Major silver deposits of Utah: Geochemical and geological reasons for world-class high- and low-grade systems

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Abstract

Utah has produced about 31.7 kt (1 billion oz) of silver, more than any state in the United States except Idaho. Several high-grade ore systems in Utah, where the mines are now closed, occur within large polymetallic limestone-hosted districts related to plutonic complexes. These mines fed several major lead smelters for nearly a century. Interaction of magmatic chloride-rich fluids with carbonate rocks localized significant bonanzas within these districts. A low sulfidation state was produced in the fluids by their passage through limestones. The Bingham openpit mine has also yielded more byproduct silver than other porphyry copper-molybdenum-gold systems. Away from exposed intrusive rocks, some large silver-only systems occur in Mesozoic sandstone and in caldera-related veins in volcaniclastic rocks.

Thick permeable latest-Proterozoic basement metaquartzite sequences present beneath western Utah may have been important, as perhaps they were in the Coeur d'Alene district of Idaho, in providing chloride and silver-rich ore fluids.

However, it is clear that specific Tertiary magmatic events played an essential role in the evolution of the Utah silver-rich metallogenic province. The largest silver districts in the state are genetically related to Tertiary porphyritic plutonic rocks.

Introduction

Mines in Utah have recovered more than 3.5 kt (100 million oz) of silver during the 25-year period from 1973 to 1998. Despite closure of the polymetallic carbonate-hosted mines that once routinely yielded 1.7 to 2.2 kt/a (1,900 to 2,400 stpy), the byproduct production alone from this silver-rich region now approximates 155 t/a (5 million oz/year).

Silver has thus always made a significant contribution to the Utah economy and tax revenues. However, the best production came in the early decades of the 20th century, with a peak of almost 2.3 kt (75 million oz) in 1915 (Stowe, 1975).

While epithermal gold-rich systems in volcanic rocks and other small veins in various environments, porphyry copper systems and carbonate-hosted skarn deposits have yielded silver production, only three ore types have made mines of major economic significance. These are here classified as:

- limestone replacement ores associated with mid-Tertiary intrusions and related extrusive volcanism,
- ores in epithermal veins in Late Tertiary volcanic rocks and silver in Mesozoic sandstone.

Each had a distinctive environment of deposition.

Limestone replacement ores associated with mid-Tertiary intrusions

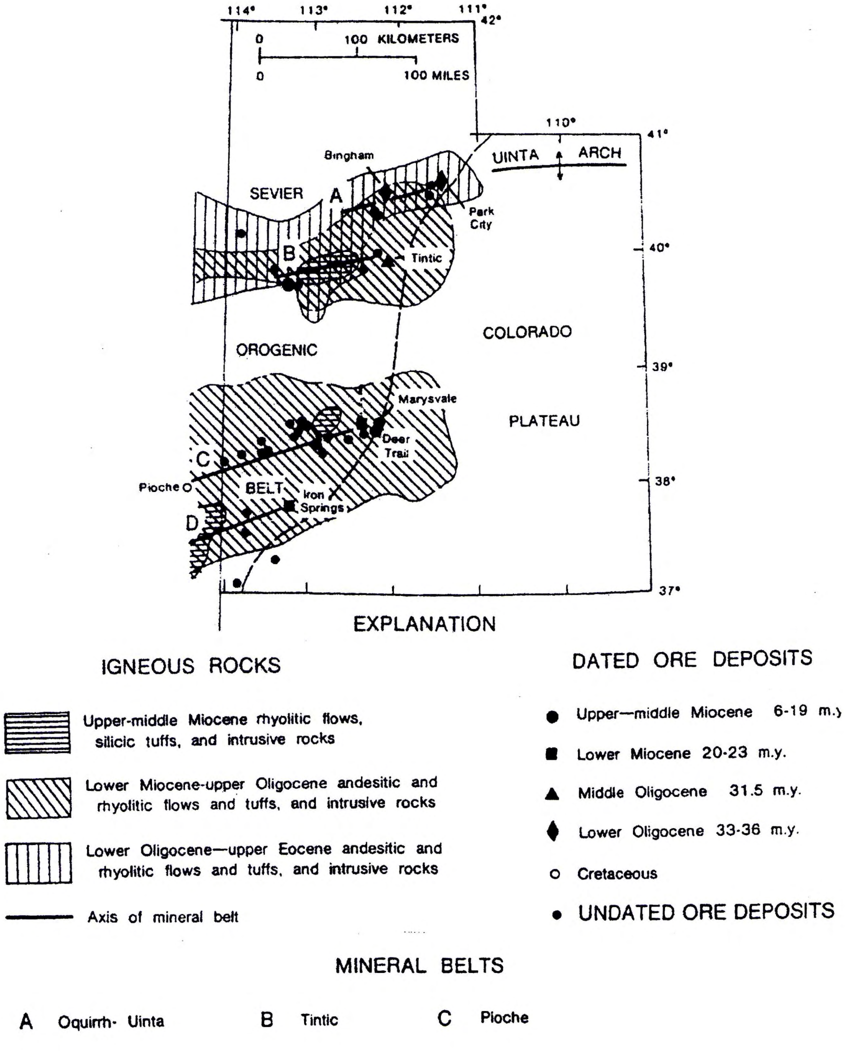
The largest sources of silver production in Utah lie along three east-northeast trending mineral belts extending from the edge of the Colorado Plateau southwestward across the Nevada border (Fig. 1). As documented by Shawe et al. (1978), these are best known as the Uintah-Oquirrh belt (Park City-Bingham-Stockton-Gold Hill), the Tintic-Deep Creek belt and the Marysvale-Pioche belt (James and Knight, 1979), after major polymetallic mining districts that largely define them. Some large to giant-sized deposits within two of these belts are discussed here, examples of variants of the most important sources of Utah silver production.

Uintah-Oquirrh Belt

The most outstanding source of silver in Utah is the state's largest and most famous district, Bingham. It is centered on a giant, high-grade porphyry copper-molybdenum-gold deposit, which also yields significant silver credits. Production of porphyry ore commenced in 1904,

FIGURE 1

Mineral belts and igneous rocks of western Utah (modified from Shawe et al., 1978). Districts associated with igneous intrusions and discussed in the text lie along (A) the Uintah-Oquirrh belt and (B) the Tintic-Deep Creek belt. Belt C, extending from Marysvale to Pioche, Nevada, contains a number of intrusive bodies with associated polymetallic deposits. Belt or linear D has fewer associated intrusions and polymetallic ores. The Escalante silver mine in Washington County lies near this belt, about 50 km (30 miles) southwest of the Iron Springs metasomatic iron ore deposits. At Escalante, no plutonic rocks have been identified.



and openpit mining scaled up rapidly to become one of the world's largest copper sources.

During the period 1908 through 1938, the bulk of the ore came from porphyry ores that had been upgraded by supergene enrichment, in contrast to mineralized wall rock. During those years, the mean recovered silver grade was 2 g/t (0.058 oz/st) or about 2 ppm (James, 1978). Only about 466 t (15 million oz) of silver was recorded to have been recovered during this 30-year period (Arrington and Hansen, 1963). At present, with production coming from porphyry and adjacent altered sedimentary rocks and virtually no supergene enrichment, the mean silver grade in ore blocks of monzonite, quartz monzonite porphyry and latite porphyry is 5.93 ppm (0.173 oz/st) (Ballantyne et al., 1997). This data suggests either an increase in silver grade with depth in the porphyry or improvements in flotation metallurgy. Also within the Bingham district are the nearby Barneys Canyon and Melco sediment-hosted gold deposits. They exhibit similar mineralogy to the Carlin-type deposits of eastern Nevada. These two deposits are notably very low in silver, less than 0.5 ppm (Gunter and Austin, 1997).

Underground vein and manto ore bodies in sedimentary rocks and barren intrusions around the Bingham porphyry center were worked for about 100 years for base metals. Silver was a significant coproduct, as noted by Rubright and Hart (1968). From the 39.8 Mt (43.9 million st) (including copper-rich, and lead-zinc dominant sulfide ores) produced through 1964, 4.23 kt (136 million oz) of silver was recovered at smelters. Thus, the silver grade averaged more than 106 g/t (3.1 oz/st). These figures may not include minor production from cyanidation of gold-rich ores, which was practiced in the 1900s. Silver grade was, of course, highly variable with ore type and location. Average grades like the above figures fail to call attention to limited, very high-grade silver veins at the fringes of the system. Averages also reflect the selective mining practiced underground.

Near Park City, 65 km (40 miles) east of Bingham on the east side of the Wasatch Mountains, the ores have tended to yield unusually high silver grades. Barnes and Simos (1968) show that 13.2 Mt (14.6 million st) of ore, mined between 1875 and 1964, yielded 7.38 kt (237.5 million oz) of recovered silver. The mean recovered grade was thus 558 g/t (16.3 oz/st). Most of these polymetallic ores, selectively mined underground, lacked significant copper, and the 13.2 Mt (14.6 million st) produced yielded only 30.2 t (972,109 oz) of gold. Like several other Utah districts, Park City was a silver and lead camp dominated by veins and mantos in sedimentary rocks in the general vicinity of major fault zones (Bromfield, 1989; Barnes and Simos, 1968). Favorable structural and stratigraphic zones were commonly defined by specific thin limestone beds and low angle (thrust) faults (for example, James, 1982).

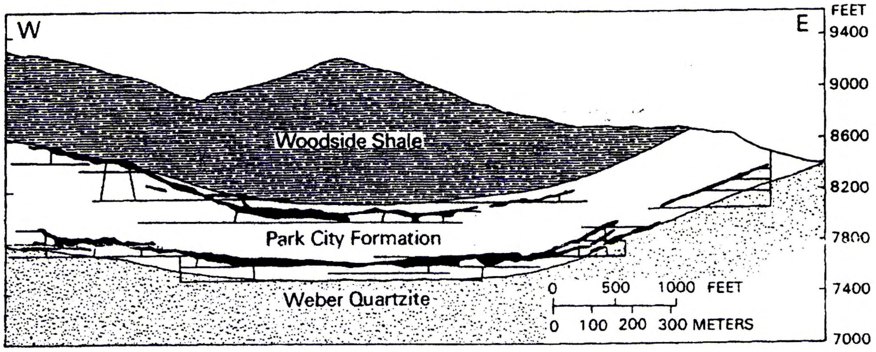
These ore bodies occur at the intersection of structures with favorable calcareous horizons in a thick package of argillaceous-arenaceous-limy Paleozoic rocks. The largest silver mines lay along an east-northeast trending fault zone (Bryant, 1990). They stretch for more than 6 km (3.7 miles) across the district and projectable another 10 km (6.2 miles) westward. The zone lies along the Uintah-Oquirrh belt, and intrusions are emplaced along the same trend. However, the best and highest-grade clusters of silver producers at Park City, such as the Silver King and Daly-Judge groups of mines, lie as much as 1.5 km (0.93 miles) from the nearest pluton exposed at the surface, although the deepest workings of the Ontario Mine encountered large intrusions. Figure 2 illustrates the localization of silver-rich mantos within the Permian Park City formation.

Despite the general near-conformity of some manto deposits with bedding and despite the relative lack of alteration in host rocks along the entire Uintah-Oquirrh belt, a spatially close association of silver-lead-zinc replacement bodies in limestone, and porphyritic, locally sulfide-bearing plutons is obvious. Emanation of ore fluids from a buried Tertiary porphyry system near Park City, as proposed by John (1997), is a logical explanation for ore genesis. High-temperature brines emanating from productive plutons carry most heavy metals as chloride complexes, such as $ZnCl_2^\circ$, $PbCl_2^\circ$ and $AgCl^\circ$. Where such fluids encounter calcareous rocks, calcium forms chloride complexes that are much more stable than those of the heavy metals. Calcium from the limestones is, therefore, capable of robbing the chloride from the heavy metals. This allows them to react with sulfide ions in solution, thus precipitating them as sulfides.

Unlike some deposits elsewhere in porous volcanic rocks, the limestone-hosted polymetallic ores tend to have very sharp geochemical boundaries. Dispersion into wall rocks mainly follows a few local fractures. Park City developed an early form of an employee pension for men too old or debilitated for hard labor. These "pick miners" were paid by the Silver King Coalition Mines to scavenge bits of high grade left in the walls of exhausted stopes (J. Ivers Jr., personal communication).

FIGURE 2

Longitudinal section of one of the most productive silver-rich areas of the Park City mining district (from Bromfield et al., 1989). Sulfide ore (black) occurs within two favorable beds of the calcareous Park City Formation, which lies between a basal quartzite and a shale. The upper "920 Horizon" and lower beds (Jenney horizon) are mineralized where they intersect a fault, the Middle vein. These two beds have yielded much of the silver production from the Park City district. They are barren away from the center of the district.



Tintic district

The East and Main Tintic mining districts comprise the eastern end of the Tintic-Deep Creek mineral belt (Fig. 3). Production from 17.5 Mt (19.3 million st) of ore yielded 8.5 kt (273.5 million oz) of silver through 1982 (Morris, 1990; James 1984). This equates to an average recovered grade of 486 g/t (14.17 oz/st) or more than 500 g/t (14.5 oz/st). The overall geometry of mineralized bodies and their relation to igneous rocks is generally similar to the Park City district. A low-grade porphyry copper system is known in the southwest corner of the district (Ramboz, 1979). Hildreth and Hannah (1996) and Hannah et al. (1992) describe a probable relationship of vein and replacement ores and ore fluids to concealed intrusive bodies. Regional extension has modified the geometry of some districts along the belt (Stoeser, 1993).

In parts of the Tintic district, irregular erosional remnants of altered andesitic volcanic rocks cover some deposits of carbonate-hosted silver ore. Morris and Lovering (1979) provide classic descriptions of individual silver-rich deposits. The alteration of these overlying volcanic rocks is typically much more pervasive than is found in the ore-hosting limestone. The sulfide assemblage and the metal content of ores in different host rocks vary significantly.

The sediment-hosted Tintic Standard ore bodies (Fig. 3; Kildale, 1957; Shepard et al., 1969), found by persistent exploration beneath altered volcanic rocks, were characterized by Lindgren (1933) as the richest silver mine in the country, perhaps in the world. Here, the famous Pothole orebody was localized at the intersection of structures with relatively unreactive sediments, as shown diagramatically by Morris and Lovering (1978).

The North Lily enargite-bearing ores (Fig. 4) represent a classic example of high-sulfidation orebodies. However, they contrast with the commonly described geometry of the top of a porphyry copper ore system, where magmatic fluids move (along steep fractures) upward and laterally outward from a deep pluton. Initially, close to the pluton, the fluids deposit ores of low sulfidation at high temperatures, with potassic alteration and chalcopyrite-bornite-magnetite-K-feldspar-biotite assemblages. This is followed by higher, but still relatively moderate, sulfidation with chalcopyrite-pyrite-muscovite (sericite) assemblages. As they cool, their chemistry reaches conditions of low pH and high sulfidation, as SO_2 reacts with water to form H_2S + H_2SO_4 and the HCl° ion-pair dissociates. Usually, such fluids are diluted by meteoric waters, and they react with the wall-rocks to deposit ores of moderate to low sulfidation. In some cases, however, magmatic solutions exit a porphyry center along restricted pathways and are not diluted significantly. Or they pass through an unreactive rock, such as quartzite. Such solutions are then capable of depositing ores such as those of the North Lily Mine.

Figure 4 (modified from Shepard et al., 1968) is drawn in the plane of a structure called the North Lily Fissure. The mine produced about 342.8 kt (377,900 st) of ore with highly variable, but rich, gold, copper and lead grades (Morris and Lovering, 1979). Pyritic gold and gold-copper ore occur within high-angle structures in the Tintic Quartzite, the thick basal rock unit of the district. This rock lacks calcite.

Locally, very high gold grades and enargite + pyrite are present (an indicator of moderately high sulfidation conditions, but less than that of the bornite + pyrite assemblage and much less than the covellite + pyrite assemblage (Barton and Skinner, 1979). Immediately above the quartzite, in limy members of the Cambrian Ophir shale, high-grade lead-silver ores occur. Enargite apparently was never found in this environment. Such a transition between classic high-sulfidation mineralization and carbonate-hosted polymetallic ores with change from basal unreactive rocks to overlying carbonate rocks is noted in other Utah districts and elsewhere.

The fluids responsible for the North Lily orebodies are believed to have emanated from a calc-alkaline intrusion nearby. At high temperatures under submagmatic conditions, above 400° C (750° F), sulfur is present primarily as SO_2. As the temperature drops, however, SO_2 reacts with water according to the reaction

$$4SO_2 + 4H_2O = H_2S + 3H_2SO_4 \qquad (1)$$

Thus, at lower temperatures, the dominant sulfur species are hydrogen sulfide and sulfuric acid. Such a solution is capable of depositing the enargite-pyrite-gold ores of the North Lily. There, the orebodies are hosted by the Tintic Quartzite, which could not react with the mineralizing fluids. In a limestone host, however, the fluids coming from an intrusion will react vigorously with calcite to reach a more alkaline pH and, therefore, a lower sulfidation state, which is coupled with pH. For this reason, sphalerite deposited in limestone is always iron-rich, and high-sulfidation assemblages are not deposited due to the more neutral fluids produced by reaction with the limestone.

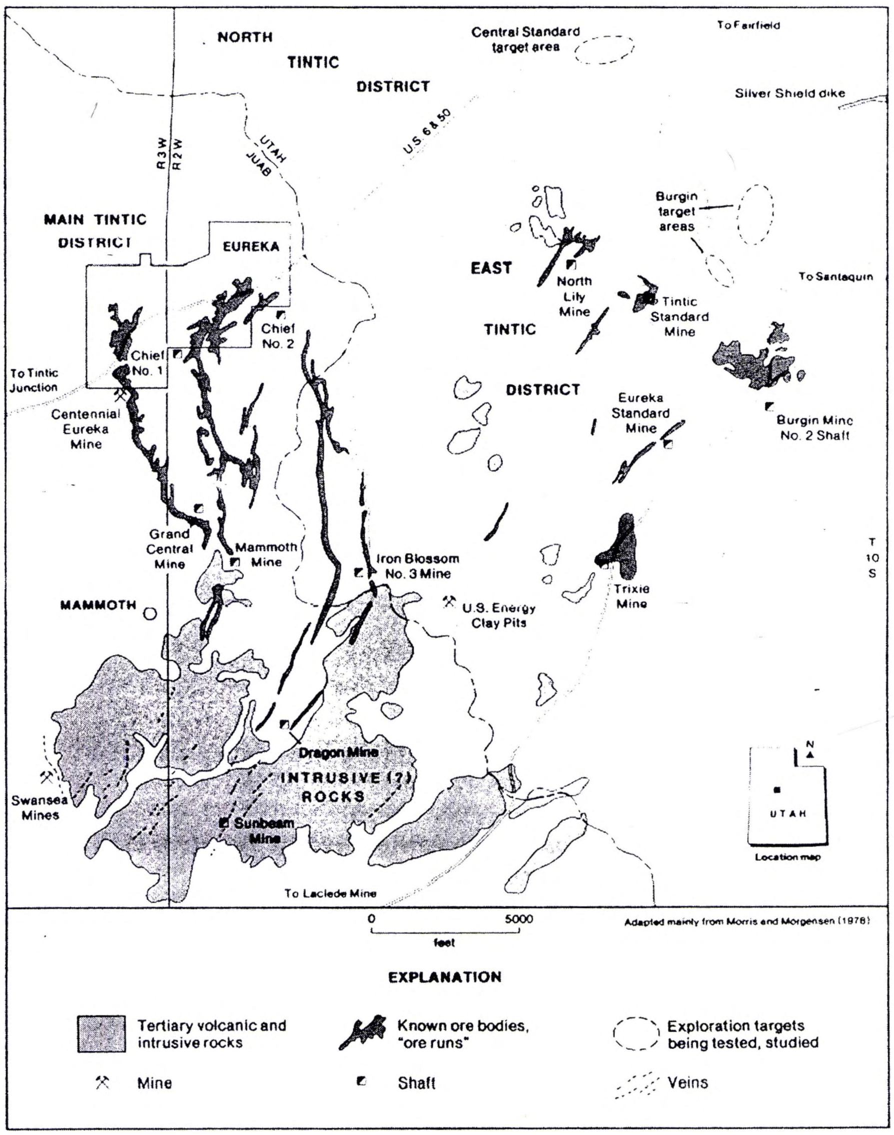
Ores precipitated in volcanic hosts are affected by wall-rock reactions to produce zoned alteration envelopes. Such reactions will raise the pH of acid solutions coming from intrusions. This may be responsible for precipitation of ores. However, evidence for other mechanisms, such as boiling and dilution by groundwater, are also present. So only one mechanism cannot usually be singled out as the cause of deposition.

Where gold-bearing solutions emanate from an intrusion and encounter limestone at high temperatures, gold (as a chloride complex) is precipitated immediately, apparently due to the reactivity of calcite and the higher stability of calcium chloride complexes than those of gold. This is seen clearly at Leadville, CO, where a high gold zone surrounds the area of the source intrusion (Thompson and Arehart, 1990), between the intrusion and the area of lead-zinc-silver orebodies in limestone. At lower temperatures, less than about 400° C (750° F), arsenic and gold are both carried by bisulfide complexes. Where the H_2S content is too low to maintain the bisulfide complexes, both Au and As will precipitate. Where there is excess H_2S, gold and arsenic can be carried much farther, even into the hot spring zone.

It should be noted that Carlin-

FIGURE 3

Map of the Tintic district (modified from James, 1984), showing distribution of orebodies and Tertiary intrusive rocks and mines discussed in the text.

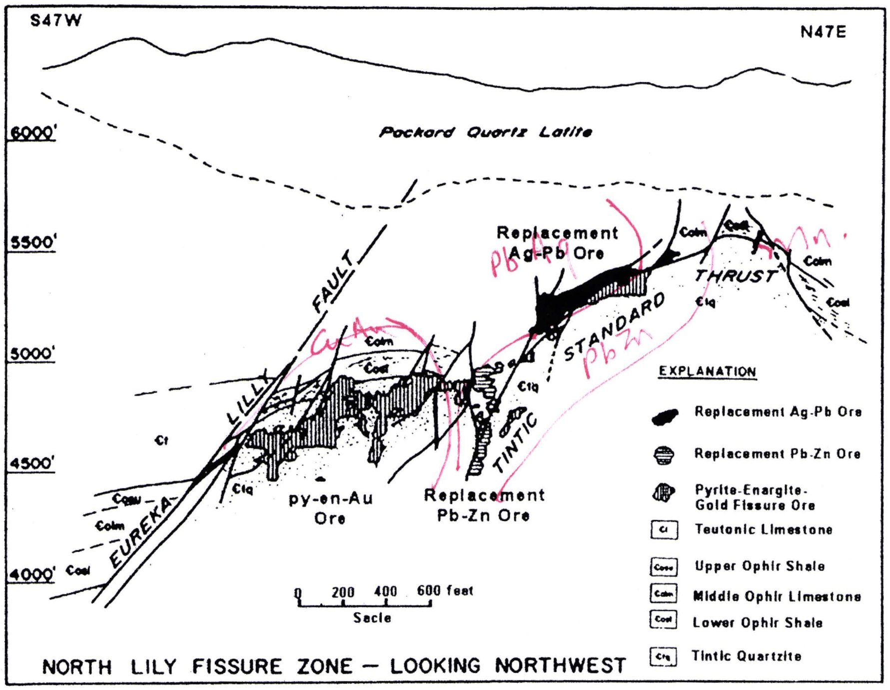


type ores commonly contain assemblages of realgar-orpiment-pyrite, which represent a fairly high degree of sulfidation. These fluids were probably not in equilibrium with the surrounding limestone, because Carlin-type ores are notably "decarbonated," (the calcite has been removed along the fracture zones), where strong silicification has taken place.

At Park City, the Park Premier stock has the attributes of a porphyry copper deposit, except that it is very small, and it is low grade (John, 1989). No other mineralizing intrusions are known beneath the volcanic rocks in that district. The productive intrusions lie to the west, and they generated the famous silver ore bodies.

FIGURE 4

Section through the North Lily Mine, along the North Lily Fissure Zone, Tintic District (modified from Shepard et al., 1969). A more detailed section appears in Morris and Lovering (1979). Note the occurrence of pyrite-enargite-gold ore only in areas with quartzite wall-rocks. Replacement Pb-Zn and Ag-Pb ores occur where wall rocks are calcareous.



Epithermal veins in young volcaniclastic rocks lacking associated plutons

The Escalante Mine, north of Enterprise, Washington County, in southwestern Utah, is the most recently developed silver deposit in Utah (Arentz, 1978). Ore textures suggest that it represents a relatively low-temperature, near-surface, ore-forming environment with no exposed intrusive igneous rocks. The Escalante Mine was developed on a vein system, with at least 1,070 m (3,500 ft) of strike length and extending to more than 240 m (800 ft) in depth. Veins consisted of banded quartz, calcite and fluorite containing argentite and acanthite-calcite (Fitch and Brady, 1984). Secondary silver chlorides and rare native silver were important near-surface ore minerals. The mineralized zone was 3 to 13.7 m (10 to 45 ft) wide. This allowed the efficient use of large trackless (diesel-powered, rubber-tired) underground equipment. The mine entered production in 1981. In May 1983, proven and stockpiled reserves were estimated at 1.48 Mt (1.63 million st), averaging 355 g/t (10.37 oz/st) contained silver (1.48 Mt, 355.5 ppm Ag). Until mine closure in 1989 and cessation of milling in 1990, the operation yielded 557 t silver and 177 kg gold from 2.1 Mt of ore (17.9 million oz of silver and 5,700 oz of gold from 2.3 million st of ore).

The ore system is hosted in rhyolitic, bedded and reworked tuff and ash deposits and overlying mud flows and breccias. The overall volcaniclastic sequence is perhaps 200 m (650 ft) in thickness. Where cut by the steeply dipping vein system, these permeable rocks developed a silicified, silver-bearing envelope, extending 15 to 30 m (50 to 100 ft) from the vein. At depth, galena and sphalerite appeared, with combined grades of 4% to 6% lead and zinc (Ranchers Exploration and Development, undated handout).

Sandstone-hosted silver

Mesozoic sandstone-hosted silver minerals are known in several areas of southwestern Utah (Proctor, 1953; Wyman, 1960; Cornwall et al., 1967). The old Silver Reef mining district is near the town of the same name in Washington County, north of St. George (Fig. 5). It produced more than 218 t (7 million oz) of silver from two thin sandstone sequences or "reefs." These reefs are separated stratigraphically by about 150 m (500 ft) of more argillaceous rocks in the Triassic Moenave Formation (Fig. 6). The grade and tonnage are difficult to establish because the ore was hand sorted in large flat stopes and some waste was later reworked or milled. Most silver was produced by leaching or amalgamation. Thus, shipment to distant smelters was seldom required.

Silver replaced carbonized trees and carbon trash, just as uranium was localized (typically in the underlying Triassic Chinle Formation) in many parts of the Colorado plateau. Locally, copper accompanied silver, as apparently did selenium and possibly mercury. Silver chlorides and, near the water table, native silver, were common ore minerals. A reduced assemblage, including silver sulfides, is poorly documented below the water table, and the mineralogy needs further study. Very low levels of gold (consistent traces in ore; 0.7 to 1.1 g/t or 0.02 to 0.03 oz/st gold; 0.07 to 1 ppm gold in silver flotation concentrates) are well documented by fire assays. Disseminated pyrite, some of it framboidal, is present locally in the sediments. Features characteristic of hydrothermal deposits, such as quartz and pyrite veining, are not observed, although Wyman (1960) emphasizes vertical controls for mineralization. Price et al. (1985) described a different variant of such a system in Texas.

Several models for ore formation have been presented. Probably the most recent is by James and Newman (1986). They noted a relationship between silver chloride and residual petroleum. A chloride formation brine, localized by an anticlinal trap, possibly precipitated silver when diluted by groundwater. The deposits are clearly different from other major Utah silver districts, as is the geologic setting. However, local sharp folding, nearby gypsum/salt domes and the proximity to laccolithic intrusions and continental-scale faulting define a variation on the typical environment characteristic of southern Utah Mesozoic rocks. Other silver-bearing districts unrelated to intrusions, including low-temperature breccia pipe deposits in Paleozoic limestone (Wenrich and others, 1985) and the Escalante Mine, are in the same region.

Characteristics of the Silver Reef deposits are similar to those of the Spar Lake, MT, area (Hayes and Einaudi, 1986). These contain native silver in association with copper sulfides and pyrite in weakly metamorphosed siltstone and sandstone of the Proterozoic Belt Supergroup.

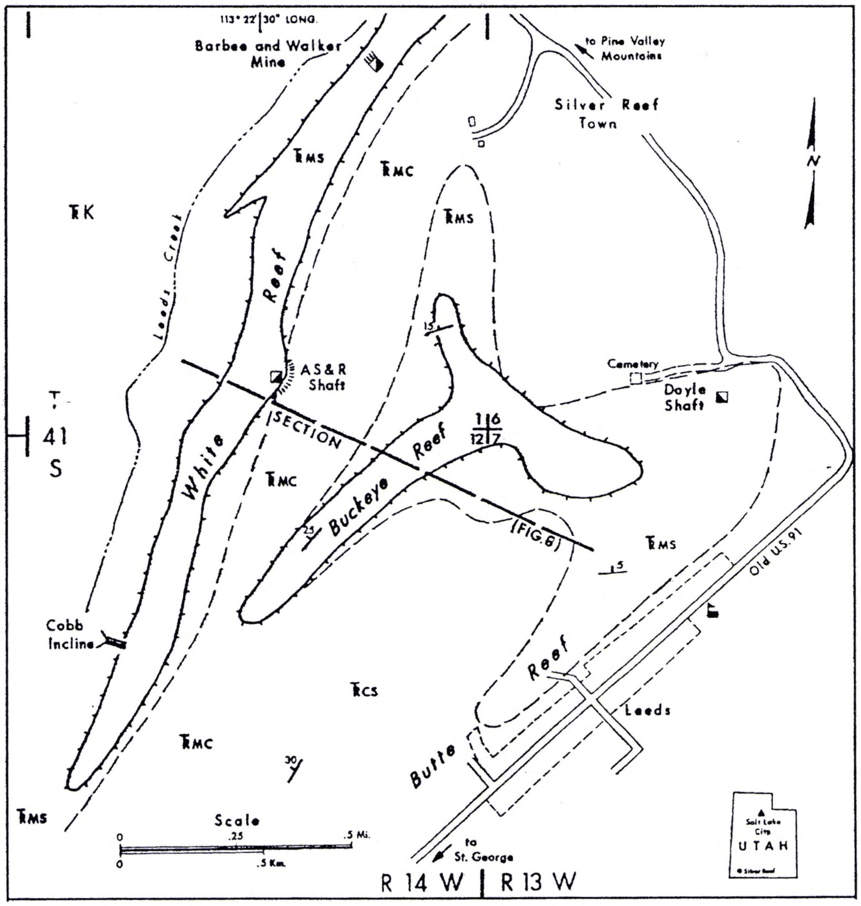
Utah deposits in a regional, metallogenic context

Silver is clearly abundant in a number of rock types in Utah, some of them unrelated to the Tertiary plutons. Arsenic is also abundant in most Utah base metal ores, and locally forms large arsenopyrite deposits poor in other metals. Spurr (1923) and Burnham (1959) noted long ago that Utah was part of an argentiferous metallogenic province inboard from the Pacific coast. Spurr described "the Great Silver Channel" extending northward out of Mexico through Utah.

While the closest spatial relationship of silver deposits to igneous rocks is evident near mid-Tertiary plutons, late Mesozoic plutons crop out in some mining districts, notably along the Uintah-Oquirrh belt (James and McKee, 1985) and its westerly extension through the Gold Hill district. Sanderson (1979), in a Ph.D. thesis study of the proterozoic Mt. Watson formation of the Uintah Mountains, concluded that the rocks were laid down in a river system flowing along a tectonic trough, bounded on the north by a fault with more than 7,300 m (24,000 ft) of downdrop on the south side. The trough lies along the boundary between the Archean rocks of the Wyoming Province on the north, and the Proterozoic rocks of the Churchill Province on the south. Unusual metamorphic rocks of the Little Willow series, immediately north of the mouth of Little Cottonwood Canyon east of Bingham (James, 1979) are limited to the north side of this suggested basement boundary. A pre-mid-Tertiary structural zone of considerable magnitude is thus suggested. Some workers, including Presnell (1997), concluded that this belt, the Uintah-Cortez axis, lies along a major Precambrian structure between basement blocks. This structure is an Archaean-Proterozoic suture. This affected Paleozoic sedimentation and was the fundamental control on plutonism and metallogeny in the Oquirrh and Wasatch mountains. Presnell (1997) states that deposits in the Oquirrh and Wasatch display subduction-related trace-element signatures

FIGURE 5

General geology of the Silver Reef Mining District, Washington County, Utah. Triassic continental sedimentary units as identified by Cornwall et al. (1967).



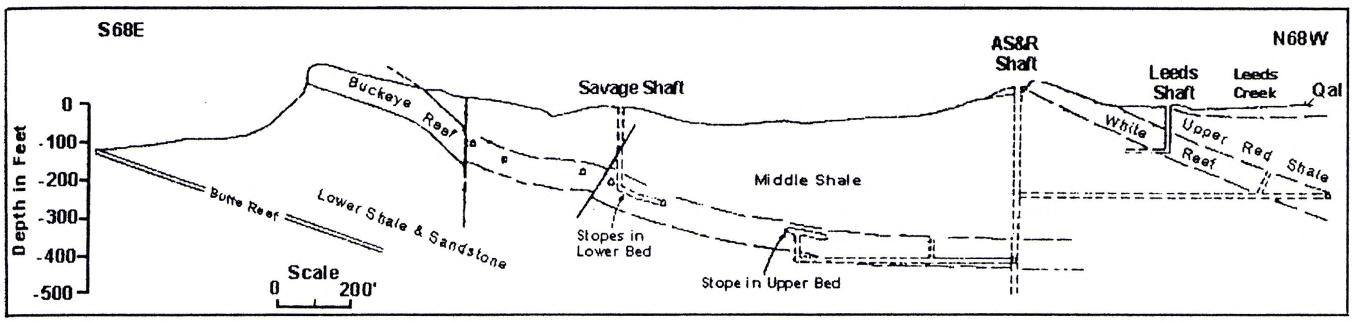
Conclusions

The precipitation of silver in the polymetallic ores of Utah accompanies deposition of lead, zinc, copper and often gold and arsenic. The reactivity of calcite with chloride-rich, sulfur-bearing solutions is a critical mechanism for the localization of high-grade sulfide ores.

While Nevada is called the Silver State (owing mainly to its early Comstock Lode and Eureka mines) and Colorado is famous for several silver-rich manto and vein districts, Utah has greatly outproduced these neighboring states. Montana, owing to the Butte porphyry/vein district plus Precambrian (Belt) sediment-hosted silver, has also been a major US silver producer. The prolific Coeur d'Alene vein district in Idaho relegated Utah to second place by the 1960s, and production continues. Idaho also has silver districts centered on mid-Tertiary plutons. But its production has not matched the major mineral belts of Utah.

FIGURE 6

Section through Silver Reef Mining District, passing through AS&R Shaft., as shown on Fig. 5 (modified from James and Newman, 1986).



The genesis of Coeur d'Alene silver-bearing sulfide vein ores is attributed to the leaching of metal-rich precursor zones during regional metamorphism of the Proterozoic Belt series rocks (Leach et al., 1988; Constantopoulos and Larson, 1991). These authors presented evidence that a local group of small intrusions, the Gem stocks, along the "silver belt" area of this large district have no genetic importance.

In Utah, mid-Tertiary intrusions are the most obvious generator of the hydrothermal systems that deposited most of the silver. However, a thick Proterozoic to Eocambrian quartzite sequence is also present, in many ways similar and to some extent coeval with the Belt basin.

Generalized geologic maps of northern Idaho and north-central Utah, thus, have important similarities, both showing easterly-trending ore systems cutting quartzitic Proterozoic basement. Possibly large quantities of chloride-rich fluids, expelled from the porous quartzites, were focused upward into fracture systems heated by plutons.

In Utah, porphyry copper systems and unmineralized hypabyssal plutons provided important magmatic fluid input. There is also an increased gold and copper content of ores, to date not adequately quantified, generally in close proximity to plutonic rocks of Utah. And there is a more pronounced localization of base metal-silver ores in favorable limestone beds.

Economics

An important economic factor in the production of silver from the Uintah and Tintic Deep Creek belts has always been the smelting of ores and concentrates. Nearly all of the ores from this region have been fed to either lead or copper smelters. Silver appears only during the further refining of the lead or copper metal thus produced. Most of Utah's silver became ingots only when lead bullion was desilverized in plants outside the state.

For more than half a century, Utah had three large lead smelting complexes, which enjoyed a "symbiotic" relationship with silver ore production. They served their own "captive" mines. And they provided geological staffs that assisted moderate-sized mining operations in finding more ore. The smelting companies also willingly bankrolled reasonable ventures. And they sometimes became major stockholders or fee owners in properties. So the successive closure of Utah's lead smelters (1950s through 1972) heavily impacted silver mining in the state.

Another economic factor was exhaustion of underground reserves in several of the largest mines, such as those in Park City, Tintic and Bingham, during frantic production efforts to support U.S. efforts during World War II. Falling prices and rising labor costs led to permanent closure of these mines during the next decade. The need for disposal of large quantities of mine water from permeable limestones may also impede future development.

Except for the Bingham openpit mine, whose silver grade is so low that copper and gold economics totally govern byproduct output, Utah silver operations are virtually dormant as this is written. Most of Utah's silver mines were designed and developed prior to World War II using labor-intensive technology and enjoying proximity to base-metal smelters. If silver prices rise significantly, the development of bulk-minable deposits that do not depend on such parameters would likely be necessary to bring about increased production. With its large tracts of desert land, Utah still has large areas within mineralized regions where new mine development at least should be feasible. ■

Acknowledgments

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