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MINERALOGY AS A GUIDE FOR EXPLORATION IN THE MONTEZUMA DISTRICT, CENTRAL COLORADO

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Abstract

The Montezuma district of central Colorado is a small base metal-silver mining district containing vein deposits associated with a Tertairy porphyry stock. The distribution of tetrahedrite having large unit-cell edges correlates in part with the distribution of more productive mines and suggests areas favorable for further production. The abundance of galena and sphalerite in veins, but not of pyrite, also correlates with the distribution of the more productive mines.

Introduction

The Montezuma district is an area of base metal-silver vein deposits associated with a Tertiary porphyry stock. It is similar to many mineralized areas associated with other Tertiary stocks in the Colorado mineral belt and elsewhere.

The district is roughly triangular in shape, with an area of 125 km^2; it is situated on the Continental Divide just south of Loveland Pass in the central Rocky Mountains (Fig. 1). Relief is about 1525 m; maximum elevation is the summit of Grays Peak (4350 m). The area has heavy snows for a large part of the year, and extensive glaciation has resulted in the formation of steep-walled cirques and U-shaped valleys, with only a few remnants of an old rolling upland surface preserved.

The first discovery of silver in Colorado was in the Montezuma district at the Coley deposit on Glacier Mountain in 1864 (Lovering, 1935, p. 65). Other deposits were discovered soon after this, and mining has been intermittent from that time until the present. Periods of mining activity have been generally coincident with high silver prices. The severe climate has limited access to the area, and the small size of the deposits has not attracted the larger mining companies. At present there is little mining activity, and there are no smelting facilities nearby.

The study of the Montezuma district was part of a larger investigation to characterize deposits associated with Tertiary porphyry stocks and to evaluate various exploration techniques applicable to these deposits. The purpose of the mineralogical study was to determine the mineralogy of the deposits and to further investigate those mineralogical characteristics that showed a relation to known production and could be possible guides for exploration of this and similar districts. The Montezuma district was

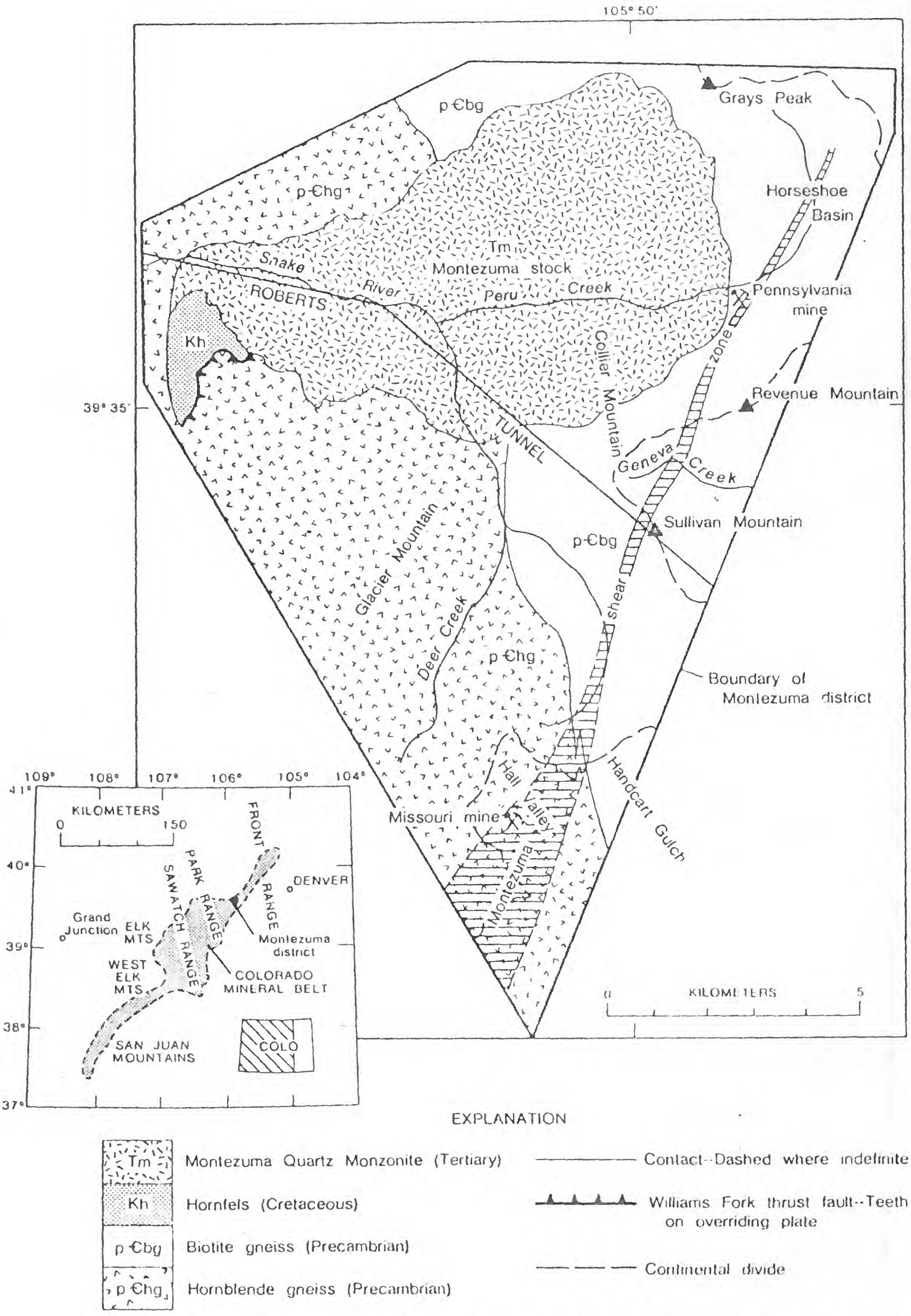

Figure 1. Index map of central and western Colorado showing Montezuma district in relation to the Colorado mineral belt, and map of Montezuma district showing localities mentioned in text.

particularly suited to this study, because the district is more or less typical of the base metal-silver districts associated with Tertiary porphyry intrusives and because some production records were available.

Geology

The Montezuma district is underlain by Precambrian schists and gneisses which have been intruded by the Montezuma Quartz Monzonite of Tertiary age. A small area of Cretaceous shales in the extreme northwestern part of the district was metamorphosed to hornfels (Neuerburg and Botinelly, 1972). Numerous faults, including the Williams Fork throust fault, cut the metamorphic rocks. As indicated by exposures in the Harold D. Roberts water tunnel (Robinson and others, 1974), the upper surface of the stock has a fairly shallow dip to the southeast. Numerous apophyses of quartz monzonite and related rocks are found to the southeast (Neuerburg and others, 1974), indicating an irregular upper surface of the stock.

Production

Incomplete records of production of silver, lead, zinc, and copper to 1929 are given by Lovering (1935). Ninety-eight percent of the recorded production came from 20 mines, the Pennsylvania mine alone producing more than half of the silver from the district. Total recorded silver production was 52,000 kg, but actual production may have been twice this amount. Silver production came in large part from just south and east of the outcrop of the Montezuma stock. Nearly 140 kg of gold was produced; more than 75 percent of this was from the Pennsylvania mine. Approximately 10,000 (metric tons) of lead, 2400 t of zinc, and 190 t of copper were produced by byproducts of silver mining.

The base metals, lead, zinc, and copper were produced in conjunction with silver, and the areas of production of these generally coincide with areas of silver production (Fig. 2). However, in the central part of the area, a rough zonal arrangement exists: zinc is abundant close to the stock; and copper is relatively abundant somewhat farther out from the stock. The southern part of the area produced little zinc and relatively large amounts of copper.

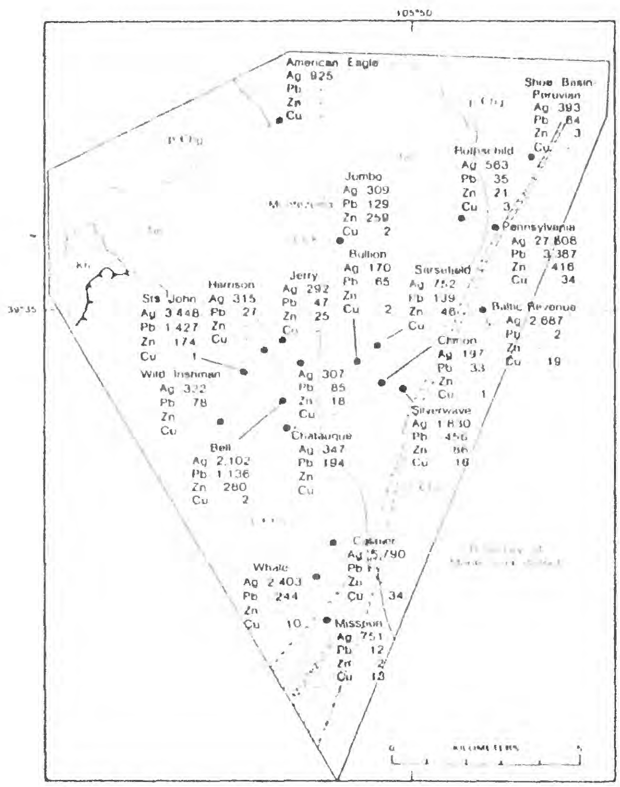

Figure 2. Recorded production of major mines in the Montezuma district. Ag in kilograms; Pb, Zn, and Cu in metric tons. Dash indicates no production.

Methods of study

From 1965 through 1975, the dumps of nearly all the mines and prospects were sampled by the author and G. J. Neuerburg, U.S. Geological Survey, in a study of methods of exploration applicable to deposits of this and related districts. As only a few mines were active, samples could rarely be obtained underground.

Certain problems arose because of the nature of the sampling. The material on the dumps is the result of a number of factors that cannot be quantitatively evaluated. Most of the mining was done before the advent of flotation and much of the ore was handsorted before shipping. Several mines were being worked intermittently at the time of sampling; minerals generally rare or absent in the mine dumps were found at these mines, a relation suggesting that the mineralogy of the deposits over the entire district is somewhat more complex than is indicated by the samples from the mine dumps. Barite presented difficulties in smelting and baritic ore was left on the dumps. Some smelters penalized for zinc, so sphalerite may be overrepresented on the dumps. A number of mines intersected more than one vein, and the dump samples are a composite of these veins. It is noticeable that the mines with high production, especially those with some sort of concentrating mill, left very little ore on the dumps. In addition, those mine dumps that are easily accessible have been picked over by mineral collectors.

Samples were studied in hand specimens and poliched section; X-ray powder patterns were used to identify many of the sulfide minerals and to determine tennantite-tetrahedrite unit-cell edges. Semiquantitative spectrographic analyses by James Nishi and Harlan Barton, U.S. Geological Survey, aided in many identifications.

Estimates of the relative abundance of the major ore and gangue minerals were made by inspection of samples from approximately 250 deposits. These deposits were selected to exclude prospects and assessment pits and to give a distribution of data over the district. The estimates were plotted on a map divided into a grid having cells 480 m on a side; the median value for each cell was arbitrarily selected as the value for that cell (Fig. 3).

The mineral occurrence maps (Fig. 3) show the occurrence of silver and base metals as minerals; the production map (Fig. 2) shows the amounts of these metals produced. The two types of maps show similarities, although based on almost antithetical quantities--one based on the minerals left on the mine dumps and the other, on the minerals shipped to the smelters. The most obvious similarity is the very low zinc production and near absence of sphalerite in the south end of the district.

In like manner, the production of lead and the occurrence of galena show a rough agreement. Silver, however, is present in galena, in tetrahedrite, and in silver sulfosalts, and copper occurs in chalcopyrite and tetrahedrite, so that production data on these elements are not directly related to occurrence data for individual host minerals.

Description of the ores

The ores are typical vein deposits, thin and without great lateral extent. However, data from exposures in the Roberts Tunnel suggest that the veins have a vertical range of at least 1200 m (Neuerburg and Botinelly, 1972). The ores are generally medium-grained and sometimes crudely banned; vugs are common. Ore and gangue minerals are usually intimately mixed. The mineralogy and textures of the ores are typical of those of many base metal deposits in the Colorado mineral belt and elsewhere.

Ore minerals

The common sulfide minerals of the ore are galena, sphalerite, pyrite, and tennantite-tetrahedrite. Gangue minerals are quartz, barite, and iron and manganese carbonates. A number of rare, complex sulfosalts of silver and lead occur in the district, but probably contributed little to the total production of silver. However, the major ore mineral of the Winning Card mine, near the American Eagle mine, was reported to be stromeyerite (Lovering, 1935, p. 116).

Galena was the major ore mineral of the district; it and tennantite-tetrahedrite probably carried most of the silver produced. Galena occurs as medium-grained masses associated with sphalerite and pyrite. The unit-cell edges of a number of galena specimens were determined; all were slightly smaller than those of pure galena, suggesting solid solution of silver bismuth sulfide (Graeser, 1971). Many powder patterns of galena showed lines of matildite. Galena is widespread in the district (Fig. 3). It in noticeably abundant at the contact of the Montezuma stock and along two linear trends: one following the Montezuma shear zone and the other following the basal part of the hornblende gneiss (Swandyke Hornblende Gneiss of former usage) as mapped by Lovering (1935).

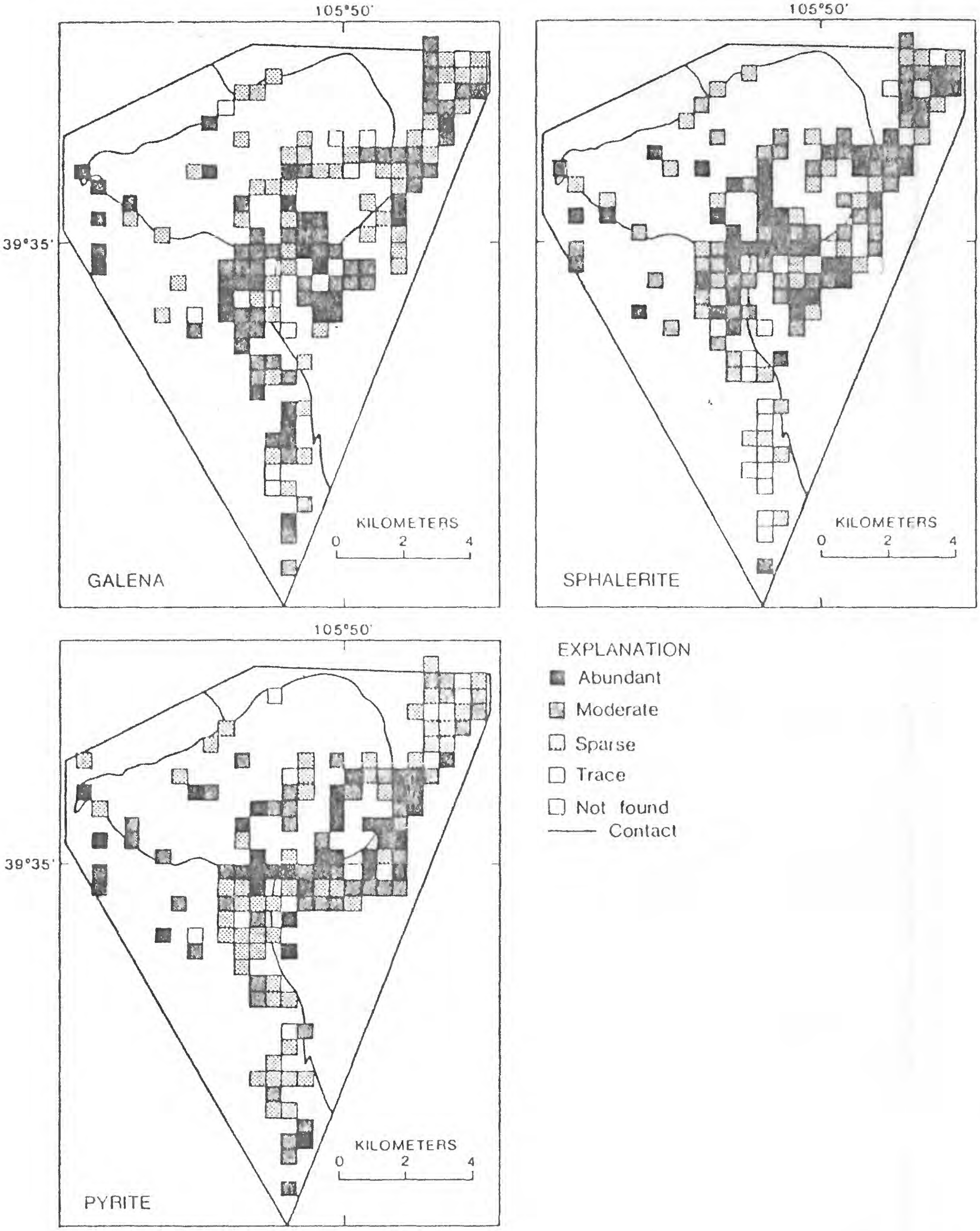

Figure 3. Maps showing abundance of minerals in the Montezuma district.

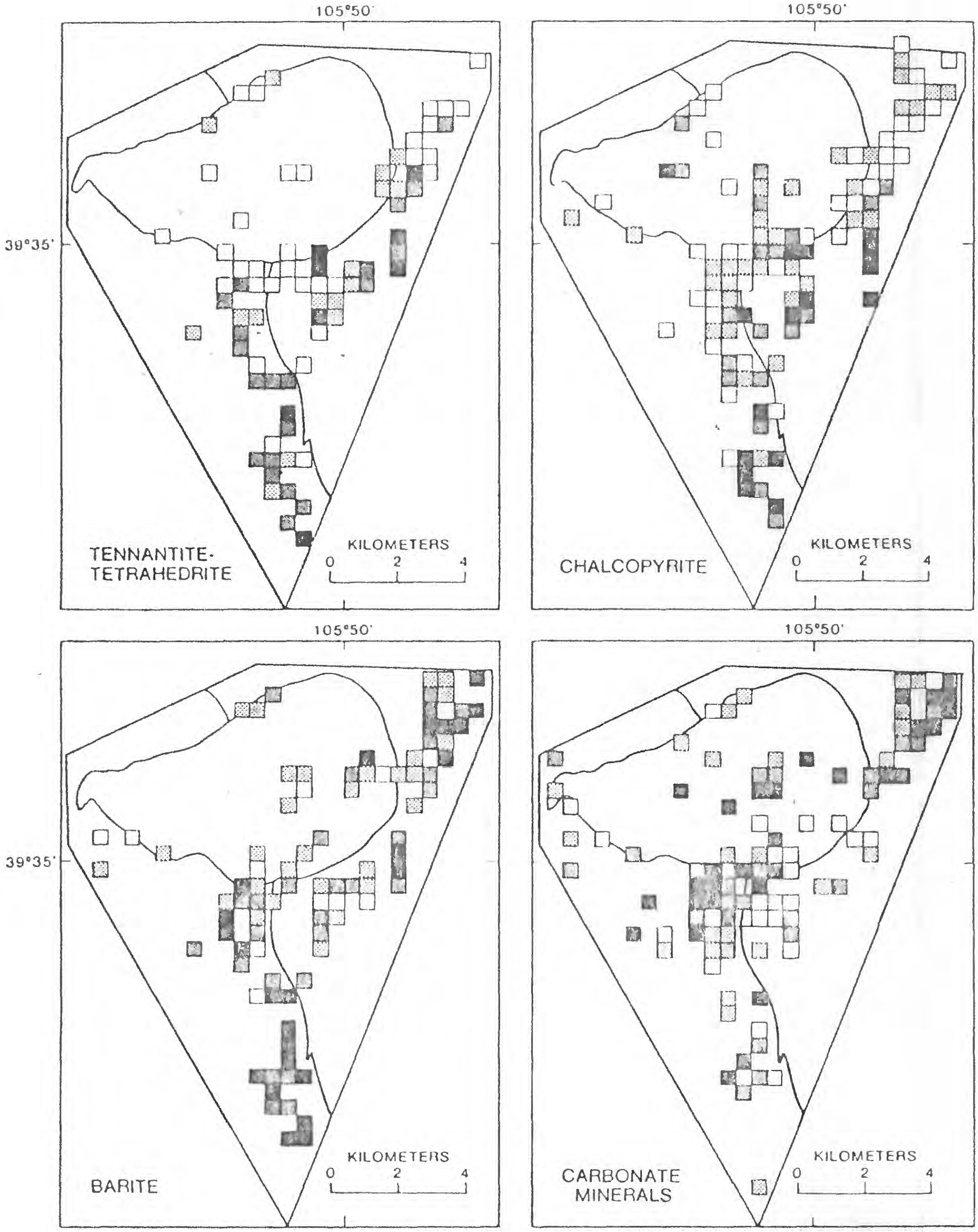

Figure 3. (continued) Maps showing abundance of minerals in the Montezuma district.

Sphalerite occurs as medium- to coarse-grained masses associated with galena and pyrite. Much of the sphalerite is black to dark green or dark red; some light yellow. Some of the sphalerite contains fine-grained inclusions of chalcopyrite. Sphalerite is apparently slightly more abundant than galena but is concentrated around the south edge of the stock, inside the stock, and along the Montezuma shear zone. Sphalerite is much less abundant than galena in the south end of the district.

Pyrite occurs abundantly as disseminated crystals and as masses; it is present in the wall rocks as well as in the veins. Although pyrite is associated with galena and sphalerite, the areas of greatest pyrite abundance do not coincide with the areas of greatest abundance of galena or sphalerite. Rather, pyrite is most abundant near the intersection of the edges of the stock and the Montezuma shear zone.

Tennantite-tetrahedrite occurs with galena and sphalerite but is closely associated with chalcopyrite in most specimens from the district. Tennantite-tetrahedrite usually forms fine-grained masses of irregular shape; tetrahedral crystals were found in a few locatilities. It occurs much less abundantly than galena and sphalerite, but the pattern of distribution is like that of galena.

Tennantite and tetrahedrite are the arsenic and antimony end-members of a series of sulfosalts common in base metal-silver deposits. Early reports referred to them as "gray coppers" or "fahlerz," and they were well known as a source of silver. The minerals of the series are cubic and the composition, showing possible substitutions, is $(Cu, Ag, Fe, Zn, Hg)_{12}$ $(As, Sb, Bi, Te)_4$ $(S, Se)_{13}$. Tennantite with the composition $Cu_{12}As_4S_{13}$ has a cell edge of 10.20 Å. Substitution of iron and zinc probably does not increase the unit-cell size; but substitution of silver and mercury for copper, of antimony, bismuth, and tellurium for arsenic, and of selenium for sulfur increases the size of the unit cell, which reaches 10.88 Å in hakite $(Cu_{2.65}Hg_{0.45})(Sb_{0.95}As_{0.06})(Se_{3.09})$ (Johan and Kracek, 1971). Antimony can completely replace arsenic. The cell edge of pure tetrahedrite $(Cu_{12}Sb_4S_{13})$ is variously reported as 10.34 (Indolev and others, 1971) to 10.3908 (Wuensch, 1963). According to Riley (1974), tetrahedrite from Mt. Isa, Queensland, contains as much as 42.5 percent silver. However, cell size reaches a maximum at 10.56 Å with 20-22 percent silver, and further increase in silver is reflected by a slight decrease in cell size. High-silver tetrahedrite is commonly called freibergite, but that term is properly restricted to tetrahedrite having Ag as the dominant atom in the sites usually occupied by copper.

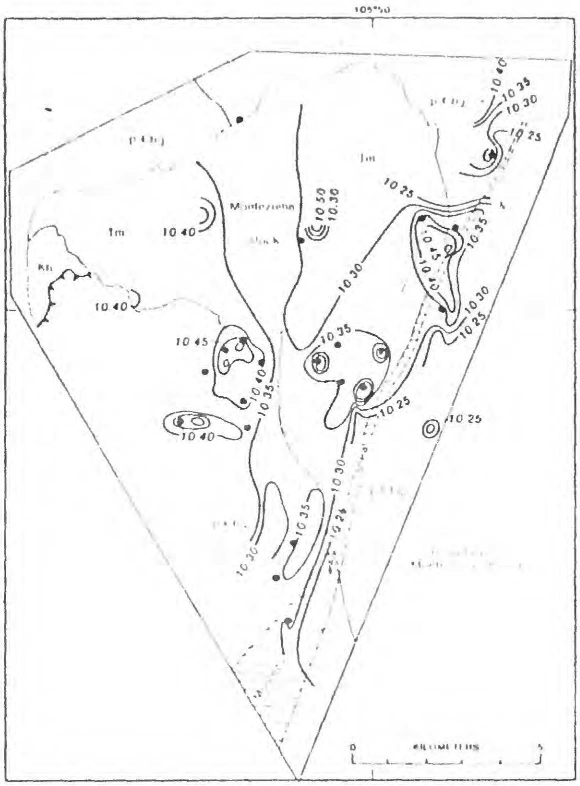

Figure 4. Contour map showing distribution of unit cell sizes (in Å) of tennantite-tetrahedrite in relation to major mines in the Montezuma district. Contour interval 0.05 Å.

Unit-cell edges were measured on about 150 samples of tennantite-tetrahedrite from the Montezuma district, wherever sufficient material existed to get a reasonably pure sample for X-ray diffraction. Film patterns taken in a 114.6-mm Philips powder camera were measured to the nearest 0.1 degree and _a_ was caluculated for each line. The median value of _a_ was selected as the cell edge for that sample. Several samples were measured from some localities; and, in a few cases, samples from the same locality had a wide range of unit-cell sizes. These may represent samples from different veins or from widely different parts of the same vein.

In the Montezuma district, cell edges of tennantite-tetrahedrite range from 10.20 Å to 10.53 Å. Mercury, selenium, and tellurium are quite scarce in the district, bismuth is only locally abundant, and it may be assumed that the larger unit-cell sizes represent extensive silver and antimony substitutions.

The cell-edge value for tennantite-tetrahedrite at each locality was plotted on a map, and contours were drawn to show the distribution of these values (Fig. 4). Also shown are the locations of mines in the district that have a published record of production of more than 150 kg of silver.

High values of cell edges occur along the south and east edges of the Montezuma stock. The more productive mines, as shown, are closely related to these highs, although few are actually located on the highs. In the Hall Valley area to the south, a large but relatively gentle high is associated with the three most productive mines in the southern part of the district. This southern area is characterized by the occurrence of enargite and may be an arsenic-rich area. The high cell edges here may represent high-silver tennantites.

Gangue minerals

Quartz, barite, and carbonate minerals form the gangue in the veins in the Montezuma district. Quartz is present in abundance in nearly all the veins. Barite, which occurs as coarse tablets and masses with quartz and sulfides, is somewhat more abundant to the northeast and to the south of the stock than at its contacts. The carbonate minerals occur as medium-grained masses and are, for the most part, intermediate members of the Fe-Mn carbonate series. Pure siderite or rhodochrosite is rare. Barite and the carbonate minerals show similar distribution patterns, although they differ in detail.

Minor minerals of the ores

Although the ores of the Montezuma district are dominantly galena, sphalerite, pyrite, and tennantite-tetrahedrite, a large variety of unusual sulfides and sulfosalts occurs in the area.

Alabandite, MnS, was reported in 1887 from the Queen of the West Mine in Horseshoe Basin area (Lovering, 1935, p. 53); alabandite was not found at the probable location of this mine but was found in samples from a small mine in Hall Valley. It occurs with galena, sphalerite, chalcopyrite, pyrite and rhodochrosite, and is veined by sulfur.

Acanthite, Ag_2S, the low-temperature form of argentite, was found in very small amounts in a number of mines, mostly those containing silver sulfosalts.

There are a number of bismuth sulfosalts of lead, copper, and silver that have similar physical characterisitics and similar structure. They occur initimately mixed with other sulfosalts and sulfides and may represent unmixing of high-temperature solid solutions. Of these, aikinite, $PbCuBiS_3$; berryite, $Pb_2(Cu,Ag)_3Bi_5S_{11}$; galenobismutite, $PbBi_2S_4$; hammarite, $Pb_2Cu_2Bi_4S_9$(?); lillianite, $Pb_3Bi_2S_6$; and schirmerite, have been identified from the Montezuma district by their X-ray powder patterns.

The type locality for cuprobismutite is the Missouri mine in Hall Valley (Fig. 1). Originally described by Hillebrand (1884), this mineral was later discredited by Palache (1940). It was reestablished by Nuffield (1952), who found it associated with wolframite, $(Fe, Mn)WO_4$, emplectite, $CuBiS_2$, aikinite, tetrahedrite, and bismuthinite, Bi_2S_3.

The type locality for schirmerite is the Treasury mine, Geneva district, Park County, Colorado (Genth, 1874). This mine is probably on Collier Mountain but the locality could not be identified. (Samples from the Treasury Vault mine studied by Genth (1885) are not schirmerite.) Genth's analyses calculate as $PbS \cdot 2Ag_2S \cdot 2Bi_2S_3$. Karup-Møller (1973) studied material from the Treasury mine via the Smithsonian Institution, the Royal Ontario Museum, and the University of Heidelberg and identified as schirmerite a mineral with the composition $4PbS \cdot Ag_2S \cdot 3Bi_2S_3$. Beegerite was described as $6PbS \cdot Bi_2S_3$ by Koenig (1881) from the samples from the Baltic Lode on Revenue Mountain; the mine locality was easily found, but beegerite has not been identified in the samples from this area. Some mineralogists suppose that beegerite is a bismuth-bearing galena or a galena containing inclusions of a bismuth mineral. Material with an X-ray powder pattern matching that of bonchevite of Kupcik and others (1969) was found in Geneva cirque; however, the pattern does not match that of bonchevite originally described by Kostov (1958) as $PbBi_4S_7$. Lillianite, $Pb_3Bi_2S_6$, was identified in samples collected by Paul K. Theobald, U.S. Geological Survey, from the Roberts Tunnel access shaft. Matildite, $AgBiS_2$, was found intimately associated with galena in a number of localities. It was detected for the most part as matildite lines in powder patterns of galena, and matildite may be the site of a large part of the silver in the galena. Kosnar and Miller (1976) described matildite crystals with quartz from Sullivan Mountain (Fig. 1).

The arsenic minerals arsenopyrite, FeAsS, and pearceite, $8\ (Ag,Cu)_2\ S \cdot As_2S_3$, occur sparsely in the northern part of the district. Enargite, Cu_3AsS_4, occurs in a number of mines in Hall Valley but was not found elsewhere in the district.

The silver sulfosalts polybasite, $8\ (Ag,Cu)_2S \cdot Sb_2S_3$, and pyrargyrite, $3\ Ag_2S \cdot Sb_2S_3$, were found in the ores of Glacier Mountain.

Sparse amounts of specular hematite, Fe_2O_3, were found in veins at a number of localities throughout the district (Neuerburg and others, 1971), but hematite is most frequently found in the northeast part of the area. It forms veins--in some cases with pyrite, but not with other sulfides.

The following minerals were found in only one or two occurrences: boulangerite, $Pb_5Sb_4S_{11}$, bournonite, $PbCuSbS_3$, bornite, Cu_5FeS_4, covellite, CuS, fizelyite (?), $Pb_5Ag_2Sb_8S_{18}$, geocronite (?), Pb_5SbAsS_8, jalpaite, Ag_3CuS_2, pavonite, $(Ag,Cu)(Bi,Pb)_3S_5$, semseyite, $Pb_5Sb_8S_{21}$, and stromeyerite, AgCuS. These were present, in most cases, only in sufficient amount for an X-ray powder pattern; and they were often admixed with other minerals. The only cobalt mineral found in the area was skutterudite, $(Co,Ni)\ As_{2-3}$, which was found in a single specimen from a prospect on the west side of Deer Creek.

Molybdenite, MoS_2, characteristically associated with Tertiary porphyry stocks, is found in the Montezuma area (Neuerburg and others, 1974). The occurrences were fine-grained disseminations in wall rocks. Large crystals (2.5 cm across) were found in vein samples from the Roberts Tunnel. Most molybdenites were the normal 2H polytype; one sample of sediments from Geneva Creek contained molybdenite that was a mixture of 2H and 3R polytypes.

Secondary minerals

Except for iron and manganese ochers, secondary minerals are scarce in the Montezuma district and are rarely found on the mine dumps. Jarosite, hinsdalite, and allied minerals are found in a few localities. The copper carbonates azurite and malachite are present in very small amounts associated with chalcopyrite and tetrahedrite. Anglesite, $PbSO_4$, and cerussite, $PbCO_3$, replace galena.

Ocher deposits (Neuerburg and others, 1976) occur widely in the Montezuma districts as small sinters and bedded deposits. They were derived from oxidation of the pyrite of hydrothermally altered rocks and of pyrite-rich veins, and are prominent in the cirques of Geneva Creek, Snake River, and Handcart Gulch. Manganese ochers occur in Morgan Gulch.

The use of ochers as a prospecting medium in this district has been discussed by Neuerburg and others (1976). Other secondary minerals are too scanty to be of use in prospecting.

Conclusions

The mineral abundance maps (Fig. 3) show where certain minerals occur in abundance in the veins. Comparison of these maps with the production map (Fig. 2) shows that the more productive mines occur in areas where galena and sphalerite are abundant not only in the larger minable deposits but also in the smaller deposits. These areas where galena and sphalerite are abundant in minor veins over an area of several grid cells are favorable areas for the occurrence of larger deposits.

In contrast, areas of highly pyritic veins are not related to the more productive mines, and these areas are thus unfavorable areas for prospecting for base metal-silver deposits in this district.

The relationship of productive veins to abundant barite and carbonate is not clearcut, but areas of high barite and carbonate minerals probably are generally favorable.

The relationship of the rare sulfosalts to the ore deposits is more complex. Bismuth sulfosalts may indicate the occurrence of molybdenum deposits (Neuerburg and others, 1974), and silver sulfosalts are notably associated with the productive mines on Glacier Mountain. There is a general suggestion that these rare minerals occur in areas where mineralization was intense.

Although the data for the tennantite-tetrahedrite unit-cell map (Fig. 4) were derived from samples from prospects as well as mines, and whether or not the cell edges of tennantite-tetrahedrite reliably indicate the silver content of members of the series, the larger mines are in most cases associated with cell-edge highs and all major highs have several of the larger mines associated with them. Thus, on the basis of their relation to known production, these highs are favorable areas for prospecting for silver deposits.

Three other highs are not associated with larger mines. These highs are (1) near the northwest corner of the district, (2) south-southeast of the latitude-longitude reference intersection of Figure 4, and (3) near the south-east edge of the district. Either these highs vitiate the otherwise good correlation of larger mines with highs, or they suggest the presence of favorable ground that has not been adequately explored.

References

Genth, F. A., 1874, On American bismuth and tellurium minerals, Amer. Phil. Soc., 14, p. 223-231.

_______, 1885, Contributions from the laboratory of the University of Pennsylvania, No. XXIV, Contributions to mineralogy, Amer. Phil. Soc., Proc., 23, p. 30-47.

Graeser, Stefan, 1971, Mineralogische-geochemische Untersuchungen an Bleiglanz and Zinkblende. Schweiz. Min. Pet. Mitt., 51, p. 415-442.

Hillebrand, W. F., 1884, A probably new mineral, Amer. Journ. Sci., 27, Third Series, p. 355-357.

Indolev, L. N., Nevoysa, G-G., and Bryzgalov, I. A., 1971, New data on the composition of stibnite (sic, tennantite-tetrahedrite) and the isomorphism of copper and silver. Doklady Acad. Sci., USSR, Earth Sci. Sect., 199, p. 115-118. Transl. from: Novyye danyye o sostave sur'myanykh bleklykh rud: izomorfizme medi serebra. Doklady Nkad. Nauk SSSR, 1971, 199, no. 5, p. 1146-1149.

Johan, Zdenek, and Kracek, Milan, 1971, La hakite, un nouveau minéral du groupe de la tetraédrite. Bull. Soc. Fran. Mineral. Cristallogr., 94, p. 45-48.

Karup-Møller, S., 1973, New data on schirmerite. Can. Mineral., 11, p. 952-957.

Koenig, G. A., 1881, On beegerite, a new mineral, Amer. Chem. Journ., 2, p. 379-382.

Kosnar, R. A., and Miller, H. W., 1976, Crystallized minerals of the Colorado Mineral Belt., Mineral. Record, 7, p. 278-307.

Kostov, Ivan, 1958, Bonchevite, Pb Bi_4Sb_7, a new mineral, Min. Mag., 31, p. 821-828.

Kupcik, V., Franc, L, and Mackovicky, E., 1969, Mineralogical data on a sulfosalt from the Rhodope Mountains, Bulgaria. Tschermaks Miner. u. Petrogr. Mitt., 13, p. 149-156.

Lovering, T. S., 1935, Geology and ore deposits of the Montezuma quadrangle, Colorado: U.S. Geological Survey Professional Paper 178.

Neuerburg, G. J., and Botinelly, Theodore, 1972, Map showing geologic and structural control of ore deposits, Montezuma district, central Colorado: U.S. Geological Survey Miscellaneous Investigation Map I-750.

Neuerburg, G. J., Botinelly, Theodore, and Kulp, R. E., 1971, The prospecting significance of hypogene iron oxide distributions in the Montezuma district central Colorado: Soc. Mining Engineers, Trans., 250, no. 2, p. 97-101.

Neuerburg, G. J., Botinelly, Theodore, and Watterson, J. R., 1974, Molybdenite in the Montezuma district of central Colorado: U.S. Geological Survey Circular 704.

_______, 1976, Ocher as a prospecting medium in the Montezuma district of central Colorado, Journal Research, U.S. Geological Survey, 4, p. 349-365.

Nuffield, E. W., 1952, Studies of mineral sulfosalts XVI-Cuprobismutite, Amer. Mineral., 37, p. 447-452.

Palache, Charles, 1940, Cuprobismutite--a mixture, American Mineral., 25, p. 611-613.

Riley, J. F., 1974, The tetrahedrite-freibergite series, with reference to the Mt Isa Pb-Zn-Ag orebody, Mineral. Dep., 9, p. 117-124.

Robinson, C. S., Warner, L. A., and Wahlstrom, E. E., 1974, General geology of the Harold D. Roberts Tunnel, Colorado: U.S. Geological Survey Professional Paper 831B.

Wuensch, B. J., 1963, Confirmation of the crystal structure of tetrahedrite, $Cu_{12}Sb_4S_{13}$, Science, 141, no. 3583, August 30.