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PRECAMBRIAN SULFIDE DEPOSITS IN THE GUNNISON REGION, COLORADO

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INTRODUCTION

Base-metal massive sulfide deposits are currently of considerable economic interest because they are characteristically high in grade. Such deposits are mined mainly for copper, zinc, and lead, but some also contain recoverable silver and gold. New exploration has been stimulated in many parts of the world by numerous studies during the last two decades concerning various syngenetic and exhalative processes of origin and the relation of stratabound sulfide deposits to certain types of host-rock lithology (King and Thompson, 1953; Horikoshi, 1969; Anderson, 1969; Matsukuma and Horikoshi, 1970; Sangster, 1972; Stanton, 1972; Hutchinson, 1973). Many massive sulfide deposits in various places in the world are now considered to be volcanogenic. Using the newer geologic concepts and newer, more refined guides to ore, mining companies have made some outstanding new discoveries, including, for example, the recent finding of two large Precambrian deposits: one containing more than 7 million tons* of zinc-copper-lead ore at Izok Lake in the Northwest Territories, Canada (Money and Heslop, 1976, p. 24–25), and another having 60 million tons of zinc-copper ore at Crandon, Wisconsin (Eyde, 1977, p. 51).

The search for minable Precambrian sulfide deposits has been extremely active in recent years in numerous areas in Colorado, New Mexico, and southern Wyoming. The initial stimulus for this renewal of interest likely was given by Giles' suggestion (1974) that a significant part of the Precambrian terrain in northern New Mexico and southern Colorado may be a "previously unrecognized volcanogenic massive sulfide metallogenic province." Data presented by Sheridan and Raymond (1977) indicated that representative samples from many long-ignored Precambrian sulfide deposits distributed throughout western Colorado are of a grade suggesting potential economic significance.

The present report is a brief description of the geology of Precambrian sulfide deposits in the Gunnison region, Colorado. In other reports in this guidebook, the Precambrian geology along parts of the Gunnison uplift is described by D. C. Hedlund and J. C. Olson, syngenetic sulfide mineralization in the Gunnison Gold Belt is described by P. A. Drobeck, and the stratigraphy, petrology, and structure of Precambrian metamorphic rocks in the Iris district are described by A. M. Afifi.

GEOLOGIC SETTING

Precambrian sulfide deposits occur in many localities in Colorado (Sheridan and Raymond, 1977) in metamorphic complexes about 1,800 million years in age (Tweto, 1980, p. 37), that is, Proterozoic X. The progenitors of these metamorphic rocks were sedimentary, volcanic, and subvolcanic intrusive rocks. The major period of Precambrian folding and regional metamorphism reached its peak in the period 1,700–1,775 m.y. ago, according to radiometric age determinations (Hedge and others, 1967; Hedge and others, 1968; Hansen and Peterman, 1968; Silver and Barker, 1968; Stern and others, 1971). Isotopic data (Hedge, 1969) indicate that no great amount of time elapsed between the original deposition and the time of metamorphism. Lead isotope studies on galena samples from Precambrian sulfide deposits in Colorado indicate an age in the same 1,700–1,800 m.y. bracket (Bruce Doe, oral communication, 1979). The age data and the metamorphic textures of the ore-bearing rocks indicate that the sulfide deposits were metamorphosed at the same time as their host rocks during the major regional metamorphism.

Metamorphism was markedly less intense in the Gunnison region than in most other areas in Colorado that contain Precambrian sulfide deposits. J. C. Olson and D. C. Hedlund (oral communications, 1977) noted that most of the Gunnison region is in the lower amphibolite facies, but locally in the western part the grade is somewhat higher where the rocks contain staurolite, kyanite, or andalusite. They noted also that in the eastern part of the region near Cochetopa Canyon the rocks are in the greenschist facies, and that original features such as pillows in metabasalts and shardlike textures in felsic metavolcanics are still recognizable. In contrast, such original textures and structures have been largely obliterated in the Park Range, Front Range, Wet Mountains, and much of the Salida region where Precambrian sulfide deposits and their host rocks were metamorphosed to the upper amphibolite facies, that is, the sillimanite zone of regional metamorphism (Sheridan and Raymond, 1977).

DISTRIBUTION OF DEPOSITS

Precambrian sulfide deposits in the Gunnison region are spatially related to a Precambrian greenstone belt, long known as "the Gunnison gold belt" (Lakes, 1896). This belt of metavolcanic rocks, the Dubois Greenstone, trends northeasterly from the Lake Fork of the Gunnison River for about 50 km and is as much as 10 km wide (fig. 1). Shown on the map are nine Precambrian sulfide deposits that were examined during brief reconnaissance studies in 1975 and 1977. Eight of these are within the belt of metavolcanic rocks, but one is in metasedimentary terrain.

In addition to the mines at these deposits, there are numerous other mines and prospects throughout the greenstone belt. Many of these are in what appear to be stratabound Precambrian sulfide deposits similar to those described in this report. Others are in veins. According to J. C. Olson and D. C. Hedlund (written communication, 1981), gold-bearing quartz-chlorite veins are Precambrian in age, whereas thorite-bearing veins are Cambrian in age.

HOST ROCKS

Most of the Precambrian sulfide deposits mentioned in this report are in host rocks of the Dubois Greenstone. As described by Hedlund and Olson (1975; written communication, 1981), the Dubois Greenstone consists principally of two groups of metavolcanic rocks: (1) hornblende schist and amphibolite that probably originated as basaltic and andesitic lavas; (2) felsite and felsite porphyry—felsic metavolcanic rocks that originated as flows and tuffs

*Figures cited from published sources are in the units originally reported.

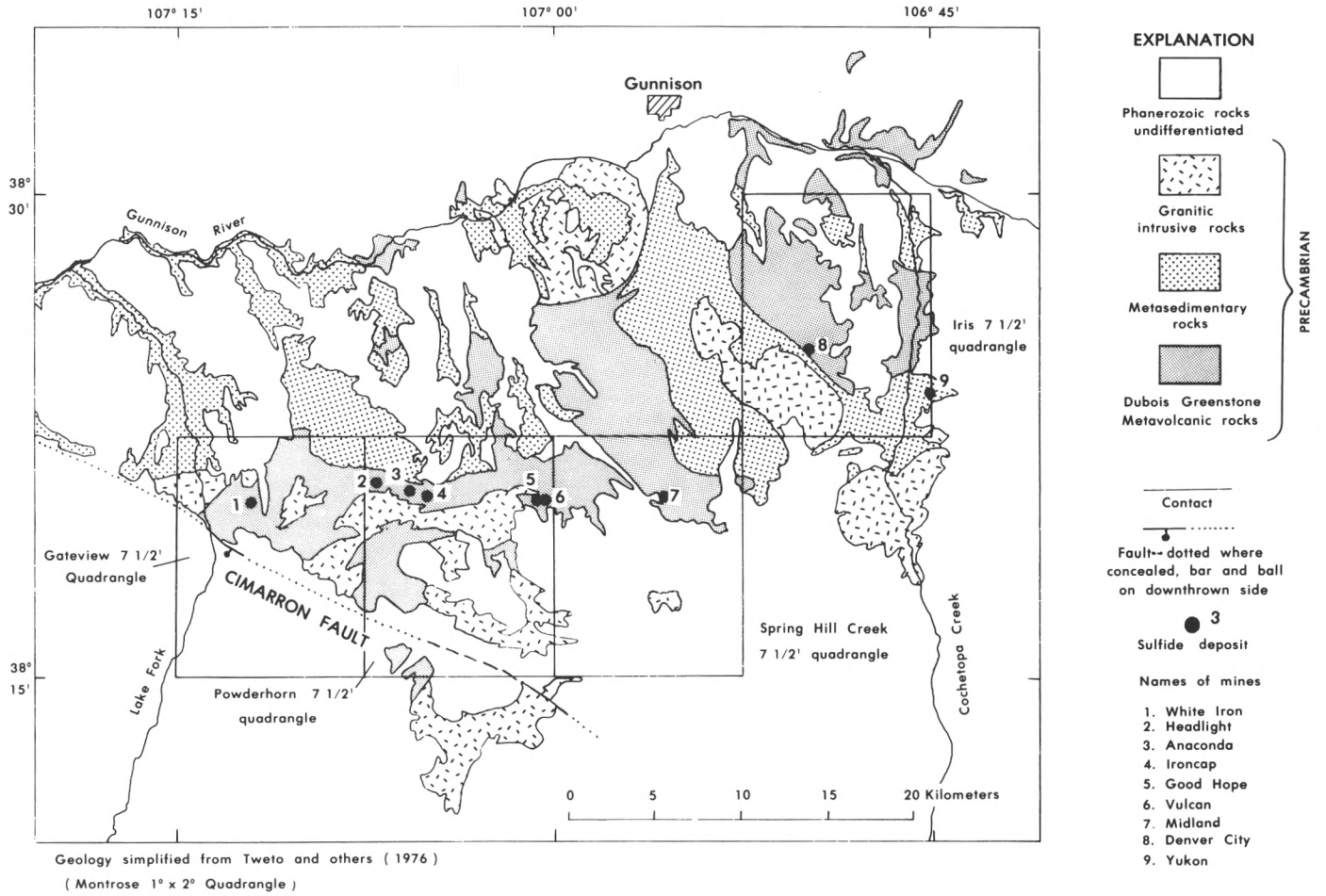


Figure 1. Distribution of Precambrian sulfide deposits in the Gunnison region, southwestern Colorado.

of rhyolite, quartz latite, and dacite. Intercalated with these are numerous beds of purplish-gray to gray, magnetite-bearing quartzite, commonly 2 to 7 m thick, that are inferred to have originated as sea-floor chert beds. Within the Dubois Greenstone in some areas are diverse metamorphosed epiclastic and pyroclastic rocks. In most places the foliation is approximately parallel to the lithologic layering.

The White Iron mine (fig. 1, no. 1) is in hornblende schist and amphibolite. The mine, although not designated by name on the geologic map of the Gateview quadrangle (Olson and Hedlund, 1973), is in the SW¼ sec. 10, T. 47 N., R. 3 W.

The geologic setting of the five mines in the Dubois Greenstone in the Powderhorn quadrangle (fig. 1, nos. 2–6) is delineated in greater detail on the geologic map by Hedlund and Olson (1975). The Headlight mine (fig. 1, no. 2) is in felsite and felsite prophyry near a contact with hornblende schist and amphibolite. Southeast of the mine, a lens of quartzite is along the contact. Westward from the mine, the unit of felsic metavolcanic rocks contains interlayered aluminous metasedimentary beds (Olson and Hedlund, 1973). The Anaconda mine (fig. 1, no. 3) is in hornblende schist, amphibolite, and a bed of quartzite. The Ironcap mine (fig. 1, no. 4) is in hornblende schist and amphibolite, and nearby are numerous beds of quartzite. Drobeck (1979, p. 103, 105) also noted abundant carbonate (marble) in the vicinity of the Ironcap mine. The Good Hope and Vulcan mines (fig. 1, nos. 5 and 6) are in the map unit of felsite and felsite porphyry, and nearby are thin lenses and layers of hornblende schist, amphibolite, and magnetite-bearing quartzite. The host rocks within about a kilometer of the Good Hope and Vulcan mines are considerably more schistose than elsewhere, and contain abundant fine muscovite and chlorite.

The geologic setting of the Midland mine (fig. 1, no. 7) is delineated in greater detail by Olson and others (1975) on their geologic map of the Spring Hill Creek quadrangle. The mine is in a bed of magnetite-bearing quartzite (metachert) within amphibole schist.

The geologic setting of the two mines shown in the Iris quadrangle on Figure 1 is delineated in greater detail by Olson (1976) on his geologic map of that quadrangle. The Denver City mine (fig. 1, no. 8) is in a unit of felsite and felsite porphyry. Nearby are elongate bodies of amphibolite and a few beds of magentite-bearing quartzite. About 1.8 km northeast of the mine is a volcanic breccia in a unit of lapilli tuff and crystal-lithic tuff. The Yukon mine (fig. 1, no. 9) is in terrain that is largely metasedimentary phyllite and schist.

SULFIDE DEPOSITS

General Character

The Precambrian sulfide deposits in the metavolcanic belt are stratabound and are elongate parallel to gradational and interfingering contacts between mafic and felsic metavolcanic rocks. Groups of deposits, such as those in the Powderhorn quadrangle, appear to be strung out parallel to the major contacts and to the abundant thin beds of magnetite-bearing quartzite. Some of the deposits are in or adjacent to a quartzite bed. The sulfides com-

monly are in laminae and elongate aggregates parallel to lithologic layering and foliation. Some specimens of ore are crudely banded. The sulfides are generally fine grained (less than 1 mm), but locally are medium grained (1–5 mm).

At some of the deposits, the ores consist mainly of base-metal sulfides alone or in a pyrite- or arsenopyrite-rich matrix. This type of ore is truly "massive sulfide," as defined by Sangster (1972, p. 11). Other deposits contain ores of a disseminated type, characterized by concentrations of base-metal sulfides in a matrix rich in silicate minerals. Locally, as at the Anaconda and Headlight mines, some of the ore is characterized by small rounded to angular fragments of rock enclosed in a matrix of sulfides. Whether this is a conglomerate or a fragmental rock of some other origin has not yet been determined.

The geology at the Vulcan and Good Hope mines differs from the geology at other deposits because a younger mineralizing event has been superimposed on the Precambrian sulfide deposits there. Modifications include the introduction of abundant tellurium and the formation of native sulfur. Abundant selenium is present also, some of which may have been redistributed from the Precambrian deposits.

Mineralogy and Texture

The principal sulfide minerals in the Precambrian deposits of the Gunnison region are sphalerite, chalcopyrite, pyrite, arsenopyrite, and galena. The predominance of one, two, or three of these major minerals, with or without abundant magnetite, characterizes each deposit. At the White Iron mine (fig. 1, no. 1) arsenopyrite is the principal sulfide. The Headlight mine (fig. 1, no. 2) in the western half of the Powderhorn quadrangle is characterized by assemblages of chalcopyrite, arsenopyrite, and sphalerite. The Anaconda mine (fig. 1, no. 3) is characterized by pyrite with minor sphalerite, and the Ironcap mine (fig. 1 no. 4) by chalcopyrite with minor pyrite. At the Vulcan district in the eastern half of the quadrangle, crudely banded pyrite and sphalerite are the predominant sulfides of the Good Hope and Vulcan mines (fig. 1, nos. 5 and 6). The gold-bearing deposit at the Midland mine (fig. 1, no. 7) is characterized by abundant pyrite and magnetite, whereas base-metal sulfides are present only in trace amounts. In the Iris quadrangle, the Denver City and Yukon mines (fig. 1, nos. 8 and 9) are characterized by sphalerite with lesser chalcopyrite and galena.

Metallic minerals occurring in minor to trace amounts with the principal sulfides include pyrrhotite, marcasite, tennantite, berthierite, molybdenite, ilmenite, magnetite, hematite, rutile, gahnite, and gassiterite(?). Native gold and native silver were not observed. Of the major and minor phases, sphalerite, chalcopyrite, pyrite, arsenopyrite, pyrrhotite, marcasite, ilmenite, and magnetite are found at nearly every deposit. The proportions of these minerals vary widely. A mineral predominant at one deposit may be present only in trace amounts at another. The metallic oxides are found in both ore and host rocks. The zinc spinel, gahnite, is intermixed with sphalerite and chalcopyrite as well as with quartz-biotite-tourmaline gangue at the Headlight mine. The interest in the occurrence of gahnite lies in its potential as a prospecting guide to Precambrian sulfide deposits (Sheridan and Raymond, 1977). A green spinel was observed by D. C. Hedlund (oral communication, 1978) in outcrops of schist about 1.6 km west of the Headlight mine.

Gangue minerals vary in accordance with the host rock of each deposit. Quartz, biotite, and chlorite are nearly ubiquitous. Other gangue minerals include sericite, muscovite, tourmaline, calcite, epidote, hornblende, plagioclase, microcline, orthoclase, apatite, sphene, and zircon. Tourmaline commonly is intermixed with sphalerite-rich ores. Some of the sphalerite at the Headlight mine is poikilitic with tourmaline inclusions.

Secondary minerals at the various deposits include marcasite, scorodite, pyrite overgrowths, malachite, covellite, cuprite, idaite, chalcocite, aurichalcite, and hydrozincite.

In the Vulcan district, a variety of tellurides and other minerals are associated with a younger mineralizing event. The Good Hope mine is the type locality of three copper tellurides: rickardite and weissite (Eckel, 1961) and vulcanite (Cameron and Threadgold, 1961). Coloradoite, petzite, tellurite, native tellurium, tetradymite(?), native selenium, native copper, native sulfur (Eckel, 1961), and tellurobismuthite are also found at the Good Hope. The tellurobismuthite occurs as myrmekites within galena interstitial to the edge of larger pyrite grains and gangue. The textures exhibited by the tellurium-bearing minerals would have been destroyed by metamorphism, thus indicating a younger mineralization than the metamorphosed host sulfides.

The parallelism of sulfides to foliation and layering reflects to a large part the original compositional layering. Some of the layered sulfides ores are massive and others are disseminated. In massive layers, only a small percentage is gangue. The gangue minerals within the sulfide ores are the same as those in the host rocks, but have a tendency to be nonfoliated when intermixed with the larger percentages of sulfides in recrystallized assemblages with annealed 120° triple junctions. Grains in the sulfide-rich ore are slightly coarser (2–3 mm across) than are sulfide grains elsewhere. Distinct alternating pyrite-rich and sphalerite-rich layers may be 1 cm thick. Disseminated sulfides are interstitial to quartz in silica-rich bands in the foliated micaceous rocks. In places, sulfide minerals have migrated to noses of folds and pyrite laminae have been boudinaged.

The mineral textures that indicate that the sulfide deposits and host rocks underwent metamorphism simultaneously, include grain size and annealing of intermixed grains of gangue and sulfide, layering, exsolved phases, and poikilitic textures. Examples of equilibration include the coarse grains of sphalerite that contain minute (less than 10 microns) exsolved blebs of chalcopyrite, some of which are crystallographically oriented. Also, coarse grains of all the major sulfides commonly contain rounded inclusions of the other sulfide minerals with which they are intermixed.

Grade

The base-metal and precious-metal contents of samples of ore from the five mines in the Powderhorn quadrangle and from the two mines in the Iris quadrangle are summarized, respectively, in Tables 1 and 2. In ores from both quadrangles the principal base metal is zinc, followed in abundance by copper and a minor amount of lead. Silver occurs in appreciable amounts in most of the ores and is accompanied by a minor but noteworthy amount of gold.

The gold content of two samples from the Midland mine (fig. 1) ranges from 1.76 to 33.9 grams/metric ton*. Unlike the other mines summarized above, however, the base-metal content of the ore at the Midland mine is extremely low. The deposit consists of abundant pyrite in a magnetite-bearing quartzite.

In addition to base and precious metals, the Precambrian ores of the Gunnison region are characterized by abundant iron, generally greater than 10 percent. Ores at the White Iron, Denver City, Yukon, and Headlight mines are characterized by high arsenic with amounts ranging from 3 to more than 10 percent.

*Analyses by fire assay and atomic absorption methods by J. G. Crock, A. W. Haubert, and Joseph Haffty, U.S. Geological Survey.

Table 1. Analyses of Precambrian ores from the Powderhorn quadrangle

	5 samples from dumps of 5 mines[1]	
	Range	Average
Copper (percent)	0.07–7.0	2.3
Zinc (percent)	.1–>10	>6
Lead (percent)	0–0.3	0.13
Silver (grams/metric ton)	3–70	30
Gold (grams/metric ton)	0.13–2.11	0.71

Data for copper, zinc, lead, and silver from semiquantitative spectrographic analyses by N. M. Conklin, U.S. Geological Survey; data for gold from analyses by fire assay and atomic absorption methods by J. G. Crock, A. W. Haubert, and Joseph Haffty, U.S. Geological Survey.

[1]One sample from each of the following mines shown by name on the geologic map of the Powderhorn quadrangle (Hedlund and Olson, 1975): Headlight, Anaconda, Ironcap, Good Hope, and Vulcan mines.

Table 2. Analyses of Precambrian ores from the Iris quadrangle

	6 samples from dumps of 2 mines[1]	
	Range	Average
Copper (percent)	0.7–>10	>4
Zinc (percent)	0.7–>10	>6
Lead (percent)	0.1–1.5	0.7
Silver (grams/metric ton)	15–150	60
Gold (grams/metric ton)	0.29–4.17	1.76

Data for copper, zinc, lead, and silver from semiquantitative spectrographic analyses by L. A. Bradley, U.S. Geological Survey; data for gold from analyses by fire assay and atomic absorption methods by J. G. Crock, A. W. Haubert, and Joseph Haffty, U.S. Geological Survey.

[1]Four samples from the Denver City mine and two samples from the Yukon mine. Both mines are shown by name on the geologic map of the Iris quadrangle (Olson, 1976).

Genesis

As a result of their detailed mapping in the Gunnison region, J. C. Olson and D. C. Hedlund concluded that the gold deposits are "spatially and probably genetically related to a belt of Precambrian metavolcanic rocks" (U.S. Geological Survey, 1970, p. A3). They noted that the discordant veins and the stratabound sulfide deposits that have been mined or prospected for gold are related to a Precambrian greenstone belt and also are considered to be Precambrian in age. The Precambrian terrain of southern Colorado was included with that of northern New Mexico by Giles (1974) in his suggestion that this terrain may be a previously unrecognized volcanogenic massive sulfide metallogenic province.

During reconnaissance studies of Precambrian sulfide deposits in the Gunnison Gold Belt, D. M. Sheridan and W. H. Raymond observed features that suggest strongly that many of the deposits are volcanogenic (U.S. Geological Survey, 1977, p. 6). These features are summarized as follows: (1) location of most of the known deposits within the metavolcanic belt, which comprises a significant part of the region; (2) elongate stratabound deposits parallel to gradational and interfingering contacts between mafic and felsic metavolcanic rocks; (3) apparent stringing out of groups of deposits parallel to major contacts and to beds of magnetite-bearing quartzite (metachert); (4) common occurrence of sulfides as laminae and elongate aggregates parallel to lithologic layering and foliation; and (5) crude banding in some of the ores. These features are believed to be significantly similar to features displayed by sulfide deposits now considered to be volcanogenic in numerous other greenstone belts throughout the world. The sulfide deposits probably formed syngenetically during deposition of the volcanic rocks and later recrystallized at the same time as their host rocks during regional metamorphism.

In considering the Gunnison gold belt, Giles (1976) also supported the general theory that the metals originated approximately contemporaneously with their host rocks, but his ideas differ slightly from those presented above. Giles (1976, p. 129–130) thought that the genetic model developed by Rye and Rye (1974) for the Homestake deposit in South Dakota could also apply to the Gunnison belt. By this model, the gold and other metals are considered to be indigenous to the volcanics and probably volcanogenic exhalative in origin. Giles proposed that the actual deposits were formed later during regional metamorphism when the "syngenetic components migrated and concentrated in dilatant zones." Although Giles' proposal is appealing, it may apply more to the quartz-rich pods and quartz veins associated with some of the deposits than to the sulfide deposits themselves.

Economic Potential

We believe that the Gunnison belt of metavolcanic rocks has considerable potential for the discovery of minable Precambrian sulfide deposits, although a limited amount of exploration in the mid-1970's was generally disappointing. Factors considered favorable to the economic potential are: (1) the belt is moderately large in size; (2) the geologic setting is favorable and is comparable to the settings in many known mining districts in greenstone belts; (3) the geologic evidence is compelling that the deposits are volcanogenic; (4) ores of noteworthy grade have been observed both on mine dumps and in drill cores. Also, the presence of clusters of old mines and prospects in various places in the belt is significant, because massive sulfide deposits are known to occur in clusters in many productive mining regions of the world (Sangster and Scott, 1976, p. 173; Solomon, 1976, p. 35).

Drilling efforts in 1975 and 1976 by two mining companies were interpreted as showing that several of the deposits are of insufficient size to mount a major mining effort, even though the ores intersected are high in grade. Interest shown by mining companies in this region has continued.

Search for larger concealed deposits could be continued in various parts of the belt, both in areas where deposits are clustered and in areas extending laterally from such clusters. The geochemical patterns found to be most useful in mineral exploration in this region have been described by Drobeck (1979, p. 149–153). Considering the location of some of the presently known deposits, favorable areas for search might be along contacts between felsic and mafic metavolcanics and along the thin layers of metachert. As noted by Sangster (1972, p. 3) the presence of so-called "millrock" (pyroclastic breccias) may prove useful in prospecting for areas in which massive sulfide deposits are likely to occur. Solomon (1976, p. 30) noted, however, that many deposits are found in areas not having such coarse-grained volcanic rocks. The fact that the Yukon mine is in metasedimentary terrain indicates that the search need not be limited to the metavolcanic rocks.

Consideration should be given to the possibility that the original (presumably tabular or discoidal) shapes of the deposits may have been modified considerably by folding during regional metamorphism. During the reconnaissance studies forming the basis of this report and during subsequent examination of samples of host

rocks and ores, several examples of tight folding were noted. More recently, detailed mapping by Drobeck (1979, p. 24, 113) in the western part of the Gunnison gold best has shown the presence of closely spaced, tight to isoclinal folds. Also, a tight syncline in the Iris area in the eastern part of the belt has been described by Afifi (1980; this guidebook). Conceivably, some or all of the deposits may have been modified to rod-shaped lenses aligned parallel to the axes of folds. If this proves to be true, conventional geophysical methods geared to the search for tabular bodies may not be effective in disclosing the presence of rod-shaped lenses that are relatively thin in two dimensions but possibly great in down-plunge length. Exploration for concealed deposits having such form and for down-plunge continuations of exposed deposits might benefit from a search for fold axes and other B-lineations defining dominant plunge directions in the favorable areas being considered for exploration. Utilization of such information, as well as consideration of the possible effects of shearing in some areas, could be significant in determining the extent and size of ore bodies.

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