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GEOLOGY AND HYDROTHERMAL ALTERATION OF THE MERCUR GOLD DEPOSIT, UTAH

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Introduction

The term "Carlin-type" deposit has been applied to a number of low-grade, sedimentary rock-hosted gold deposits that have been discovered and brought into production in the western United States since the 1960s. Carlin-type deposits are characterized by replacement of carbonate and silty carbonate rocks by silica, pyrite, barite, various arsenic, mercury, antimony, and thallium minerals and by introduction of micron-size gold (Radtke and Dickson, 1974). These deposits are believed to have formed in the upper few kilometers of the earth's crust under conditions that are similar in some respects to present-day geothermal systems.

The Mercur mining district in west-central Utah contains a number of gold deposits of this type. The district is located approximately 90 km southwest of Salt Lake City in the southwest portion of the Oquirrh Mountains, a typical north-south-trending range of the Basin and Range physiographic province (Fig. 1). Two major orebodies, Mercur-Sacramento and Marion Hill, are present in small hills in the center of the steep, east-west-trending Mercur Canyon. Initial production of silver in the Mercur district was from an interval of silicified limestone known as the "Silver ledge" (Spurr, 1895), a term which was later changed to "Silver chert." Fine gold was discovered in 1883 in a stratigraphic interval 30 m above the Silver chert. Production terminated in 1917 after more than 1.2 million ounces of gold had been produced (Butler et al., 1920). The district was reopened in 1983 with the Getty Mining Company as the principal operator.

The first geologic description of the Mercur district was given by Spurr (1895). Butler et al. (1920) gave a concise, accurate review of the geology, stratigraphy, and mineral production at Mercur. Gilluly's (1932) work remains the most comprehensive published study of the southern Oquirrh Mountains. Lenzi (1973) published data on the background geochemistry at Mercur. Tafuri (1976) described the general geology and mineralization at Mercur.

This communication gives a detailed discussion of the hydrothermal alteration of the Mercur deposits. The discussion will provide a framework for continuing studies of the paragenesis and geochemistry at Mercur as well as allowing comparison with alteration assemblages of other Carlin-type deposits.

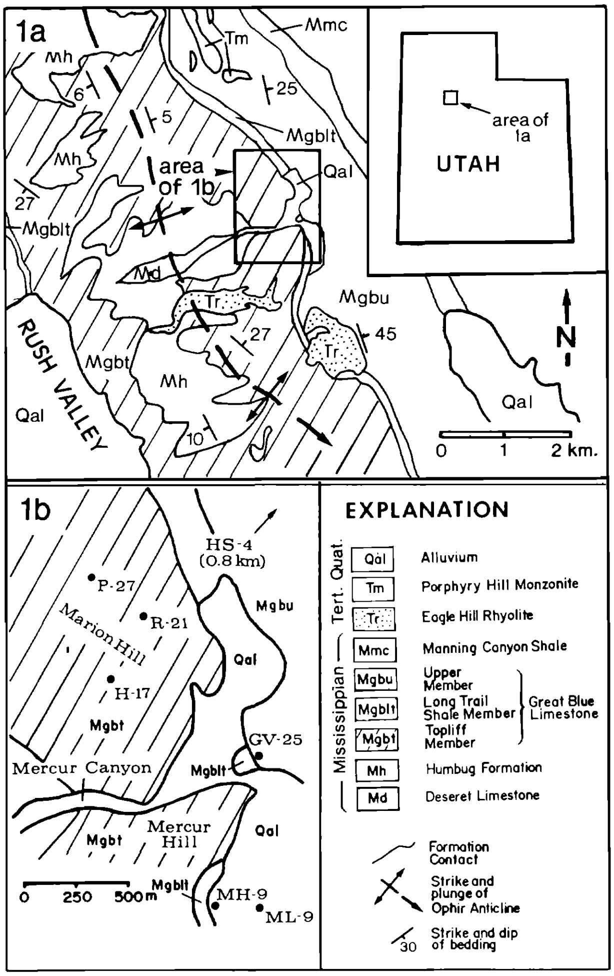

FIG. 1. (a). Generalized geology of the southwestern portion of the Oquirrh Mountains, Utah (after Guilly, 1932). (b). Generalized geology in the vicinity of Mercur (after Getty Mining Company maps). P-27, R-21, etc., are locations of diamond drill holes used in this study.

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TABLE 1. Description of Upper 60 to 80 m of the Topliff Limestone Member and Lower Long Trail Shale Member, Great Blue Limestone

Rock unit	Thickness	General description
Long Trail Shale	30–50 m	Contact with the Topliff Limestone Member is not distinctive; for the purposes of illustration in Figure 2, it is drawn at the base of a 2- to 3-m thick sequence of noncalcareous, black shale 40 m above the top of the Mercur beds. Long Trail Shale appears to consist of approximately equal amounts of carbonate and clastic rock
Upper beds	30–40 m	Limestones which grade from massive mudstones into massive wackestones and packstones interbedded with lesser amounts of siltstones and calcareous shales. Stylolitic dissolution and intraformational breccias are common. Zones of interbedded siltstones and mudstones labeled the Middle streak and Upper vein by Butler et al. (1920) are not distinguished as subunits of the Upper beds
Mercur beds	8 m	Sequence of porous, thin- to moderately well bedded packstones, wackestones, and siltstone. The Mercur beds are host for the highest amount of gold mineralization throughout the Mercur district. Alteration in the form of decalcification and minor silicification of the Mercur beds is pervasive, even in the relatively unaltered, deep diamond drill hole north of Mercur (Fig. 2). The Mercur beds interval appears to have a higher porosity and greater amount of siltstone and shale than the rest of the upper Topliff carbonate. Original Mercur beds appear to have been thinly bedded with abundant fenestrate bryozoa and diagenetic pyrite
Barren beds	20–25 m	Lower portion is largely mudstones, shales, and calcareous siltstones which grade upward into massive to moderately well-bedded mudstones. A distinctive, 2-m-thick interval named the Apex vein by Butler et al. (1920) is recognized 5 to 7 m above the top of the Magazine sandstone. The Apex consists of interbedded mudstones and siltstones with distinctive, very delicate cross laminations and flaser bedding which aided in correlations between drill holes (Fig. 2)
Magazine sandstone upper sandstone	4–5 m	Largely silt-sized sediment. Coloration varies from gray to brown. A distinctive marker horizon at the top of the upper Magazine is a zone of worm burrows
median limestone	5 m	Mudstone-packstone-shale sequence separating the two sandstone subunits
lower sandstone	4–5 m	Massive to porous, ochre to brown color, and composed of fine sand to coarse silt-sized quartz grains. Thin sections show 35 to 45 percent subrounded, well-sorted quartz grains in a matrix of calcite, illite, and minor pyrite and iron oxides
Unnamed	unknown	Massive limestones

Observations are largely from unaltered to weakly altered rocks in diamond drill hole HS-4 spudded 0.75 km northeast of Mercur (Fig. 2)

Geology

Rocks in the southwest portion of the Oquirrh Mountains are Upper Mississippian carbonate and clastic rocks and Tertiary igneous rocks. From oldest to youngest, the sedimentary formations are the Deseret Limestone (200 m thick), the Humbug Formation (190-200 m thick), the Great Blue Limestone (910–1,150 m thick), and the Manning Canyon Shale (230–350 m thick). The relatively thick Great Blue Limestone is separated into three members. The lowermost of these is the Topliff Limestone Member. The Topliff Member in the Oquirrh Mountains is composed of 150 to 200 m of limestones and minor shales which are correlated with exposures of the Topliff type section in the Tintic Mountains to the south (Gilluly, 1932). Although recent regional mapping has made this correlation questionable (T. Faddies, pers. commun., 1984), the Topliff designation is retained to avoid conflict with previous publications. The upper portion of the Topliff Member is host to most of the Mercur ores and will be discussed in greater detail below. The second member of the Great Blue Limestone is a 30- to 50-m thickness of shales and limestones that overlie the Topliff and was named the Long Trail Shale Member by Gilluly (1932). It is sparsely mineralized at Mercur. The upper, third member of the Great Blue consists of 600 to 900 m of massive limestones with minor chert and shale which are unmineralized.

Gilluly (1932) mapped two semicircular to elliptical intrusive stocks of the Eagle Hill Rhyolite south of Mercur (Fig. 1). Irregular, sill-like masses of this unit occur 0.5 to 1.0 km south of Mercur Hill (Fig. 1) (M. Bryant and T. Faddies, pers. commun., 1982). The Eagle Hill Rhyolite has a K-Ar age of 31.5 m.y. (Moore, 1968). The age of the Mercur hydrothermal system is unknown due to ambiguous field relationships and the lack of hydrothermal minerals which are suitable for dating.

The structure of the Mercur district is dominated by the broad, northwest-trending, south-plunging Ophir anticline (Fig. 1). The hinge of the anticline transects Mercur Canyon approximately 2 km west of the Mercur mine. Rocks in the Mercur area generally dip 20° to 30° to the east. A number of east-west normal faults are recognized within the Mercur orebodies (T. Faddies and R. Blair, pers. commun., 1982). These high-angle faults may have been the conduits for ascending hydrothermal fluids, although their exact relationship to mineralization is unknown.

Upper Topliff Limestone Member in the vicinity of Mercur

Alteration at Mercur is confined to the upper 60 to 80 m of the Topliff Limestone Member and the lower portion of the Long Trail Shale. The upper Topliff Member was subdivided into the Magazine sandstone, the Barren beds, the Mercur beds, and

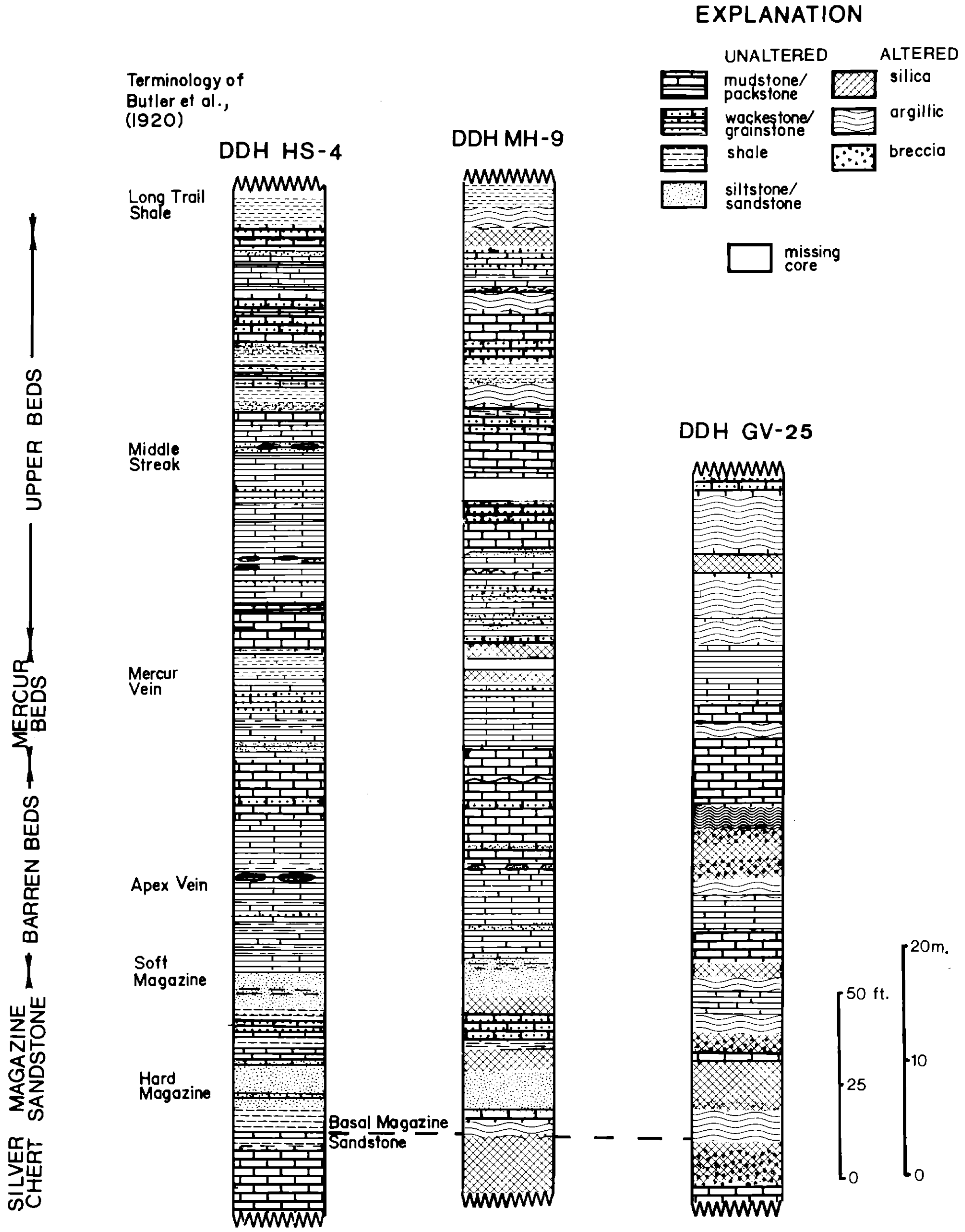


FIG. 2. Lithologic logs of the upper portion of Topliff Limestone Member, Great Blue Limestone. Diamond drill hole HS-4 is weakly to unaltered, MH-9 is weakly to moderately altered, and GV-25 is strongly altered. Datum is base of the Magazine sandstone.

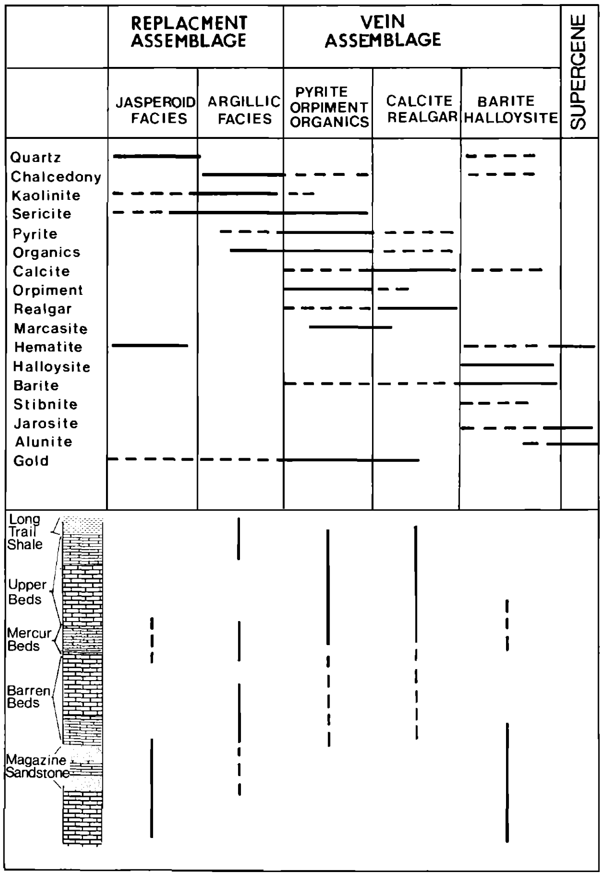


FIG. 3. Paragenetic sequence and idealized spatial distribution of hydrothermal alteration at Mercur. Solid lines show strong presence of mineral assemblages, and dashed lines show minor amounts of the assemblage.

the Upper beds by Butler et al. (1920). Descriptions given in Table 1 are based on hand samples and petrographic observations from a deep diamond drill hole located 0.75 km northeast of Mercur which encountered an unaltered to weakly altered Topliff section (Fig. 2). The classification of Dunham (1962) is used in carbonate rock descriptions.

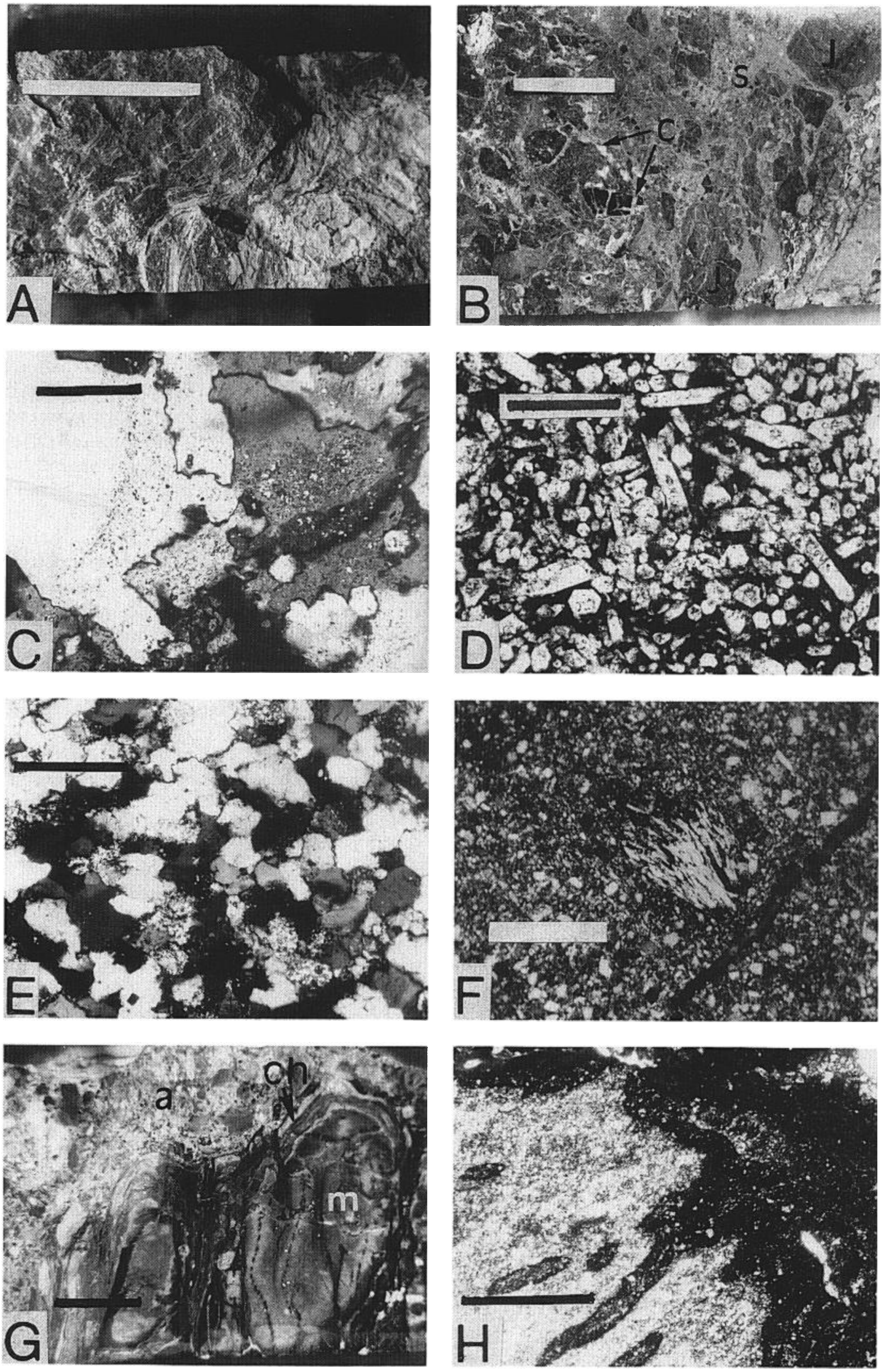
The allochemical constituents in the upper Topliff are largely pelloids and fossil fragments. Fenestrate bryozoa are characteristic of the more thinly laminated lithologies, whereas the more massive mudstones and wackestones usually contain echinoids, crinoid fragments, and less commonly, corals and brachiopods. The calcite mud matrix is cryptocrystalline. The amount of fine-grained indigenous organic matter is sufficiently high to give the Great Blue Limestone its characteristic medium to dark gray color. Pyrite is ubiquitous and ranges from euhedral cubes as large as 1 cm to individual grains, aggregates, and veinlets only microns in size. Quartz is usually well rounded and less than 50 μm in diameter. Lathlike illite grains up to 20 μm long are characteristic of the siltstones and shales. The illite is colorless in thin section and often displays a reticulated habit. X-ray analysis reveals the presence of kaolinite and illite in unaltered Topliff samples. Petrographic identification of kaolinite is difficult, but it appears to occur as fine-grained clots associated with the illite. No phyllosilicate mineral other than illite and kaolinite has been found in unaltered Great Blue Limestone.

Hydrothermal Mineral Assemblages

Temporal and spatial relationships of hydrothermal mineral assemblages were established by examination of outcrops, open pits, 300 hand samples, and 120 thin sections from both surface and drill core samples. Alteration and mineralization at Mercur are divided into a mineral assemblage which replaces the host limestones and mineral assemblages which occur in veins (Fig. 3). The replacement assemblage can be separated into an early jasperoid facies and a contemporaneous to somewhat later argillic facies. These facies are predominant at different stratigraphic intervals in the upper Topliff Member (Fig. 3). From earliest to latest the vein assemblages consist of pyrite-orpiment-organics ± marcasite, calcite-realgar, and barite-halloysite-calcite. Detailed discussion of each assemblage follows.

Replacement assemblages

Jasperoid facies: Silicification of selected horizons of the upper Topliff Member is the earliest and most widespread form of alteration at Mercur. The most conspicuous zone of this alteration is a 5- to 20-m-thick interval of jasperoid known as the Silver chert which is located immediately below the Magazine sandstone. The Silver chert jasperoid forms massive, outcrop-forming ledges on Marion Hill, and less conspicuously, on Mercur Hill. In outcrop, the Silver chert is typically aphanitic, dense, and medium to light gray, although brown and grayish-black varieties are not uncommon. Preservation of original sedimentary features is observed locally in thin sections and hand samples (Fig. 4A). The Silver chert shows widespread brecciation (Fig. 4B), particularly in the Marion Hill area. Much of this brecciation is attributed to premineralization karstification of limestones below the Magazine sandstone throughout the southern Oquirrh Mountains (R. Blair, pers. commun., 1984). Significant brecciation could also be caused by the process of "chemical brecciation" (Sawkins, 1969) whereby a change in rock composition can cause high internal stresses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within the rock. A significant amount of postalteration tectonic breccia is found within the Silver chert; it is usually distinguishable from hydrothermal breccia by slickensides and fault gouge which crosscut alteration. Matrix material of the jasperoid breccias consists of clay, barite, and clear crystalline quartz, although vugs and open space remain.

Silicification of the Magazine sandstone is widespread and often makes recognition of the Silver chert-Magazine sandstone contact difficult (e.g., drill hole GV-25, Fig. 2). Minor amounts of jasperoid are localized in the Mercur beds and lower portion of the Barren beds.

In thin section, three quartz textures typical of jasperoids are recognized (Lovering, 1972). The earliest texture consists of xenomorphic quartz grains which range from submicroscopic to 150 μm in diameter. The xenomorphic-textured jasperoids typically contain submicroscopic earthy iron oxide, allophane, and organic carbon(?) particles (Fig. 4C). The very fine grained nature of this material prevents its positive identification. Minor sericite and kaolinite occur as overgrowths and interstitial grains. Lovering (1972) has interpreted jasperoids with xenomorphic textures to be the result of crystallization from a silica gel.

A second, later texture consists of reticulated quartz grains up to 0.5 mm in length. The reticulated texture appears to be gradational with the xenomorphic texture in some jasperoid specimens. The reticulated quartz grains are tightly interlocked with little intergranular material. Small unidentified, birefringent minerals and carbon(?) often outline crystal growth planes, a feature which indicates deposition of the silica as crystalline quartz.

The third and latest common quartz texture consists of discrete, euhedral quartz grains in a matrix of clay and earthy, ferric iron oxides (Fig. 4D). Locally, the euhedral quartz displays cockscomb overgrowths on earlier silicification. Euhedral quartz contains small numbers of small (less than 10 μm diameter) fluid inclusions. All fluid inclusions are liquid dominant with no daughter minerals.

Argillic facies: Decarbonation of limestone and alteration of preexisting phyllosilicate minerals in the upper Topliff Member constitutes the second alteration facies at Mercur. Argillic alteration postdates the silicification on the basis of matrix material in jasperoid breccias and crosscutting relationships observed in thin sections (Fig. 4E and F).

X-ray diffraction analysis of 17 samples in representative unaltered and altered lithologies reveals that, with the exception of two samples, kaolinite and sericite are the only phyllosilicate minerals at Mercur. In sample MH-9-174 (Mercur beds, Mercur Hill) pyrophyllite was identified. In sample MH-9-275 (silicified Magazine sandstone, Mercur Hill) a minor amount of smectite was found.

All stratigraphic intervals of the upper Topliff Member host argillic facies alteration, although it is particularly well developed in the Mercur beds, Upper beds, and the lower portion of the Barren beds (Fig. 2). Argillic alteration appears to be preferentially developed in silty and shaly lithologies, but replacement of massive limestones is also observed (Fig. 4G). Brecciation of argillic material and cementation by somewhat darker argillic material is common, although locally this lighter to darker sequence is reversed. Textures of the argillic material vary from punky, structureless masses to thinly laminated rock in which original sedimentary bedding and fossils are well preserved. Microscopic examination of the argillic rocks shows sericite as discrete grains and aggregates which range from 20 to 100 μm in length and aggregates of irregular interlocking kaolinite crystals up to 15 μm. Sericite crystals viewed perpendicular to the *c*-axis have a pale green pleochroism. Sericite grains are observed

FIG. 4. Photographs of replacement assemblages. A. Split core of Silver chert from Marion Hill, DDH R-21. Note light-colored banding which may be relic bedding. Scale bar is 5 cm. B. Slabbed core of Silver chert breccia, Marion Hill, DDH H-17; c = crosscutting calcite veinlets, j = dark gray clasts of early jasperoid, s = amorphous silica-clay. Scale bar is 2 cm. C. Photomicrograph of xenomorphic quartz grains in the Silver chert horizon, Marion Hill, DDH P-27. Note bands of fine-grained minerals (allophane?) which crosscut crystal boundaries and suggest deposition of the silica as a gel prior to formation of individual quartz crystals. Scale bar is 100 μm. D. Photomicrograph of euhedral quartz in matrix of iron oxides and carbon(?). Silver chert horizon, Marion Hill, DDH H-17. Scale bar is 0.5 mm. E. Photomicrograph of xenomorphic quartz overprinted by later silica-clay clots. Lower portion of the Barren beds, Marion Hill, DDH H-17. Scale bar is 200 μm. F. Photomicrograph of sericite aggregate overgrowth on quartz-sericite-kaolinite matrix. Mercur beds, Mercur Hill, DDH ML-9. Scale bar is 200 μm. G. Slabbed core section of mudstone being converted to argillic breccia; a = argillic breccia, ch = chalcedony overgrowths on mudstone, m = mudstone (dark strings are fenestrate bryozoa clasts). Note the crosscutting nature of the alteration to the original sedimentary bedding (shown by the bryozoa clasts). Mercur beds, DDH GV-25. Scale bar is 0.5 cm. H. Photomicrograph of oxidized argillic alteration being overprinted by later organic-rich alteration. Mercur beds, Mercur Hill, DDH ML-9. Scale bar is 1 mm.

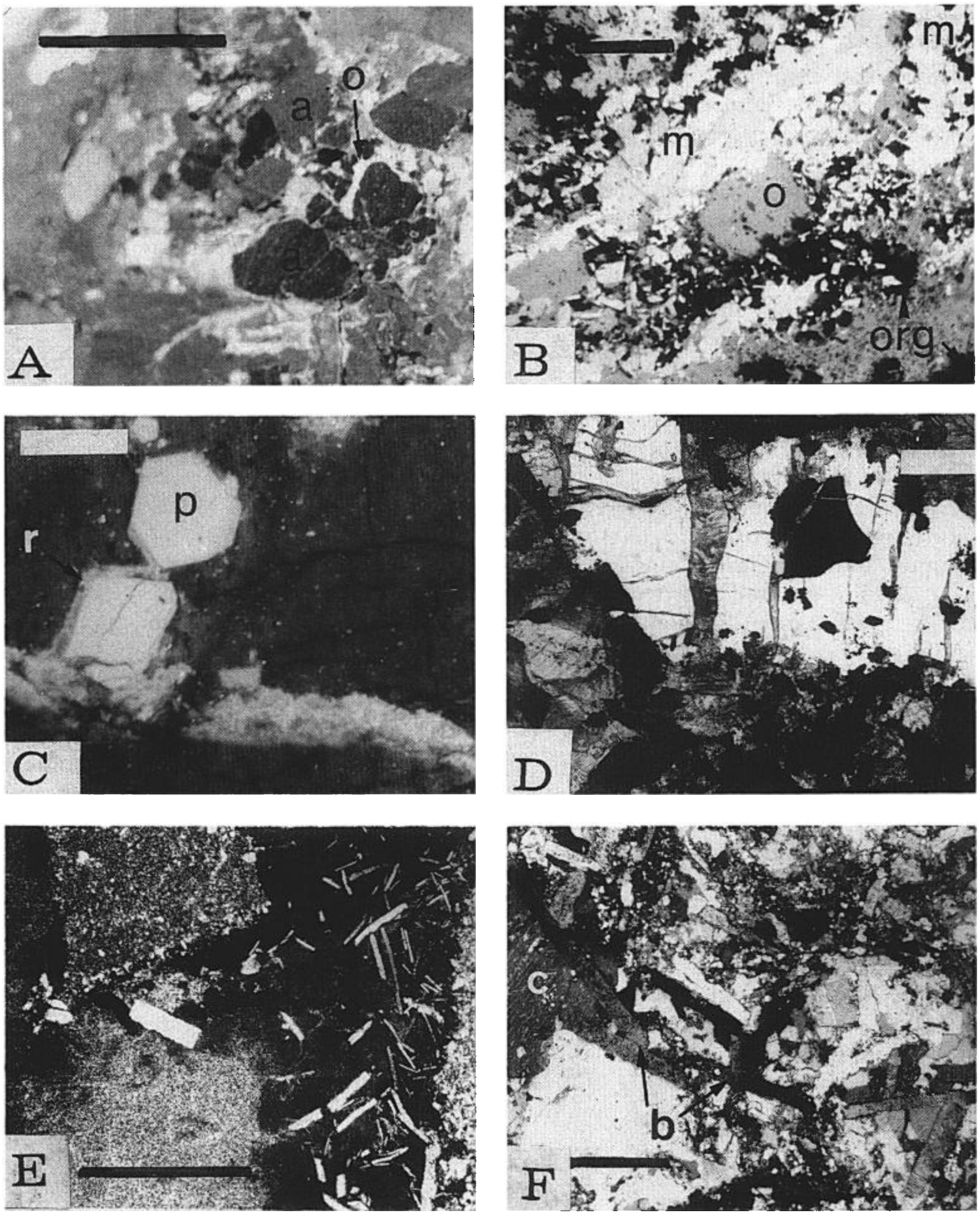

FIG. 5. Photographs of vein assemblages. A. Slabbed core section of argillic breccia; a = dark clasts of argillic material, in matrix of lighter argillic material, o = orpiment vein material. Mercur beds, Mercur Hill, DDH MH-9. Scale bar is 5 mm. B. Reflected light photomicrograph of pyrite-orpiment-organics ± marcasite mineral assemblage; m = marcastie, o = orpiment, org = organics. Mercur beds, Mercur Hill, DDH ME-8. Scale bar is 200 μm. C. Slabbed core section of calcite-realgar vein in massive mudstone; p = pyrite, r = realgar. Note overgrowth of realgar on euhedral pyrite, which may be diagenetic in origin. Barren beds, DDH GV-25. Scale bar is 3 mm. D. Photomicrograph of organic matter encased by jasperoid facies quartz and crosscut by hydrothermal calcite. Mercur beds, DDH GV-25. Scale bar is 200 μm. E. Photomicrograph of euhedral barite crystals in massive halloysite. Square clast is jasperoid. Silver chert, Marion Hill, DDH R-21. Scale bar is 1 mm. F. Photomicrograph of euhedral barite laths and calcite from barite-halloysite-calcite assemblage; b = barite, c = calcite. Median limestone of Magazine sandstone, Marion Hill, DDH R-21. Scale bar is 0.5 mm.

both crosscutting and conforming to the outline of quartz grains, suggesting that deposition of sericite was contemporaneous to slightly later then deposition of the quartz. Orientation of the sericite grains conforms to laminations in the rock. This, plus the sericite pleochroism, serves to distinguish hydrothermal sericite from sedimentary illite. Sericite has not been observed replacing illite in thin section.

Oxidation associated with this style of alteration is extremely varied and gives these rocks colorful red, maroon, brown, and olive green colors. Oxidizing conditions existed in both hypogene and supergene fluids and make categorization of oxidation difficult. The existence of hypogene oxidation is established by the overprinting of oxidized, decarbonated lithologies by later hydrothermal organic material (Fig. 4H) and occurrences of massive, oxidized, partially decarbonated limestones.

Vein assemblages

Pyrite-orpiment-organics ± marcasite: Deposition of pyrite, orpiment, organic material, and minor marcasite characterizes the transition from replacement of the host limestones to deposition in veins and open spaces. This assemblage is typically developed in the Mercur beds, but lesser amounts are found in the Upper beds, and more rarely, the Barren beds and the median limestone of the Magazine sandstone. This assemblage occurs in a variety of habits. Irregular masses are more typical than discrete veins (Fig. 5A). The orpiment is poorly crystalline and typically intergrown with very fine grained pyrite, marcasite, and amorphous organic carbon (Fig. 5B). Subhedral to euhedral calcite and realgar are common but volumetrically minor associates of this assemblage. Sericite, chalcedony, and quartz also appear in close spatial association with the pyrite-orpiment-organics ± marcasite assemblage.

Calcite-realgar: A second vein assemblage consists of discrete, well-defined veins of calcite and realgar up to 2 cm in width (Fig. 5C). The calcite and realgar occur in widely varying proportions, although the calcite is usually the earlier of the two minerals. Vein selvages consist of drusy calcite with abundant organic material. The vein centers typically consist of clear calcite and realgar (Fig. 5D). Both calcite and realgar contain fluid inclusions which are less than 15 μm in diameter. The calcite-realgar veins are a discrete mineral assemblage with little overlap to earlier or later minerals of the paragenesis, although hydrothermal organic material and pyrite are typically found close to the veins.

Barite-halloysite-calcite: The final hypogene assemblage recognized at Mercur consists of barite, halloysite, and minor calcite. These minerals are found in both of the Mercur orebodies but are particularly well developed on Marion Hill. Most barite-halloysite mineralization is confined to open spaces and veins in the Silver chert, although minor amounts are also present in all other units of the upper Topliff Member.

Halloysite is the earlier of the two minerals. Halloysite generally occurs as vitreous white masses of minute, interlocking low birefringence crystals.

Barite occurs as euhedral crystals which replace or are coeval with halloysite (Fig. 5F) and hydrothermal calcite (Fig. 5E). In the Upper, Mercur, and Barren beds, barite is commonly observed in spatial association with the pyrite-orpiment-organic ± marcasite assemblage. Crystal length ranges from 0.1 mm to 3.0 cm. Fluid inclusions up to 25 μm in diameter are abundant and often aid in the identification of barite in thin section. Euhedral quartz crystals are a local but minor associate of the barite.

Stibnite is locally observed as open-space fillings in the Silver chert and an antimony trace element signature is often found in other portions of the Topliff stratigraphy. The relative scarcity of stibnite makes its position in the paragenetic sequence tenuous (Fig. 3).

Late hypogene or supergene minerals

Jarosite is abundant throughout the Mercur district in veins and as a replacement of pyrite. Alternating deposition of jarosite and hematite occurs locally. Jarosite crystals are relatively coarse grained (50-100 μm in diam) and show a distinctive yellow-green pleochrism. On the basis of petrographic evidence alone, it is unknown whether the jarosite is hypogene or supergene.

Alunite has been observed in one thin section and was detected in association with jarosite by X-ray diffraction. Alunite overgrowths on jarosite crystals establish the relative age of the two minerals.

Spatial and temporal association of gold mineralization

The exact paragenesis of gold mineralization at Mercur has not been established. Assays of various lithologies suggest the following generalizations, however. (1) Locally high amounts of gold and silver are found in the Silver chert. Silica encapsulation of the gold has not been reported (W. Tafuri, pers. commun., 1982). (2) The bulk of the gold mineralization is located in the Mercur beds in association with argillic facies alteration and/or pyrite-orpiment-organics ± marcasite veins. (3) The Upper and Barren beds have very irregular amounts of gold mineralization which is associated with alteration similar to that found in the Mercur beds.

Comparison with Other Sediment-Hosted Gold Deposits

The Mercur deposits share some fundamental similarities with gold deposits described elsewhere. The most thoroughly studied sediment-hosted gold deposit is Carlin (Radtke et al., 1980; Radtke, 1985). Other deposits with extensive published descriptions include Getchell (Joralemon, 1951), Cortez (Wells et al., 1969), and Gold Acres (Wrucke and Armbrustmacher, 1975). All of these deposits are in the Basin and Range province of Nevada. A summary of most known sediment-hosted precious metal deposits in the western United States is given by Bagby and Berger (1985).

Mercur is somewhat anomalous among other gold deposits in that alteration is controlled by distinct lithologies within a restricted stratigraphic sequence. Mineralization at Carlin, Cortez, Getchell, and Gold Acres seems to be more strongly controlled by normal faulting. The Roberts Mountains thrust fault is also found near the Cortez, Carlin, and Gold Acre deposits.

All sediment-hosted gold deposits have gold which is invisible to the naked eye, and in all cases, the paragenesis of the gold is poorly understood. Mercur, Carlin, and Getchell all have visible arsenic minerals and carbonaceous material which has been deposited by hydrothermal fluids.

Widespread jasperoid is reported at Carlin but not at Cortez, Gold Acres, or Getchell. Like Mercur, the jasperoid at Carlin appears to have no direct relationship to the gold mineralization. Unlike Mercur, jasperoid at Carlin is late in the paragenetic sequence and occurs stratigraphically above the bulk of gold mineralization.

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