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Mineral paragenesis, structure, and "ore shoot" geometry at the U.S. Treasury mine, Chloride mining district, New Mexico

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Introduction

The U.S. Treasury mine is located in the southeastern portion of the Chloride mining district, Sierra County, New Mexico (Fig. 1). A segment of the St. Cloud–U.S. Treasury epithermal vein system, which contains copper, lead, zinc, silver, and gold mineralization, was exploited by mining activity. The entire vein system is approximately 7,700 ft in strike length. Near the U.S. Treasury mine, the vein generally trends N45°W, dips 65°SW, and is hosted by debris-flow breccias and other volcaniclastic deposits of the Eocene–Oligocene, lower Rubio Peak Formation. A K–Ar radiometric age date of 26.5 ± 1.1 m.y. (late Oligocene) was obtained from vein adularia in the St. Cloud portion of the vein system (Mike Bauman, First Mississippi Corp., pers. comm. 1984).

The U.S. Treasury deposit was discovered and initially worked in the 1880's and early 1890's; additional development and mining were done just before World War I. Production from this early activity was estimated at $20,000 by Harley (1934). In the early 1980's St. Cloud Mining Company (Goldfield Corp.) produced approximately 235,000 ounces of silver and 4,000 ounces of gold from about 60,000 tons of ore and development rock.

Previous geologic reports on the vein system include descriptions of the old U.S. Treasury mine by Harley (1934) and details of recent mining activity and geology at the St. Cloud mine by Freeman and Harrison (1984). General geology of the Chloride mining district was described by Harrison (1986). Behr (1987) analyzed the geochemical aspects of ore deposition for both St. Cloud and U.S. Treasury deposits; initial results were reported by Behr and Norman (1986).

Mineral paragenesis

Two pulses of sulfide mineralization are recognized at the U.S. Treasury mine: an early Pb, Zn, Cu (Ag, Au) pulse (stage 1) and a later Cu, Ag (Zn, Pb, Au) pulse (stage 2; Harrison, 1986). These two stages are notably lacking in iron mineralization, with only minor amounts of pyrite, hematite, and magnetite. Gold mineralization occurs sporadically in both stages.

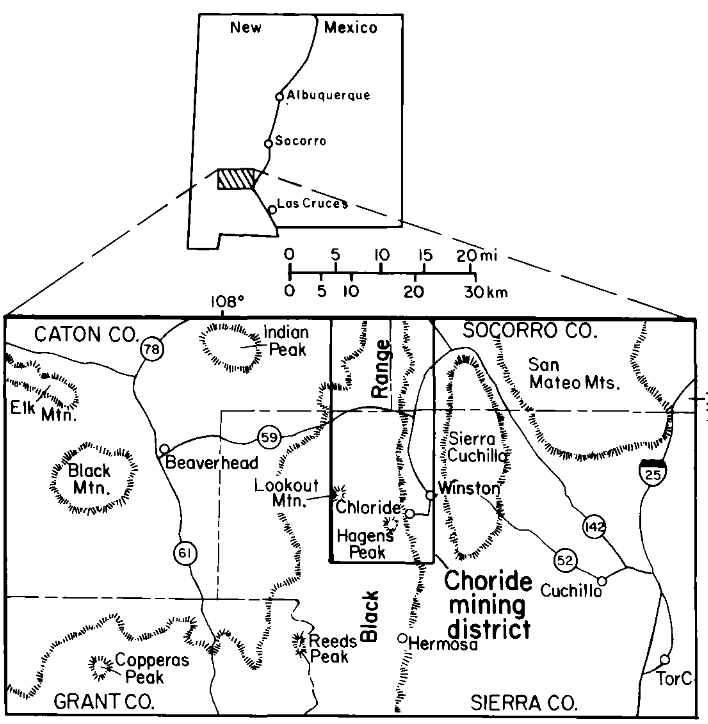

FIGURE 1—Location maps of the Chloride mining district.

TABLE 1—Metal content vs. elevation for U.S. Treasury stage 1 mineralization. Data is tabulated from "ore shoot" occurrences; lower-grade mineralization (although showing the same metal ratios) is not included.

Elevation (ft)	Cu%	Pb%	Zn%	Ag oz/ton	Au oz/ton
6,800–7,050	0.80	0.05	0.05	3.1	0.01
6,600–6,800	0.60	1.00	1.80	4.9	0.03
6,300–6,600	0.80	1.20	2.10	6.0	0.03
6,000–6,300	0.40	2.80	3.60	4.8	0.04

TABLE 2—Metal content vs. elevation for U.S. Treasury stage 2 mineralization; only mineralization from "ore shoot" is tabulated.

Elevation (ft)	Cu%	Pb%	Zn%	Ag oz/ton	Au oz/ton
6,850–7,050	0.02	0.01	0.01	5.00	0.13
6,700–6,850	0.52	0.14	0.37	8.80	0.08

Mineralization stages 1 and 2 are both contained within the U.S. Treasury deposit, with two distinguishable substages of stage 1 and an additional late stage (stage 3) consisting of supergene secondary minerals. In paragenetic order, stage mineralogy present at the U.S. Treasury mine are 1a) medium- to coarse-grained galena, sphalerite, and chalcopyrite as fracture-fill and replacement of silicified wall rock; 1b) medium-grained chalcopyrite (galena, sphalerite, molybdenite) disseminations in white quartz, and pale-green amorphous silica; very fine grained to medium-grained bornite, stromeyerite (AgCuS), jalpaite ($Cu_{0.45}Ag_{1.55}S$; sphalerite, galena) occurring as bands and disseminations; and late, secondary native silver, copper, and gold with cuprite and copper carbonates in localized areas. Gangue mineralogy for all stages is dominantly quartz with some calcite. A very late, massive, fracture-filling calcite cuts all other mineralization.

Stage 1 mineralization of the U.S. Treasury mine shows a large variation in metal content with depth, but the same simple mineralogy is found throughout. Table 1 illustrates the overall change in metal content, particularly displayed by base metals, for stage 1 mineralization at the U.S. Treasury mine. Silver in stage 1 mineralization occurs both as minor substitutions for copper in chalcopyrite and as spotty occurrences of light ruby silver (proustite, Ag_3AsS_3). Iron content in sphalerite from stage 1 mineralization was determined by x-ray analysis; it is about 4–5%.

Stage 2 mineralization is the main silver-bearing phase at the U.S. Treasury mine as well as in other vein systems in the southern portion of the Chloride mining district. Unfortunately, sampling of stage 2 mineralization during mining activity or drill core exploration has taken place only above 6,700 ft in elevation at the U.S. Treasury mine. From this depth to the surface, a moderate, vertical zonation in metal content is found (Table 2).

Stage 2 mineralization in the southern portion of the Chloride mining district is intriguing because silver occurs primarily as substitutions for copper in the lattice of copper-bearing minerals and in solid solution Cu–Ag sulfides. Chemical analysis of bornite from the St. Cloud deposit reveals about 1.4 wt% Ag. Neal and Larson (1986) reported 0.7 wt% Ag in bornite and even more in chalcocite from the nearby Hoosier vein system. Skinner (1966) found that up to 3.4 wt % of silver can substitute in chalcocite at 63.3°C. Using

Skinner's maximum Ag value, it is possible for chalcocite to contain almost 600 oz/ton Ag. This explains the occurrence of pockets of high-grade silver mineralization at the U.S. Treasury mine and St. Cloud deposits that contain no primary silver sulfides. Skinner (1966) also indicated that a solid solution series exists from Cu_2S (chalcocite) to $Cu_{0.96}Ag_{1.04}S$ below 93.3°C. Jalpaite ($Cu_{0.45}Ag_{1.55}S$) was tentatively identified by Robert North (pers. comm. 1981) and probably formed by breakdown of $Cu_{0.8}Ag_{1.2}S$ at 94.4°C to jalpaite and $Cu_{0.96}Ag_{1.04}S$ as described further by Skinner (1966).

Mineralization textures vary greatly throughout the U.S. Treasury deposit. These textures include wide, open-space, fissure-filling quartz and calcite veins with minor sulfides; thin, massive-sulfide stringers; banded and crustiform fine-grained sulfides alternating with quartz and calcite; and sulfide disseminations in wall rock as much as 100 ft away from the main vein structure. In places, post-mineralization faulting has produced a crushed texture of sugary quartz and sulfides. A generalized cross section through the vein structure on the lower level of the U.S. Treasury mine (Fig. 2) shows the various mineralization textures, as well as relationships between paragenetic stages and fault development.

"Ore grade" mineralization is a difficult term to define because of changing mineral economics and uncertainties in cost factors in mining. Therefore, rather than showing locations of "ore," the plan map of the U.S. Treasury mine (Fig. 3) highlights areas of mineralization ≥5 oz/ton Ag equivalent (.015 oz/ton Au equals 1 oz/ton Ag). Note that such mineralization occurs not only within the massive quartz

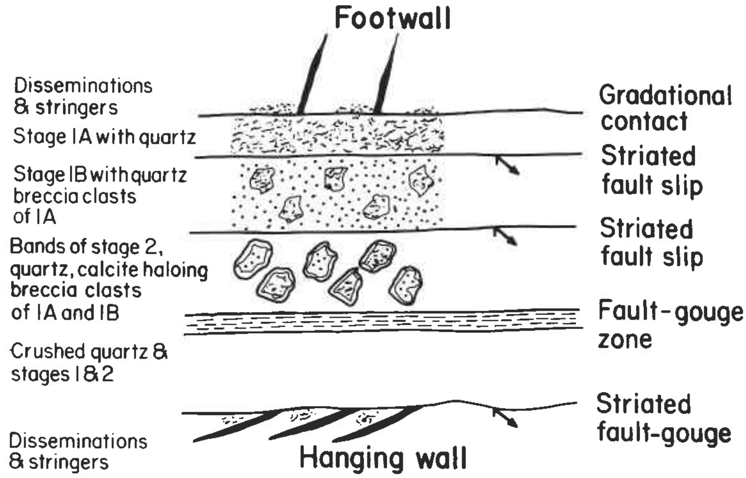

FIGURE 2—Generalized cross section through vein structure on lower level of U.S. Treasury mine showing various mineralization textures. Note the overall development of fault structure from footwall to hanging wall depicted by paragenetic sequence.

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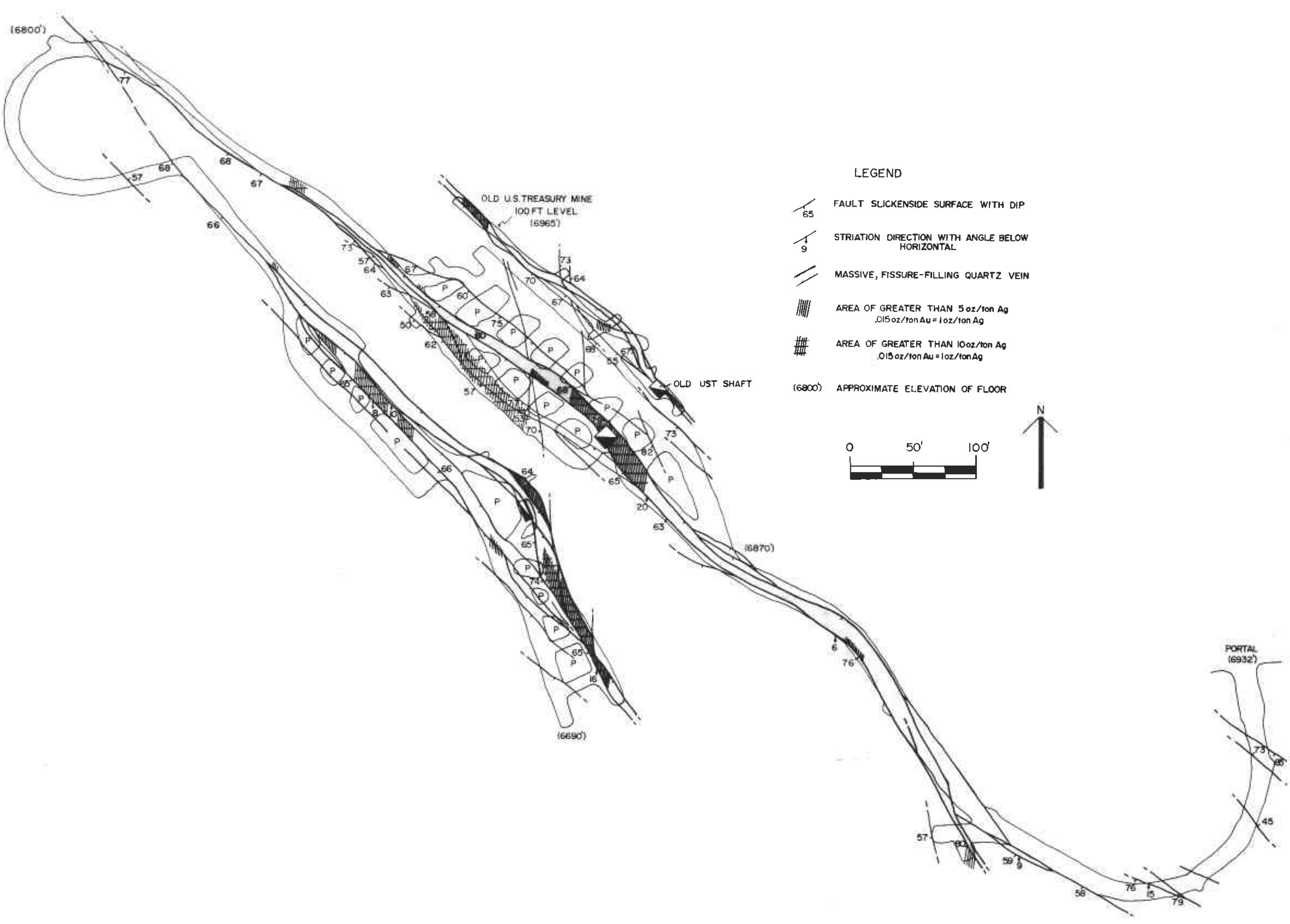

FIGURE 3—Plan map of U.S. Treasury mine. Note that areas of anomalous mineralization occur within massive quartz vein, as well as within both the hanging wall and footwall. Note also, location of north–south fractures and prominent north–south trend of massive quartz on the lower level of the mine. Cross section of Figure 2 is located just east of the shaft on the lower level. **P**, pillars.

Continued from page 11
vein, but also as disseminations and stringers in both the hanging wall and footwall.

Alteration accompanies mineralization at the U.S. Treasury mine and throughout the Chloride mining district. In general, rocks in the district are propylitically altered, particularly those rocks of intermediate composition. This alteration assemblage is typically epidote, calcite, chlorite, and pyrite. In more felsic rocks, silicification and kaolinization are the dominant alteration products with epidote occurring as coatings on joints and other fractures. In the vicinity of the U.S. Treasury deposit, some of the most intense alteration of the entire district is found. Within the U.S. Treasury vein system, silicification, chloritization, and potassic alteration are associated with sulfide mineralization. X-ray analysis of chlorite from a hanging wall "ore" zone indicates that gonyerite [$(Mn,Mg,Fe)_6Si_4O_{10}(OH)_8$] is the dominant chlorite species. This chlorite is strongly associated with high-grade silver and gold mineralization (select samples commonly reach 50 oz/ton Ag and 1.0 oz/ton Au).

Structure

U.S. Treasury fault structure shows pre-, syn-, and post-mineralization movement. A progressive fault development from footwall to hanging wall is apparent for syn-mineralization movement (Fig. 2). Offset of stratigraphic horizons indicates that the overall fault structure is normal (hanging wall down) with approximately 150–200 ft of dip separation. Overall strike direction of the U.S. Treasury quartz vein is N46°W, with an average dip of 65° to the southwest. Above the 300-ft level of the mine, sinuations from N30°W to N60°W occur in the quartz vein. Below this level, a segment of the vein bends to a nearly north–south direction (see Fig. 3). On the lower level of the mine, this north–south dogleg extends for about 100 ft along strike and appears to be increasing in length with depth. This observed north–south trend coincides with the intersection of the vein and a set of fractures along the same trend present at the surface and in the shallow levels of the mine. Within the mine, these fractures are observed mainly in the vein's footwall and are commonly filled with quartz and/or epidote. They are vertical to steeply dipping, hairline to 0.5-inch wide, and cover a zone approximately 50 ft in width. There is no indication of movement along their surfaces. Figure 4 is a compass-rose diagram of surface fracture attitudes in the footwall of the U.S. Treasury structure.

A component of left-lateral oblique movement is suggested by numerous slickenside surfaces occurring across the width of the structure. Striations on slickensides are abundant and are dominantly low-angle oblique, from 6–20° to the southeast in the plane of the vein. Some horizontally striated, flat-lying slickensides and a few higher-angle oblique slickensides, about 55° to the southwest, have been observed along hanging wall areas in the structure. Most of the slickenside surfaces found in the U.S. Treasury fault are definitely post-mineralization in origin; however, the higher-angle striated surfaces appear to be remnants of syn-mineralization movement.

During the late Oligocene, northwest-trending extensional structures of the southern Rio Grande rift developed in response to regional northeast–southwest least principal stress direction (Seager et al., 1984; Lipman, 1981; Eaton, 1979; Chapin and Seager, 1975).

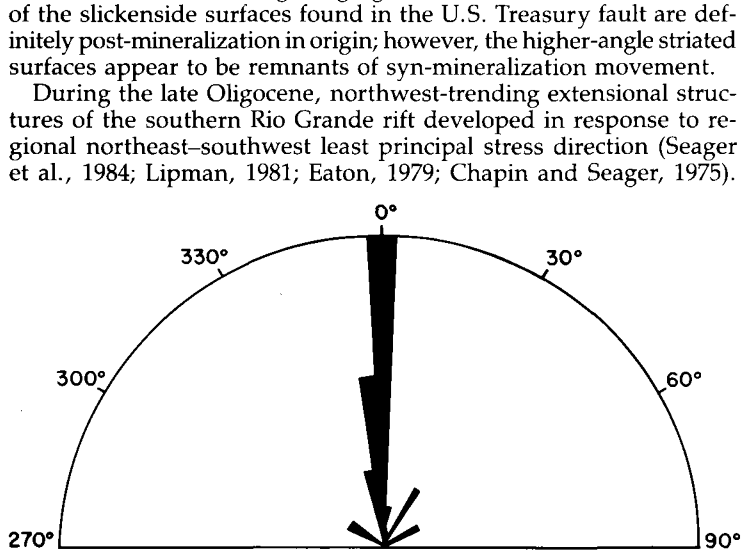

FIGURE 4—Compass rose diagram of surface fractures in footwall of U.S. Treasury structure.

It was during this regime that the veins of the Chloride mining district formed, in conjunction with a thermal event related to regional rhyolitic magmatism (Harrison, 1986). Quartz veins and silicified structures in the area of the U.S. Treasury mine formed along dominant northwest-trending dip slip structures. The north–south fractures and vein segment acted as fundamental controls on mineralization, as discussed later, and probably reflect buried basement fabric. The few north–northeast-trending structures in the area are lower Tertiary strike-slip faults (Harrison, 1986) and, because they presented an unfavorable direction for either wrenching or normal faulting during the period of late Oligocene mineralization, they are poorly mineralized.

The domain of dominantly northwest-trending structures found in the U.S. Treasury area is anomalous for the Chloride mining district as a whole. Throughout the rest of the district north–south, northeast, and east–west vein structures of similar age are dominant (Harrison, 1986). It is quite possible that the area of northwest-trending structures around the U.S. Treasury mine overlies a buried pluton or cupola that has, in effect, cancelled the majority of pre-existing basement fabric as discussed by Chapin in Aldrich et al. (1986). The inferred pluton thus allows the development of the new structural fabric in response to tectonic stresses (i.e., northwest-trending normal faults in response to northeast–southwest directed least principal stress). Correspondingly, veins throughout the rest of the Chloride mining district would probably represent reactivation of basement fabrics where no buried igneous body exists.

"Ore shoot" geometry

The U.S. Treasury mineralized system consists of a wide zone of dominantly sub-economic, sulfide mineralization. Mineralized intervals commonly exceed 60 ft of true horizontal thickness. Mineralized rock was intercepted for 62 ft (horizontal) during deep diamond drilling, 500 ft below the lowest mine level. It was assayed to contain 0.11% Cu, 0.10% Pb, 0.37% Zn, 0.92 oz/ton Ag, and 0.01 oz/ton Au. Occurring within this broad zone of low-grade mineralization are areas of higher-grade material: "ore shoots." "Ore shoots" exist in virtually all epithermal vein deposits (Buchanan, 1981) and are largely structurally controlled phenomena. In theory, "ore shoots" represent areas of high permeability that accommodate the flow of deeply circulating hydrothermal fluids, and thus, are the sites of major mineral deposition.

"Ore shoot" geometry at the U.S. Treasury deposit reflects the paragenetic sequence of mineral stages in combination with structural controls on location of mineralization. Figure 5 shows the geometric orientation of "ore shoots" for the U.S. Treasury deposit in longitudinal section. This "ore shoot" geometry closely approximates that of closed-cell convection systems described by Berger and Eimon (1982). In their closed-cell model, no permeability barriers exist to restrict the upward movement of hydrothermal fluids and, therefore, near-vertical "ore shoots" develop.

In Figure 5, the first "ore shoots" to form were the stage 1–footwall shoot centered on the lower end of the U.S. Treasury shaft and the stage 1–hanging wall quartz vein. The hanging wall quartz vein partially overlies the footwall shoot in longitudinal section. Structural controls for the stage 1–footwall shoot consist of a near-vertical, concave-to-hanging wall flexure in the upper portion of the shoot and a structure that parallels the north–south fracture intersection in the lower portion of the shoot. Remnants of the stage 1–footwall shoot are found above the line of north–south intersection as breccia clasts haloed by stage 2–quartz vein mineralization.

The stage 1–hanging wall quartz vein is a structure that bifurcates near the western margin of the main U.S. Treasury vein on the lower level of the mine (see Fig. 3). It contains an "ore shoot" that subparallels the north–south fracture intersection between elevations 6,450 and 6,600 ft and merges upward into a near-vertical stage 2–hanging wall stringer "ore shoot" that is superimposed upon it.

Along the western margin of the U.S. Treasury vein is a narrow "ore shoot" that parallels the line of north–south fracture intersection. This shoot contains footwall disseminations of stage 1 mineralization and is anomalously high in gold content (in excess of 0.15 oz/ton). This shoot is cut by development drifting, but its full extent

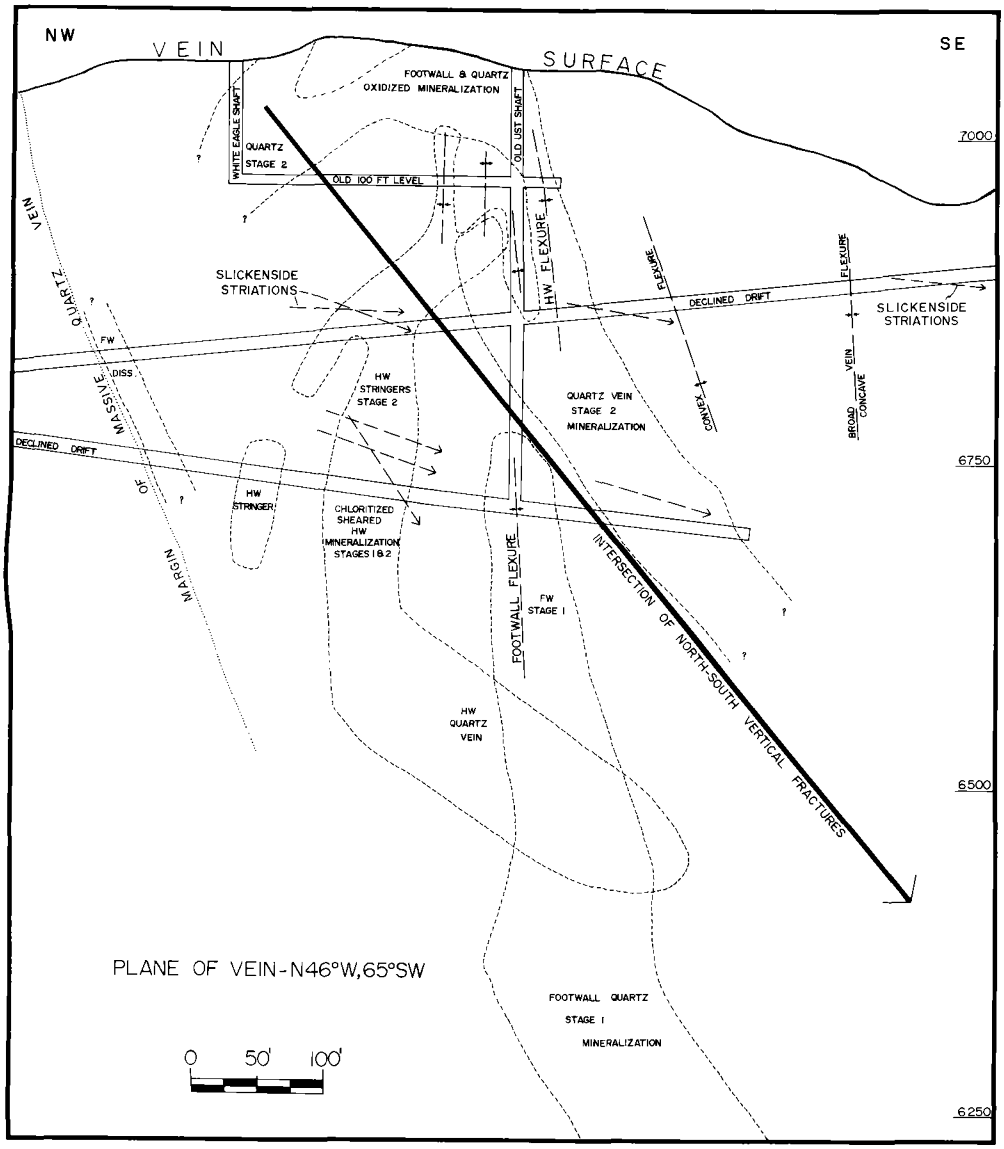

FIGURE 5—Longitudinal section of U.S. Treasury vein showing relationships between "ore shoots" and structural features. "Ore shoot" geometry above 6,700 ft elevation is based on mine sampling and mapping; below 6,700 ft, geometry is interpreted from drill core data.

is unknown because the overlying surface is poorly exposed, and the shoot is not penetrated by exploration drilling.

By far, the bulk of past mining activity at the U.S. Treasury mine has occurred on "ore shoots" of stage 2 mineralization. Geometry of these shoots is strongly controlled by the intersection of north–south fractures as seen in Fig. 5. Not only does the stage 2–quartz vein shoot lie adjacent to and parallel to the intersection, but stage 2 "ore shoots" in the upper portions of the U.S. Treasury deposit display numerous margins perpendicular to the north–south intersection. Such margins are interpreted to indicate control on open-space development by movement parallel to the north–south fractures. To some degree, small near-vertical flexures appear to control stage 2 "ore shoot" geometry around the old U.S. Treasury 100-ft level (see Fig. 5). In particular, concave-to-hanging wall flexures contain higher-grade mineralization than convex-to-hanging wall flexures. A component of oblique-slip (along the north–south fractures) is necessary to open space along these vertically oriented flexures.

Total vertical extent of the stage 2 quartz vein "ore shoot" is unknown due to lack of drill core data along its trend to depth. At the nearby St. Cloud deposit, stage 2 mineralization extends to a depth of 6,100 ft elevation. Because epithermal systems tend to maintain upper and lower levels to "ore horizons" within individual hydrologic areas, it is reasonable to expect a similar bottom depth at the U.S. Treasury deposit along structurally controlled "ore shoots."

Summary

There are three main points in this paper that are worth re-emphasizing. First, significant base- and precious-metal resources are related to tectonic processes associated with the Rio Grande rift in southwestern New Mexico. The U.S. Treasury deposit and other epithermal mineral deposits in the Chloride mining district represent some of these resources (as do perhaps other similar deposits along the southwestern margin of the rift). Second, the U.S. Treasury deposit consists of multiple pulses of mineralization in a structurally complex setting. And finally, structural features control epithermal mineral deposition, and once recognized, they can be used to predict trends in "ore shoot" geometry. At the U.S. Treasury deposit, intersection and relative movement between the northwest-trending fault structure and north–south fractures are the primary controls on location of mineralization. In the 2,300 ft between the U.S. Treasury deposit and the St. Cloud deposit on the same vein structure, a minimum of three relatively unexplored structural intersections occur, all of which show anomalously high surface values of silver and gold.

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