The Artillery Manganese District in West-Central Arizona

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Pure manganese is a grayish-white metal that resembles iron, but is harder and very brittle. These two elements lie side-by-side in the periodic table of the chemical elements and have similar chemical behavior. Manganese is essential to modern industrial society. It is a strategic and critical mineral primarily required for the production of steel, but also used in other commodities, such as some types of batteries.

Manganese deposits are abundant in west-central Arizona and southeastern California, where they are scattered over an area of approximately 40,000 square kilometers, herein referred to as the western Arizona manganese province. Most of the deposits are vein deposits, which formed when mineralizing aqueous fluids filled fractures within host rocks and the minerals precipitated because of chemical or physical changes within the fluid. The greatest amount of manganese, however, is in the stratiform manganese deposits in the Artillery Mountains. Stratiform deposits are deposits that are parallel to the enclosing sedimentary beds. The origin of the stratiform manganese deposits in the Artillery Mountains is not well understood, but may be related to low-temperature, alkaline, saline water that flowed beneath playas or lakes, which were present in the area several million years ago. This same water may have caused potassium metasomatism, a chemical alteration during which the amount of potassium in the rock was greatly increased.

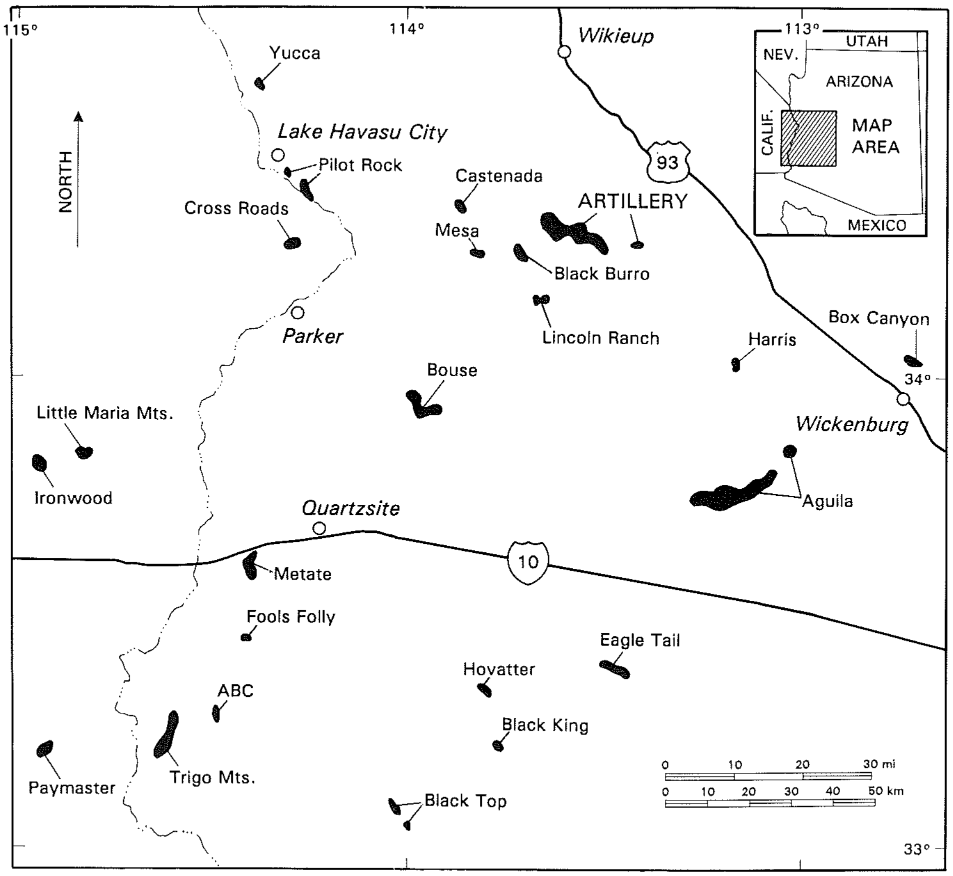

Figure 1. Mineral districts in the western Arizona manganese province that have recorded manganese production (see Table 1). Data from Davis (1957) and Keith and others (1983).

The manganese deposits of the Artillery manganese district are the largest and perhaps only significant group of manganese deposits in the United States. This technical article describes the uses and economics of manganese, as well as the geology and origin of manganese deposits within this district.

USES AND ECONOMICS OF MANGANESE

Manganese is the fourth most widely used metal in the United States, following iron, aluminum, and copper. It is an essential ingredient in steel: When added to iron, manganese acts as a deoxidizer that impedes the formation of defects ("pinholes"); combines with residual sulfur and prevents the formation of iron sulfide, an impurity that detracts from the desired metallurgical properties of steel; and improves mechanical properties, such as hardness, strength, wear resistance, and rolling and forging qualities. Manganese is also used for dry-cell batteries, ceramics, bricks, agricultural fertilizers and fungicides, water and waste treatment, fuel additives, welding, and many other processes and products (Weiss, 1977).

Virtually all manganese used in the United States is imported (90 percent) or obtained from recycling (10 percent). More than 800,000 tons of manganese were imported in 1988 (the last year for which statistics are available), primarily as manganese ore, concentrated ore, and ferromanganese. Ferromanganese is a manganese-iron alloy that contains 78 percent manganese. In 1988, approximately 416,000 tons of manganese were imported in the form of ferromanganese at a cost of $340 to $550 per ton of manganese. Most of this was imported from France and South Africa. In addition, 250,000 tons of manganese in the form of ore or concentrate, which contained an average of 48 percent manganese, were imported from Gabon, Australia, Mexico, and Brazil at a cost of about $120 per ton of manganese (Jones, 1990).

Although manganese deposits in western Arizona are not of sufficient grade or tonnage to mine them economically today, minor production from several mines in this area occurred intermittently during much of this century. Most of the production occurred between 1953 and 1955, when the U.S. government purchased manganese at depots in Arizona and New Mexico (Farnham and Stewart, 1958). Much of the manganese mined during this brief period still sits in a large black pile at a U.S. Bureau of Mines storage facility next to the railroad tracks just east of the town of Wenden in west-central Arizona. It is part of the U.S. strategic- and critical-mineral stockpile that is intended to provide domestic manganese if foreign sources are suddenly cut off.

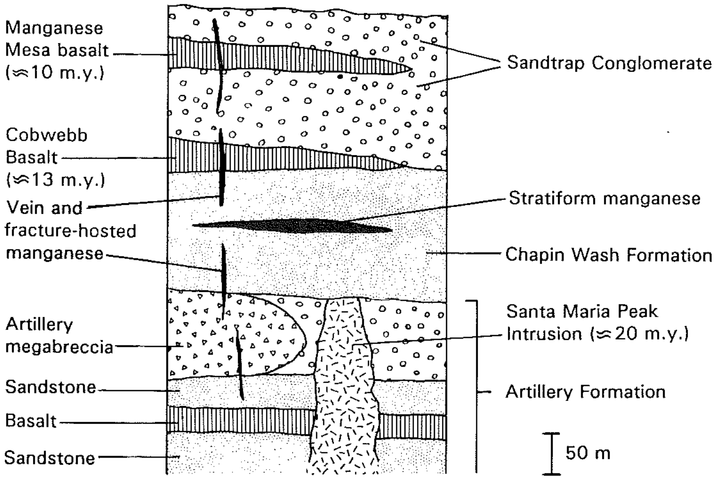

Figure 2. Schematic stratigraphic column of the upper Artillery Formation, overlying pre-Quaternary strata, and manganese deposits. Data from Lasky and Webber (1949), Spencer and others (1989a), and J.E. Spencer (unpublished data).

THE ARTILLERY MANGANESE DISTRICT

Numerous small to moderately sized, low- to medium-grade manganese deposits, many of which have recorded production (Keith and others, 1983), are present in western Arizona and southeasternmost California (Figure 1) and make up the western Arizona manganese province. Parts of the Artillery and adjacent Lincoln Ranch and Black Burro manganese districts contain stratiform manganese deposits. In contrast, virtually all other deposits in the province are vein and fracture-filling deposits that are typically associated with calcite and barite. Both types of deposits are known or suspected to be of Miocene age and probably formed during or shortly after an episode of volcanism, normal faulting, and basin formation that greatly modified the geology and landscape of western and southern Arizona (Spencer and Reynolds, 1989).

The Artillery manganese district (Figure 1) contains both stratiform and vein manganese deposits that are hosted in Tertiary strata (Figures 2 and 3). More than 95 million pounds of manganese have been produced from the district (Table 1; Keith and others, 1983).

Geologic Setting

The manganese deposits of the Artillery manganese district are within a thick sequence of sedimentary and volcanic rocks (Figure 2) that are estimated to range in age from about 8 to 25 million years (m.y.). The strata are tilted to the southwest, and the dip of the strata decreases stratigraphically upward. Strata at the base of the sequence dip approximately 30° to 40°, whereas dips at the top of the sequence are approximately 10° to 20° (Figure 3; Spencer and others, 1989a). The upward-decreasing dip of the sequence indicates that the strata were deposited during tilting.

The Artillery manganese district lies above a gently northeast-dipping, large-displacement normal fault known as the Buckskin-Rawhide detachment fault. This detachment fault is exposed along the southwestern side of the district (Figure 3). Granitic and gneissic rocks below the detachment fault were displaced out from beneath the Artillery Mountains and ranges to the east. Tilting of strata in the Artillery Mountains was related to movement on this underlying fault. Normal faulting, basin formation, sedimentation, volcanism, and formation of stratiform manganese deposits all occurred within an approximately 10-m.y. period.

The strata that make up the lower and middle part of the sequence were designated the Artillery Formation (Figure 2; Lasky and Webber, 1949). The Artillery megabreccia, an enormous, catastrophic debris-avalanche deposit that contains intact blocks of rock hundreds of meters across, forms the top unit of the Artillery Formation. The formation is overlain by the Chapin Wash Formation, a characteristically brick-red sandstone that is black where it contains stratiform manganese. The Artillery Formation is cut by an igneous intrusion at Santa Maria Peak that is, in turn, depositionally overlain by the Chapin Wash Formation. Biotite from the intrusion has been dated by the K-Ar method at 20.3 m.y. (R. Miller, oral commun., 1988). The Artillery Formation, therefore, is older than approximately 20 m.y., and the Chapin Wash Formation is younger. The Cobwebb Basalt, dated at 13.3 m.y. by the K-Ar method (Eberly and Stanley, 1978), overlies the Chapin Wash Formation, and is, in turn, overlain by the Sandtrap Conglomerate. The Manganese Mesa basalt is interbedded with the Sandtrap Conglomerate and has been dated by the K-Ar method at 9.5 m.y. (Shafiqullah and others, 1980).

Stratiform Manganese Deposits

The Chapin Wash Formation contains large, low-grade, stratiform manganese deposits that are exposed in two northwest-trending belts (Figure 3). The southwestern belt contains numerous lenses, up to several tens of meters thick, of manganiferous sandstone that are within and separated by nonmanganiferous sandstone. Little mining has occurred within this zone. The northeastern belt contains a 5-kilometer-long zone of stratiform manganiferous sandstone and siltstone that ranges in thickness from a few meters to many tens of meters. Most of the manganese is, by far, in the northeastern belt.

Lasky and Webber (1949) estimated that the Chapin Wash Formation contains a total of at least 200 million tons of material averaging 3 to 4 percent manganese, which includes about 2 to 3 million tons of material containing more than 10 percent manganese. Most of this manganese consists of very fine-grained oxides within pore spaces in sandstone and siltstone. Approximately 15 million tons of material described as "hard ore" averages 6.5 percent manganese. The hard ore is recrystallized, possibly because of interaction with ground water long after the deposit originally formed.

Table 1. Recorded manganese (Mn) production from mineral districts in the western Arizona manganese province. Data from Davis (1957) and Keith and others (1983).

MINERAL DISTRICT	COUNTY	MANGANESE PRODUCTION (LBS)
Artillery	Mohave	95,108,000
Aguila	Maricopa	42,457,000
Lincoln Ranch	La Paz	24,000,000
Paymaster	Imperial (Calif.)	24,000,000±8,000,000
Ironwood	Riverside (Calif.)	12,800,000±7,200,000
Little Maria Mts.	Riverside (Calif.)	10,000,000±6,000,000
Bouse	La Paz	9,659,000
Cross Roads	San Bernardino (Calif.)	2,800,000±1,200,000
Trigo Mts.	La Paz	2,096,500
Box Canyon	Yavapai	1,002,000
New Water*	La Paz	512,900
Black Burro	Mohave	331,000
ABC	La Paz	300,000
Planet*	La Paz	237,500
Black Top	Yuma	224,000
Yucca	Mohave	175,400
Kofa*	Yuma	148,000
Fools Folly	La Paz	105,700
Harris	Yavapai	100,500
Hovater	Yuma	93,000
Mesa	Mohave	60,000±20,000
Black King	Yuma	29,000
Eagle Tail	La Paz	19,000
Bonegas	Mohave	15,000
COMBINED TOTAL		226,273,500±22,420,000

*Most Mn production was as a byproduct of other metal production.

Vein Manganese Deposits

Many vein deposits of manganese oxides, calcite, and barite are within or near the northeastern belt of stratiform deposits (Figure 3). Vein deposits in the northwestern part of this belt, at the Shannon mine and along faults north of this mine, typically consist of fine-grained to microcrystalline manganese oxides and coarse white and black calcite. Manganese oxides form colloform (globular) encrustations up to 1 centimeter thick along fractures at the Shannon mine. These deposits are within the Sandtrap Conglomerate and interbedded 9.5-m.y.-old Manganese Mesa basalt (Spencer and others, 1989a).

The Priceless mine, which is near the southeastern part of the northeastern belt of stratiform manganese deposits, contains pervasive, fracture-filling, colloform manganese-oxide encrustations up to 1 centimeter thick that are composed of ramsdellite and cryptomelane. A several-meter-thick barite vein projects toward the mine from the north, but no barite is present at the mine. Near Black Diamond and Neeye mines, manganese oxides are within numerous subvertical veins of black, gray, and white calcite. Analysis of fluid inclusions within calcite, barite, and chalcedonic quartz associated with all of these vein deposits indicates that mineralizing fluids were of fairly low salinity (0 to 3 weight percent NaCl equivalent; Figure 4; Spencer and others, 1989a).

Origin of Deposits

The origin of the stratiform deposits is unclear. Earlier studies (Lasky and Webber, 1949; Mouat, 1962) indicated that manganese mineralization occurred at or near the Earth's surface and that surface water eroded sandy and silty manganiferous sediments and redeposited them within less manganiferous or nonmanganiferous sediments. This indicates that manganese either was detrital (Lasky and Webber, 1949; Mouat, 1962) or was deposited by chemical processes so near the surface that manganiferous sediments were locally reworked by sedimentary processes.

The brick-red sandstone that hosts the manganese deposits in most of the Artillery Mountains is strongly altered by potassium (K) metasomatism (R. Koski, oral commun., 1991). K metasomatism is thought to occur under low-temperature conditions in the presence of saline alkaline water beneath or near lakes or playas and occurred over large areas in west-central Arizona during the Miocene (e.g., Roddy and others, 1988; Spencer and others, 1989b). In some areas, K metasomatism has completely converted rocks to an assemblage of potassium feldspar, quartz, and hematite. Because K metasomatism can chemically modify large volumes of rock and apparently removes manganese, it seems feasible that chemical and hydrological conditions associated with this type of alteration could liberate, transport, and reconcentrate manganese (Roddy and others, 1988).

The vein deposits are several million years younger than the stratiform deposits; thus, the two types are not obviously related. The spatial association of the two deposits, however, suggests that manganese in the vein deposits was derived from the stratiform deposits. This movement of manganese could be due to hydrothermal circulation associated with basaltic magmatism or to ground-water movement unrelated to magmatism. Four fluid inclusions in chalcedonic quartz from the Priceless mine formed at a minimum temperature of approximately 165°C, which is consistent with either mineralizing process. Mineralization, however, was not related to movement of basin brines (10 to 25 weight percent NaCl equivalent), such as those that caused detachment-fault-related mineralization (e.g., Roddy and others, 1988).

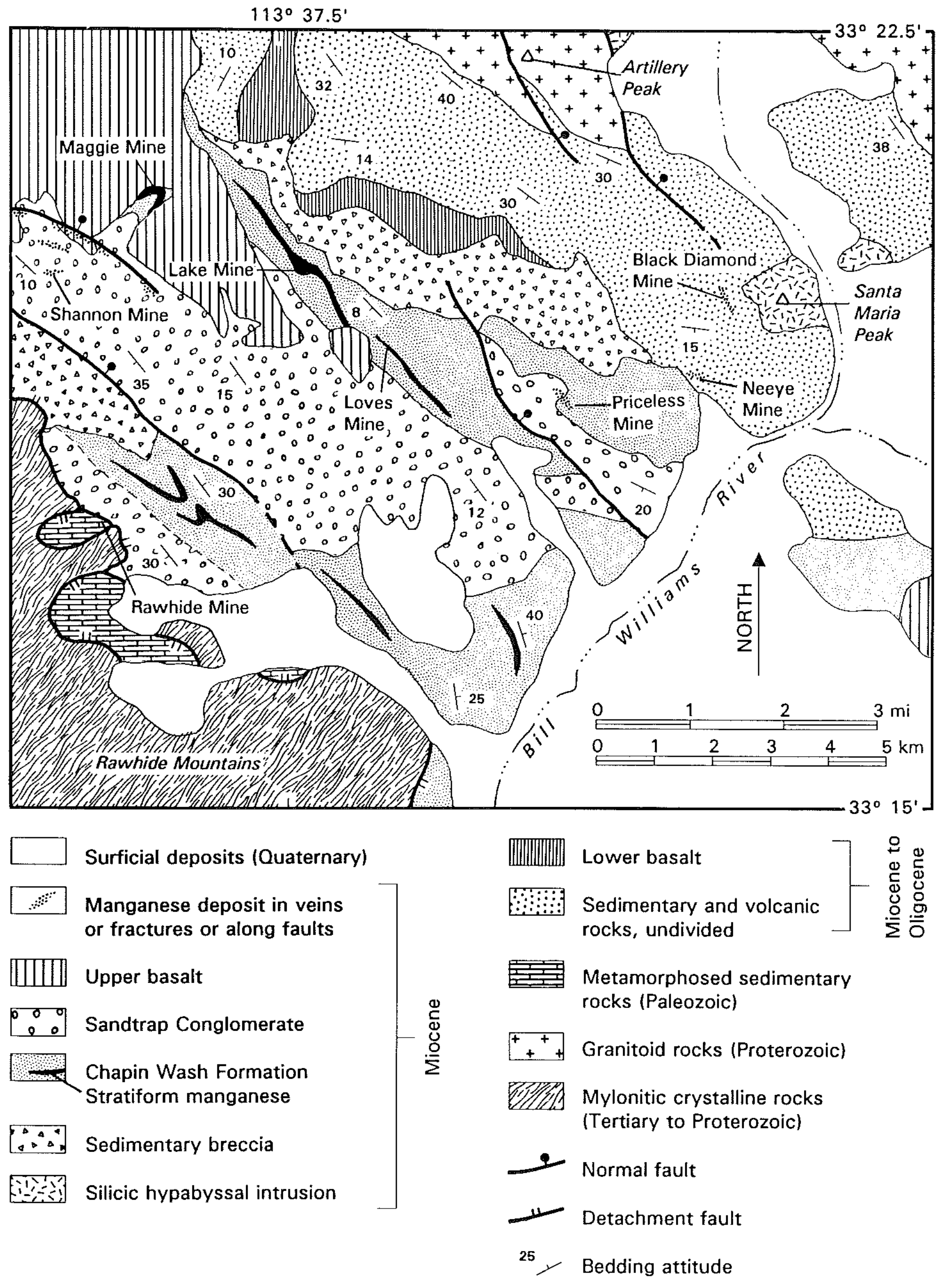

Figure 3. Simplified geologic map of the southern Artillery Mountains and adjacent areas. Data from Lasky and Webber (1949), Shackelford (1989), Spencer and others (1989a), B. Bryant (unpublished data), and J.E. Spencer (unpublished data).

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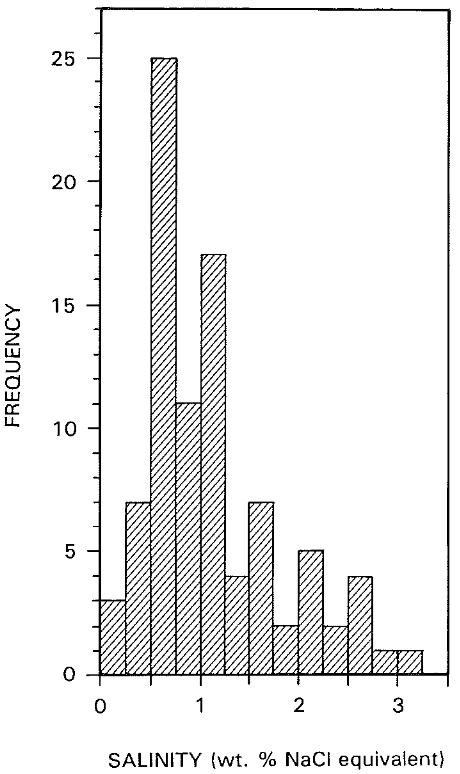

Figure 4. Histogram of fluid-inclusion salinities from vein deposits in the Artillery manganese district. Samples are from the Shannon mine area (33 inclusions in calcite), Priceless mine area (43 inclusions in barite and 4 in chalcedonic quartz), and Black Diamond mine (9 inclusions in calcite). Analyses by J.T. Duncan (unpublished data) and Spencer and others (1989a).

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Thesis Discusses Oil and Gas Potential

A new M.S. thesis by David A. Cook contains detailed information on the depositional environments and oil and gas potential of a hydrocarbon source rock in Arizona. The 800-foot-thick Walcott Member of the Kwagunt Formation (Chuar Group) was deposited in a northwest-trending rift basin on a carbonate ramp that was probably connected to the sea. Eustatic or tectonic changes in base level created alternating deposits of carbonates and organic-rich black shale. This 158-page thesis includes section descriptions from Nankoweap Butte and Sixtymile Canyon in the Grand Canyon, Rock-Eval TOC data, Van Krevlen diagrams, burial-temperature indicators, outcrop maps, and clay-mineralogy data used to predict oil potential. To purchase a copy of *Sedimentology and Shale Petrology of the Upper Proterozoic Walcott Member, Kwagunt Formation, Chuar Group, Grand Canyon, Arizona,* with color plates and vellum cover, contact David A. Cook, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011; tel: (602) 774-3577.

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