Cu, 405 oz Ag, and 14.2 oz Au were reportedly shipped from Scholle. However, this production is not included because the silver and gold contents are too high for sedimentary-copper deposits; production for 1938 is estimated. It is likely that this shipment came from somewhere other than the Scholle mining district. In 1916, approximately \$700 worth of radium also was produced from this district (McLemore, 1984). These data are the best data available and were obtained from published and unpublished sources (NMBGMR unpubl. files). However, mining district data are subject to change as new data are obtained. Production data are reported in English units according to the original publications to avoid conversion errors.

YEAR	NUMBER OF MINES	ORE (short tons)	Cu (lbs)	Pb (lbs)	Ag (oz)	Au (oz)	VALUE \$
1915	5	188	25,143	—	124	—	4,463
1916	13	3,172	331,475	—	2,600	—	83,254
1917	14	2,169	200,626	326	1,312	1.45	55,910
1918	7	637	78,757	—	361	—	19,814
1919	2	75	5,468	—	25	—	1,045
1922	1	16	1,740	—	13	—	248
1923	2	59	6,476	—	15	—	964
1928	7	1,943	187,083	—	1,952	8.22	25,253
1929	4	2,001	160,500	—	1,413	—	29,001
1930	2	120	9,000	—	57	—	1,192
1933	1	56	2,000	—	17	0.29	140
1936	1	25	1,500	—	5	—	142
1937	1	48	2,000	—	5	—	246
1938	1	40	1,500	—	5	—	250
1943	2	220	19,000	—	135	—	2,566
1953	1	192	6,400	100	13	—	1,862
1954	2	1,086	11,100	—	2	—	3,276
1956	2	146	4,600	—	17	—	1,970
1957	2	2,876	69,500	—	81	—	20,992
1961	1	8	100	—	0	—	60
Reported total 1915-1961	—	15,037	1,122,468	426	8,147	9.96	252,398

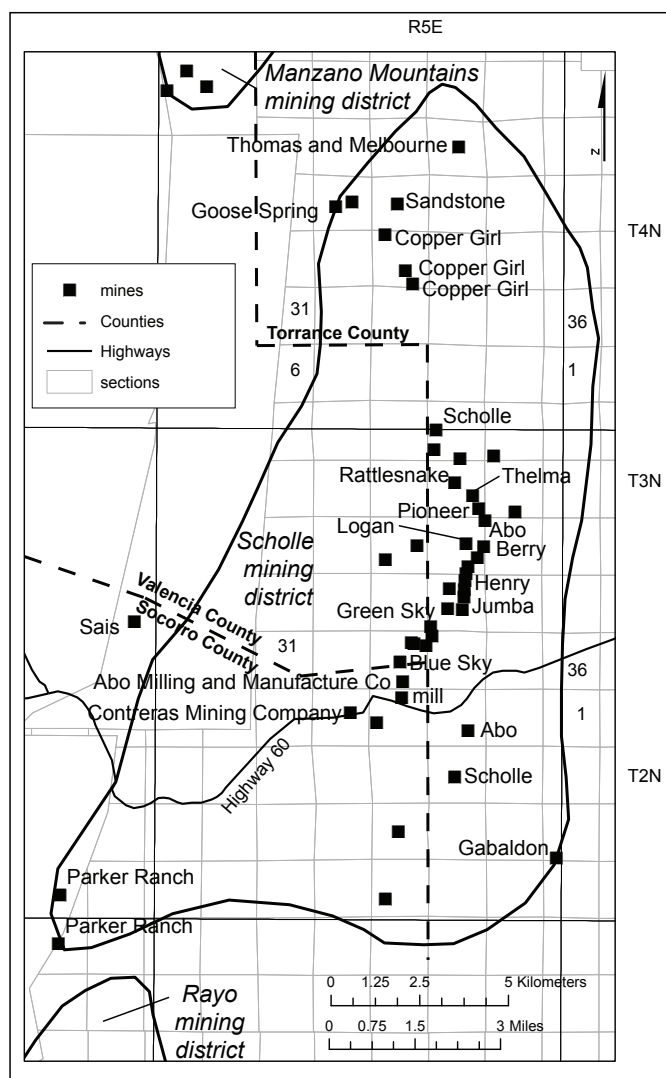


FIGURE 2. Sedimentary-copper deposits in the Scholle district. More details on mines in Appendix 1.

face (within several meters), above the water table, and were mined by surface and underground methods. Ore bodies range in size from small occurrences containing less than a ton of ore to large deposits containing several thousand tons of ore. Open pits and trenches in the Scholle district are less than 3-m-deep and adits range in length from a few meters to 30 m. Shafts are less than 23 m deep. The largest workings with the most production are from the Abo (a.k.a. Sandstone, NMTO0021), Abo Milling and Manufacture Co. (a.k.a. Blue Star, NMVA0001) and Copper Girl (NMTO0024) mines. The ore was hand sorted and shipped to El Paso, Texas, for processing. Several leaching plants attempted unsuccessfully to recover copper and uranium during the 1950s and 1960s; one was at Scholle along Highway 60 (mill, NMSO0135), another at Abo Milling and Manufacturing Co. Mill Site (NMSO0322), and another was at the Abo mine. These operations used sulfuric acid, which was consumed quickly by the high calcite content cement of the sandstone hosting the ore.

Bates et al. (1947) released the first geologic map of the Scholle area. The Scholle quadrangle was later mapped by

Myers (1977) and more recently by Scott et al. (2005). Early descriptions of the copper deposits were by Emmons (1905), Lasky (1932), Lasky and Wooten (1933), Soule (1956), Phillips (1960), LaPoint (1974, 1976, 1989), Hatchell et al. (1982) and McLemore (1984).

GEOLOGY

The Scholle district is dominated by gently-dipping Pennsylvanian to Permian limestones and sandstones belonging to the Bursum, Abo, and Yeso formations (McKee et al., 1967; Myers, 1977; Myers et al., 1981; Kues and Giles, 2003; Scott et al., 2005). Along the western edge of the district, the Pennsylvanian limestones form vertical to overturned ridges and are faulted against Proterozoic rocks.

Small, uneconomic stratabound sedimentary-copper deposits at Scholle are restricted predominantly to the lower member of the Abo Formation, with minor occurrences in the upper member of the Bursum Formation and the Meseta Blanca Sandstone Member of the Yeso Formation. The Abo in the Scholle district consists predominantly of red mudstone and siltstone with subordinate coarser units including sandstone, arkosic sandstone, and conglomerate (LaPoint, 1976; Hatchell et al., 1982). Cross stratification and channel trends described by several workers (McKee et al., 1967; Kottowski and Stewart, 1970; LaPoint, 1974; Hatchell et al., 1982; V.T. McLemore, unpubl. data) confirm a northeastern source, most likely the Pedernal uplift (Fig. 1). The Bursum Formation was deposited in a transitional marine to coastal plain environment, whereas the Abo and Yeso Formations were deposited in fluvial, floodplain, deltaic, and coastal plain environments, probably during arid conditions (Kues and Giles, 2003).

Detrital minerals within these sandstones include quartz, feldspar, rutile/ilmenite, magnetite, mica, and other trace minerals and rock fragments that are cemented by clay minerals and/or calcite. Pink orthoclase, limestone, and quartz clasts are found in the coarser units. The orthoclase and quartz clasts along with most of the detrital minerals are similar to Proterozoic rocks in the Pedernal uplift, which is a likely source as determined from cross stratification and channel trends.

DESCRIPTION OF MINERAL DEPOSITS

The larger deposits are in the basal Abo Formation and smaller occurrences are in the Bursum and Yeso formations. Several horizons of copper and uranium deposits are associated with bleached pink or gray sandstone or siltstone within predominantly red mudstone, siltstone, arkose, and sandstone. The host sandstones are typically paleochannel deposits where organic material is abundant and mudstones are thin. Copper and uranium minerals in the Abo Formation occur: (1) as disseminations within bleached arkose, limestone-pebble conglomerate and siltstone; (2) along bedding planes and fractures at or near sandstone-shale, sandstone-siltstone and sandstone-limestone contacts; (3) as replacements of wood and other organic materials; and (4) as replacements of clay or calcite cement within the host sandstone. The mineralized bodies typically occur as

lenses or blankets of disseminated and/or fracture coatings of copper minerals, with rare small pods containing up to 40-50% Cu; however, most deposits in the Scholle district contain less than 5% Cu. The deposits in the Scholle district, like similar deposits elsewhere in New Mexico, range in size from 1 to 20 m thick and are as much as several thousand meters long. Locally, sedimentary features such as bedding, crossbedding, paleochannels, and intraformational slumping also appear to control mineralization.

Copper oxides, chalcocite and chalcocite are the predominant copper minerals, whereas tyuyamunite, metatyuyamunite, carnotite, and uraninite are the predominant uranium minerals (Collins and Nye, 1957; NMBGMR unpubl. files). Most uranium is associated with copper, but the highest uranium concentrations do not always correspond to the highest copper concentrations. Silver averages approximately 0.5 oz/short ton (17 ppm) and typically increases with increasing copper concentrations. Gold is rare in these deposits. Vanadium minerals (probably as copper vanadate minerals) are found with the uranium minerals. LaPoint (1976) includes analyses of 60 samples from Scholle that contained up to 27% Cu, 100 ppm Ag, 200 ppm Pb, 123 ppm Zn, and 500 ppm V. Analyses by the NMBGMR are in Table 2.

The Abo mine consists of an adit (4.2 m long) and open pit and had the greatest production. Chalcocite is the main copper mineral and carnotite and tyuyamunite were identified (Collins and Nye, 1957), as well as djurleite (Lueth and Whitworth, 2009). Pyrite is rare. Several small, but scattered ore bodies were located in the subsurface by drilling in meandering channel sandstones. However, none of these mineralized bodies were of economic grade during the 1950s (Collins and Nye, 1957).

Uraninite with chalcocite were identified from the Copper Girl mine, also in the Abo Formation (Collins and Nye, 1957). Approximately 250 short tons of 0.15% U_3O_8 was identified by drilling at the Copper Girl mine in 1957 (NMBGMR unpubl. files).

Small sedimentary-copper deposits were found in the Meseta Blanca Sandstone Member at the Gabaldon mine (NMTO0025), which consists of a 6 m adit and pit. Disseminat-

ed chalcocite, malachite, and azurite are found in a well-sorted, white to gray quartz sandstone, bounded above and below by gray shales. Locally, the sandstone is cemented by copper minerals. Organic material is absent in these sandstones. Select samples were assayed to contain as much as 5.5% Cu, 0.001% U_3O_8 , and 0.98 oz/ton (33 ppm) Ag (Table 2).

DISCUSSION

The timing of the ore formation is not well known. However, the copper minerals in nearly all of the sedimentary-copper deposits in New Mexico, including the Scholle district, are disseminated and occupy original porosity, typically in paleochannel sandstones. Replacements of organic material and clay/calcite cement are common. The host rocks are reduced. Therefore, the ore minerals must have been deposited after deposition of the host rock, but before the host rocks lost their permeability.

This evidence suggests a potential model of formation of sedimentary-copper deposits by groundwater enriched in copper, uranium, and other metals. Copper and other metals were probably transported in low-temperature brine solutions through permeable sediments along bedding planes and faults shortly after burial. Replacement textures and diagenetic features of the organic material indicate mineralization occurred during or after diagenesis. The source of the metals and other constituents also is not well constrained, but some sandstone-copper deposits in New Mexico unconformably overlie Proterozoic rocks that contain copper-vein and disseminated deposits (i.e., Zuni Mountains), suggesting that the Proterozoic deposits may be a source of copper and other metals. In the Scholle district, evidence (discussed above) strongly supports the Pedernal uplift as a potential source (Fig. 1). Thus, oxidizing waters could have leached copper and other metals from at least three sources: (1) clay minerals and detrital mineral grains and rock fragments within the red-bed sequences, (2) Proterozoic rocks enriched in these metals, and (3) Proterozoic base-metal deposits (La Point, 1974, 1976, 1989; Brown, 1984, 1989). Sources for chloride and carbonate needed to form soluble cuprous-chloride or cuprous-carbonate and other metal

complexes (Rose, 1976, 1989) occur in Paleozoic evaporite and carbonate sequences. Transport of metal-bearing waters occurred laterally through the aquifers from Proterozoic highlands or, in some cases, by circulating ascending fluids (Brown, 1984, 1989). Geologic, mineralogic and isotopic studies of similar deposits elsewhere in the United States suggest that these waters are in approximate chemical equilibrium with quartz, feldspar, hematite, and mica at temperatures less than 75°C (Rose, 1976, 1997). Precipitation occurred at favorable oxidation-reduction interfaces in the presence of organic material or H_2S -rich waters.

Geologic membrane processes have been proposed as a possible concentration mechanism in these deposits, but the role of this process in

TABLE 2. Chemical analyses of selected samples from the Scholle district. All chemical analyses were by aqua regia acid digestion and analyzed by atomic absorption spectroscopy (AAS) by Lynn Brandvold and associates, New Mexico Bureau of Mines and Mineral Resources Chemical laboratory in 1981-1982.

Mine ID	Mine name	Cu %	U_3O_8 %	Ag oz/ton (ppm)	Pb %	Zn %
NMTO0027	Pioneer	4.18	0.002	0.56 (19)	0.02	0.05
NMTO0024	Copper Girl	0.83	0.005	0.05 (1.7)	0.02	0.05
NMTO0021	Abo	6.36	0.001	3.18 (108)	0.05	0.02
NMTO0021	Abo	11.11	0.002	3.00 (102)	0.02	0.01
NMSO0322	Mill site	14.37	0.017	0.54 (18)	0.03	
NMTO0025	Gabalon	1.2	0.001	0.54 (18)	0.005	0.07
NMTO0025	Gabalon	3.1	<0.001	0.98 (33)	0.006	0.002
NMTO0025	Gabalon	3.5	0.001	0.98 (33)	0.004	0.001

deposition is still a matter of debate (Lueth and Whitworth, 2001, 2009). However, geologic membranes offer the best explanation for the localization of the deposits. These deposits tend to be in sandstone and siltstone where the shale beds are thinner. Subsequent geologic processes, such as groundwater movement and dissolution, igneous intrusions (such as at Sacramento), and/or structural events could have modified, altered or even destroyed some deposits (La Point, 1976).

OUTLOOK FOR MINERAL RESOURCE POTENTIAL IN THE FUTURE

Most sedimentary-copper deposits in the Scholle district, like elsewhere in New Mexico, are low grade, low tonnage, and far from existing copper mills to allow current development for copper. They are generally low in silica and are not suitable as silica flux material. Drilling of several deposits in the district during the 1950s and 1960s identified several small deposits (Chapman and Wood, 1954; Collins and Nye, 1957; NMBGMR unpubl. files), but none were mined due to poor economic conditions. However, past increases in copper and silver prices has sporadically renewed interest in some of the larger deposits, such as in the Scholle district. Detailed petrography and geochemical studies, along with an understanding of the alteration of the host sandstones could further refine the model described here and provide insights into district zoning and identification of additional deposits.

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