

## Geology of the Gibraltar Copper-Molybdenite Deposit, East-Central British Columbia (93B/9)

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**KEYWORDS:** Gibraltar Mine, Granite Mountain Batholith, copper-molybdenite deposit.

### INTRODUCTION

During its 25 years of production from 1972 to 1998, the Gibraltar Cu-Mo mine in east-central British Columbia (Figure 1) milled a total of 324 million tons of ore containing an average 0.351% Cu from four open pits. Fieldwork during 2000 involved just over two weeks of detailed pit mapping at the mine. Results of this work and several earlier intervals of pit mapping conducted in 1998 and 1999 are summarized below. This detailed examination of the deposit followed an evaluation of its regional geological setting in 1998 (Ash *et al.*, 1999a, b) which built on early work by Panteleyev (1977 and unpublished data).

This paper documents controls copper and molybdenite mineralization at the Gibraltar mine. Detailed results of recently obtained isotopic ages for magmatism (U-Pb), mineralization (Re-Os), and alteration (Ar-Ar), as well as a detailed analysis of structural data will be presented elsewhere (Ash *et al.*, in preparation).

### PREVIOUS WORK

Initial published descriptions of the Gibraltar Mine geology and related mineralization (Sutherland Brown, 1966; Eastwood, 1970) occurred during the period of increased exploration preceding mine development. Simpson (1970) described the mineralogical and textural character of host plutonic rocks in the mine area. Publications detailing deposit geology during the active mine life include those of Drummond *et al.* (1973, 1976), Sutherland-Brown (1974) and Bysouth *et al.* (1995). Recently, Raffel (1999) completed a study of element mobility associated with a localized hydrothermally altered shear zone at the Gibraltar and Pollyanna pits.

### GEOLOGICAL SETTING

The Gibraltar Cu-Mo deposit is hosted within the Granite Mountain Batholith. This is a Late Triassic ( $215 \pm 0.8$  Ma; Ash *et al.*, in preparation), medium to very coarse-grained quartz diorite to tonalite intrusion that has been variably deformed, metamorphosed and hydrothermally altered. Primary compositional and textural changes are mappable within the batholith (Figure 2). These are indicated by a progressive increase northward across the batholith in quartz content (15-20% to 35-40%) and grain size (2-3mm up to 1 cm), accompanied by a reduction in the mafic mineral content (35 to 10%) (Figure 2). A late, volumetrically minor leucocratic dike phase with minimal mafic minerals (1-2%) intrudes the batholith in the mine area.

Primary contact relationships of the batholith with surrounding lithologies are poorly constrained. To the east and west it is most likely bordered by faults which juxtapose it with Late Paleozoic oceanic Cache Creek rocks. These rocks consist of disrupted chert argillite deposits that range from broken formation to mélange with blocks or lenses of limestone and mafic basalt. Eight samples of chert from several variants of the chert-argillite unit were processed and evaluated for radiolarians, but were unproductive due thermal recrystallization (Fabrice Cordey, personal communication, 1999). Samples from

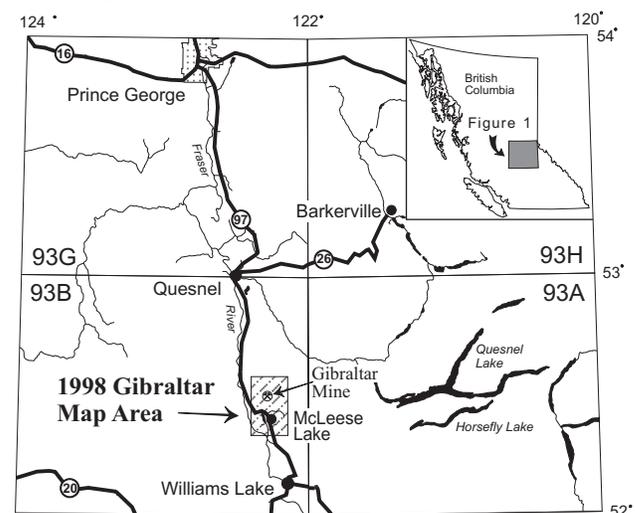


Figure 1. Location of the Gibraltar map area.

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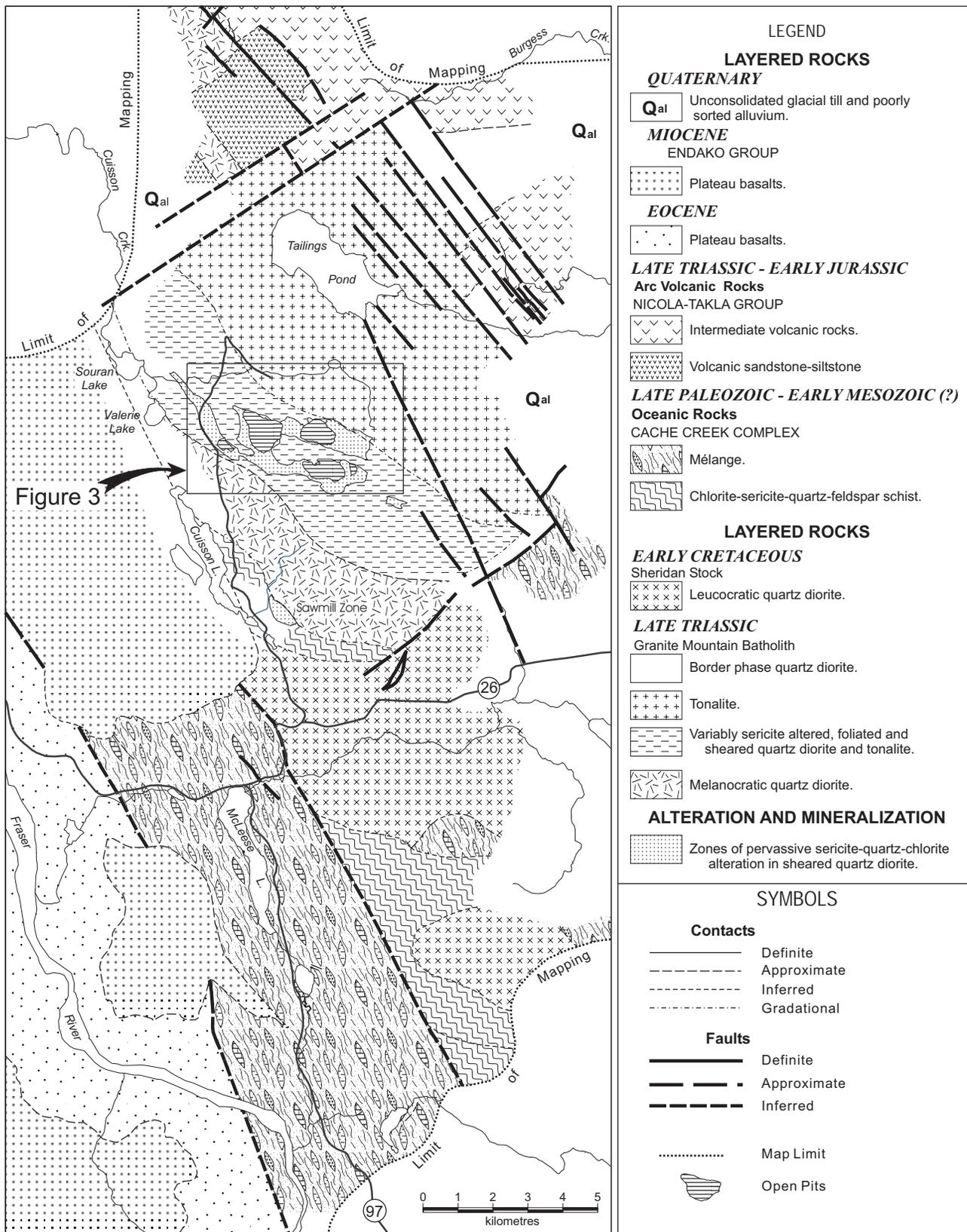


Figure 2. Regional geological setting of the Gibraltar mine (modified after Ash *et al.*, 1999).

three limestone blocks in Cache Creek mélange were examined for conodonts but no diagnostic fauna were identified (Orchard, 2000).

The southern margin of the batholith is in part faulted against and in part separated from the Late Cretaceous Sheridan stock along a broad, low-angle, north-dipping shear zone. The Sheridan stock is a  $108.1 \pm 0.6$  Ma (Ash *et al.*, in preparation) medium-grained, massive to locally strongly foliated, predominantly leucocratic quartz diorite. The shear zone is dominated by chlorite-rich schists with mylonitic fabrics that are locally well developed. A characteristic feature of this unit is veining from several centimetres up to a metre in thickness, consisting of quartz, chlorite, carbonate or epidote, or some combination of these minerals. Protoliths are interpreted to include both melanocratic phases of the Granite Mountain Batholith and most likely basaltic volcanics from the Cache Creek terrane.

To the north, the pluton is juxtaposed against a variably deformed succession of epiclastic and volcanoclastic rocks (Figure 2). These have been interpreted as Quesnellia, arc-derived clastic rocks and correlated with

the latest Early Jurassic Hall Formation (Wheeler and McFeely, 1991). The nature of the contact is unknown.

## GIBRALTAR MINE GEOLOGY

The geology of the Gibraltar mine is exposed in four open pits that include Gibraltar West, Gibraltar East, Pollyanna and Granite Lake (Figure 3). These all occur between 900 and 1200 metres elevation (above sea level) on the west-facing slope of Granite Mountain and extend from 100 to 300 metres below the surface, the deepest being Gibraltar East.

Pit mapping, conducted at 1:2000 scale was limited by an inability to safely access the majority of the pit walls. Mapping focused mainly on the western and northwest wall of the Gibraltar East pit where the haulage road provided access to a large vertical and lateral section. Conveniently, it is oriented at a high angle to the dominant northwest-trending structural fabric and is also centered on a section of high-grade Cu ore. Mapping was also conducted in lesser detail throughout safely accessible areas of the Pollyanna and Gibraltar West pits. The Granite

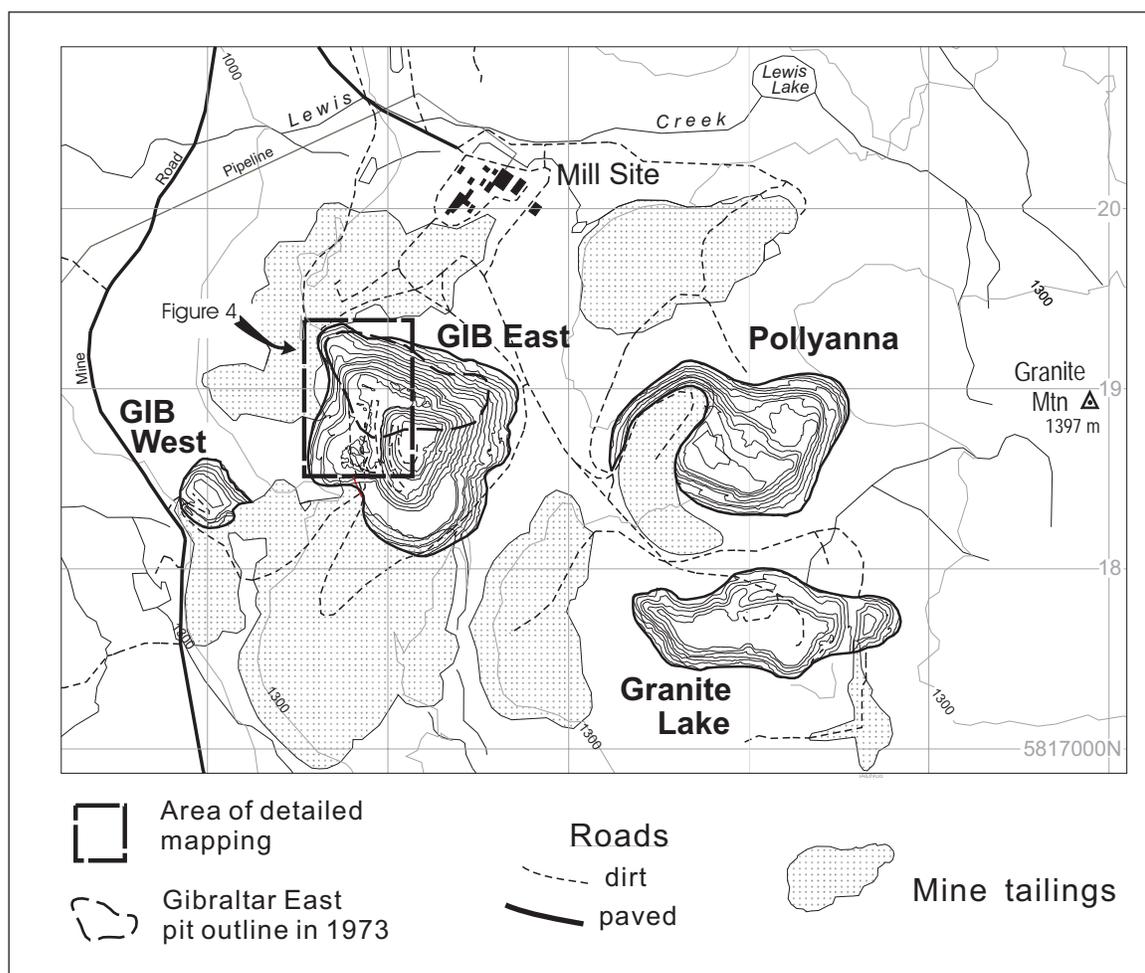


Figure 3. Detailed location map of the Gibraltar Mine area.

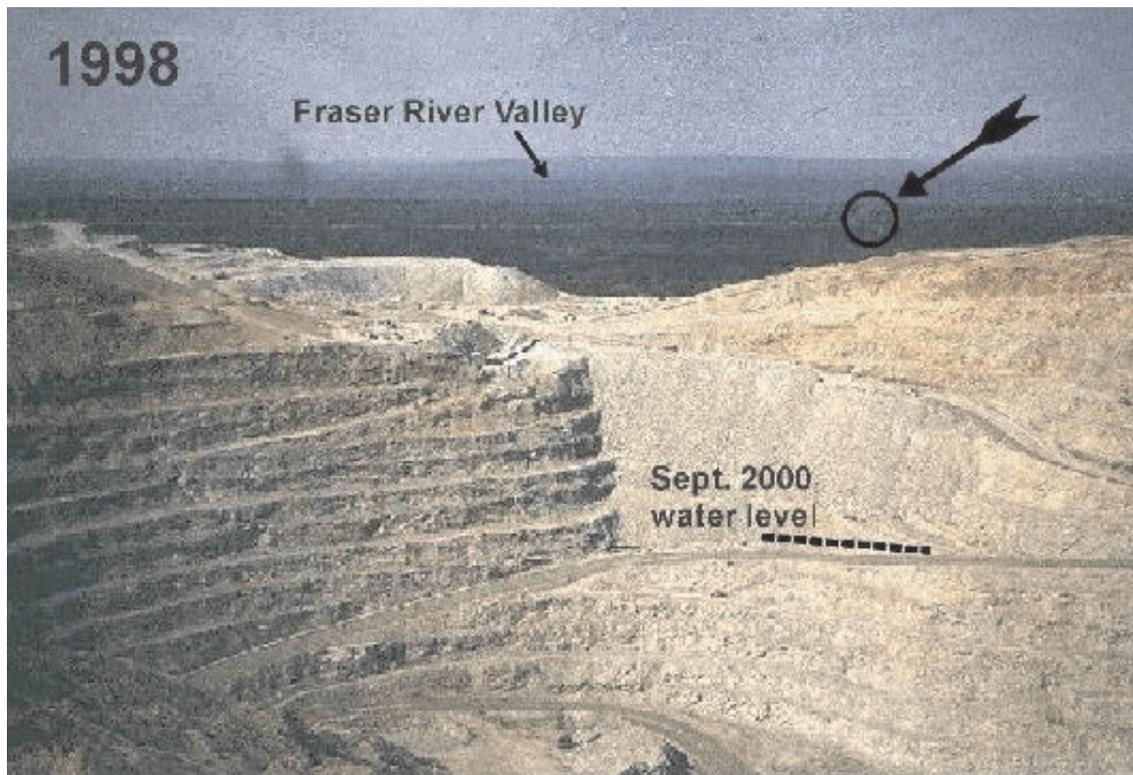


Photo 1. View of the Gibraltar East pit, looking west just prior to mine closure on the 2640 ft bench level in 1998 (top photo) compared to mining a year after start-up on the 3365 ft bench level in 1973 (bottom photo, Plate IV of Sutherland Brown, 1974). Circled area in background gives an idea of relative scale and position of the individual photos. Position of the pit in 1973 relative to that of the current pit outline is illustrated in Figure 3.

Lake pit was not mapped during this study. In many instances the other areas examined are either vertically or laterally restrictive but provided sufficient information to characterize mine scale relationships. Mapping and sampling of this pit was timely as pumping of water into it from the tailings pond was started in February, 1999, and deeper levels are becoming progressively flooded. As this was the initial startup pit in 1972 and also where mining ended in 1998 (Photo 1), significant superficial variation in the appearance of similar rock units has resulted from varying periods of surface oxidation, which diminishes with pit depth.

The four pits lie in a zone of pervasively greenschist metamorphosed, variably hydrothermally altered and veined, deformed and recrystallized tonalite referred to as the 'mine phase tonalite' (Bysouth *et al.*, 1995). Where undeformed it is medium to coarse-grained, equigranular rock (Photo 2) and displays a relatively uniform grain size and mineralogical composition throughout the mine area. All primary minerals excluding quartz, are partially to completely replaced by alteration assemblages reflecting greenschist grade metamorphism which is characteristic of the batholith as a whole. It consists of 35-40% (relict) plagioclase, 25-30% quartz, 20-25% epidote and zoisite, 15-20% chlorite, 5-10% sericite and trace amounts of sphene, zircon, apatite, iron oxides, carbonate and  $\pm$  sulphides. Weathered surfaces are light grey to buff white and commonly display a distinctive splash of disseminated pistachio-green epidote.

## Map Units

Throughout the pit area variations in the appearance of the Mine Phase tonalite result from either differences in the style and type of veining or superimposed deformation and associated hydrothermal alteration. Veining is prevalent throughout the mine area and varies in type and intensity (vein density). In contrast, hydrothermally-altered and deformed rocks are restricted to discrete planar zones where the tonalite is converted to schists and phyllonites.

Three primary mappable variations of the Mine Phase tonalite are distinguished on the basis of vein morphology, structural style and alteration. These include from oldest to youngest (1) stockwork tonalite, (2) sheeted tonalite and (3) schistose tonalite. The early quartz stockwork tonalite is restricted in occurrence to the Pollyanna pit and has no visible mineralization. In contrast, the later types are prominent throughout the mine area and constitute the subdivision of individual mine units mapped in the Gibraltar East pit (Figures 4a, b). Sheeted tonalite includes two distinct types of prominent heterogeneously developed, sub-parallel planar vein sets that are designated as 'sheeted veins' and 'sheeted veinlets'. Both sheeted vein sets are locally cut by and deformed where marginal to later, hydrothermally altered, phyllosilicate-rich, high-strain zones. Two distinct ages of later high-strain schistose tonalite zones are recognized. An older sequence of several stacked, sub-horizontal, undulating zones is openly, upright folded against

a younger northwest trending sub-vertical zone of highly crenulated schistose rock (Figures 4a, b).

## STOCKWORK TONALITE

This earliest style of veined tonalite was identified only in the southwest wall of the Pollyanna pit. Stockwork tonalite is characterized by randomly oriented quartz stockwork veining in medium-grained massive tonalite (Photo 3a and b). Veins range from 0.5 to 1 centimetre in width and consist of fine-grained white quartz. Although in general the veining is random, it locally contains planar vein sets that dip at intermediate angles to the southwest (Photo 3c).

Dikes of white aphanitic to medium-grained tonalite from several centimetres to several tens of centimetres wide display multiple intrusive relationships with the quartz stockwork veins. Quartz veins are in places cut by the leucocratic tonalite dikes as illustrated in the bottom right portion of Photo 2a. In other areas quartz veins of similar character cut these tonalite dikes.

The leucocratic tonalite phase is best represented along the opposite, north wall of the Pollyanna pit where several large, 2 to 6 metre wide northeasterly dipping dikes intrude the more mafic host tonalite (Photos 4.a, b). The age of these dikes has been interpreted from U-Pb dating at  $212 \pm 0.4$  Ma (Ash *et al.*, in preparation) which is 2 to 3 million years younger than the magmatic age of the host batholith, at  $215 \pm 0.8$  Ma. On the basis of the multiple intrusive character and relative age relationships the stockwork veins are considered to be late syn-magmatic. Stockwork tonalite is affected by all subsequent styles of veined and/or deformed tonalite described below.

## SHEETED TONALITE

Sheeted tonalite is characterized by the presence of two distinct sub-parallel planar vein sets including both 'veins' and 'veinlets'. Both are generally openly S-folded with moderate to steep dips to the southwest except where folded adjacent to later shear zones. Sheeted veins are thicker, more widely spaced and compositionally distinct



Photo 2. Typical textural character of undeformed mine phase tonalite from the west wall, Gibraltar East pit.

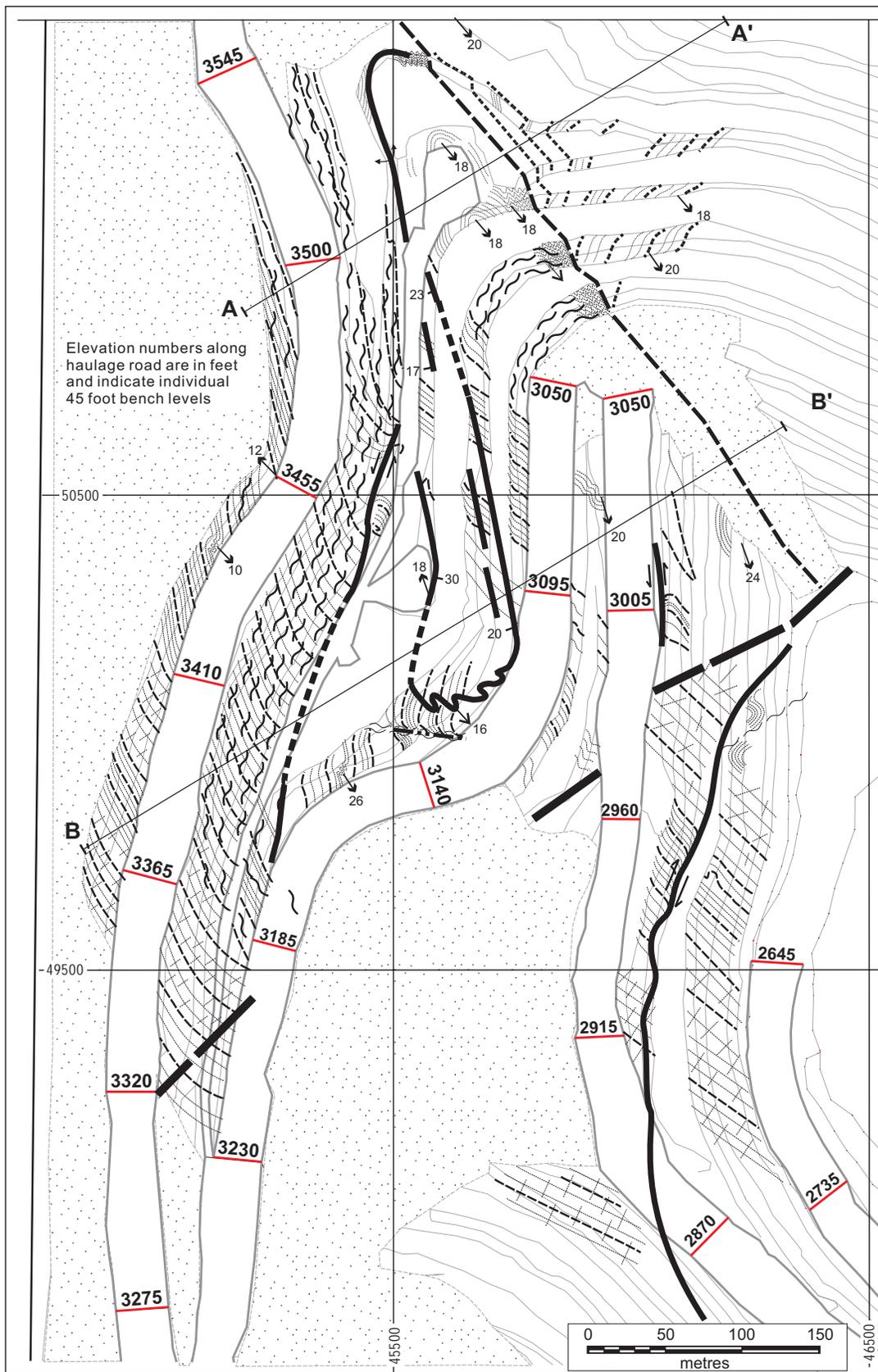


Figure 4a. Generalized geology of the northwest portion of the Gibraltar East pit. Location of map area indicated in Figure 3.

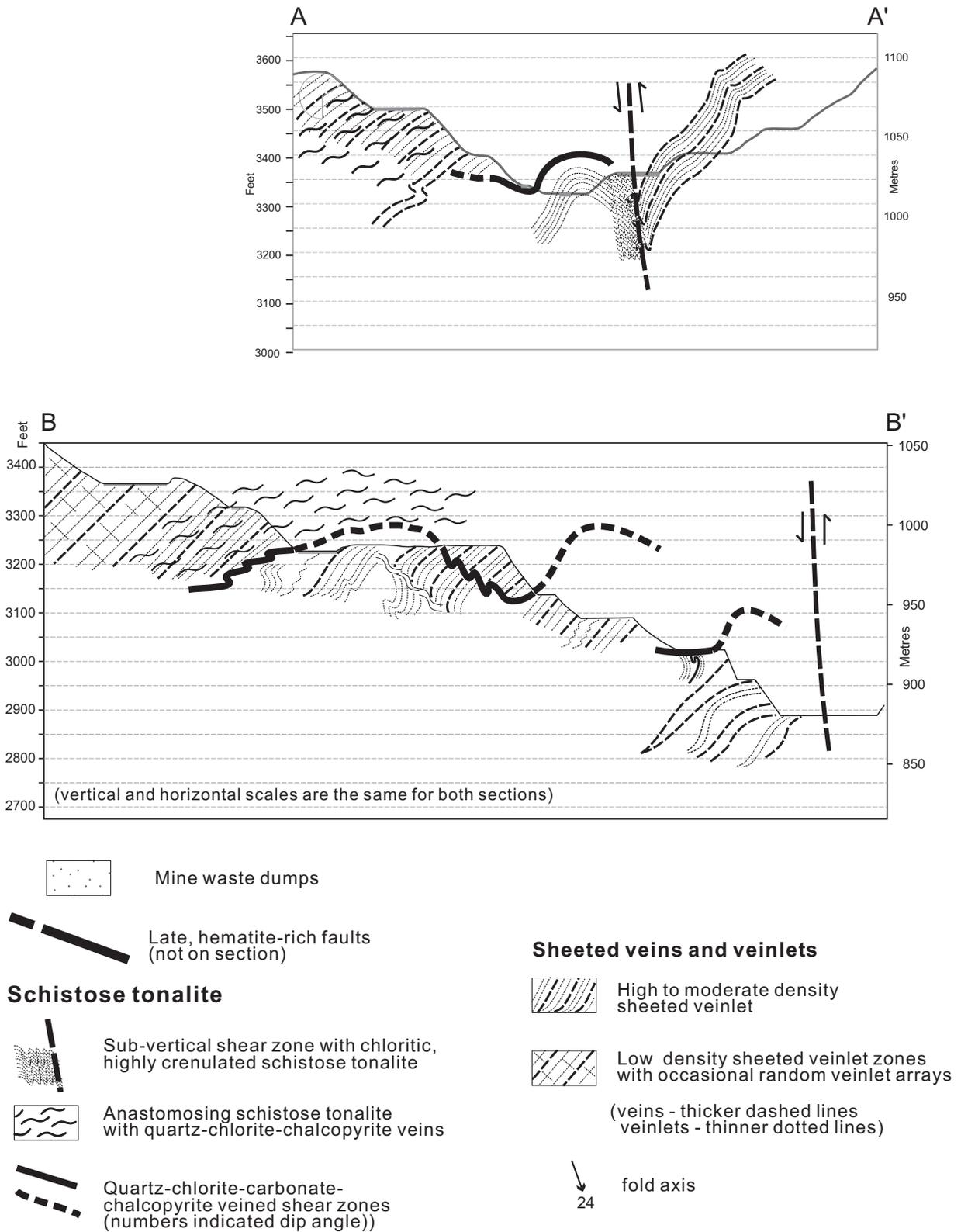


Figure 4b. Generalized cross-sections through of the northwest wall of Gibraltar East pit. Line of section located in Figure 4a.



Photo 3a. Quartz stockwork veining in tonalite along the 3750 foot bench, southeast wall of the Pollyanna pit.



Photo 3b. Detailed character of quartz-stockwork veined massive equigranular tonalite.



Photo 3c. Local development of planar quartz veins in the stockwork tonalite.

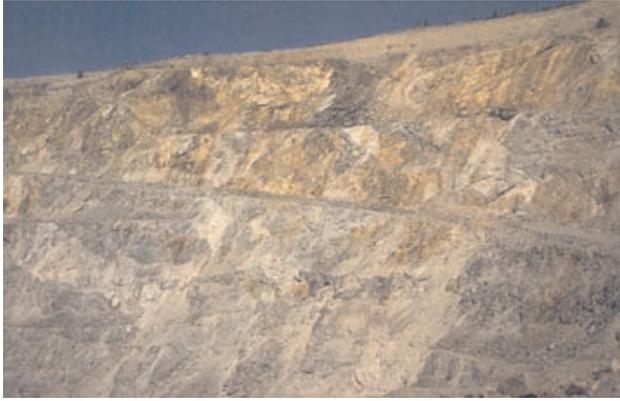


Photo 4a. White leucocratic tonalite dikes intruding lighter grey tonalite along the north wall of the Pollyanna pit.



Photo 4b. Detailed intrusive relationship along the upper margin of one of the dikes shown in photo 4a. Field of view is approximately 4 meters.

from the thinner sub-parallel sheeted veinlets (Photo 5). In general, sheeted veins are thicker and more numerous in zones of high-density sheeted veinlets.

### ***Sheeted Veins***

Sheeted veins are characterized by high sulphide content and well-developed sericitic vein envelopes. These veins are the most prominent features throughout the pits due to their high Fe-sulphide content and distinctive rusty-brown weathering colour. They occur over intervals of three to five metres and typically range from 5 to 25 centimetres in width but may be up to 60 centimetres wide. Sericitic vein envelopes range from several to 15 centimetres in width and are usually strongly sheared. The veins are dominated by quartz and sulphides, mainly pyrite which comprises from 30 to greater than 50% of the vein material (Photos 6a,b). Pyrite is well banded and sometimes associated with thinner bands of molybdenite. Pyrite also occurs as disseminations throughout the quartz veins and in the sericitic vein envelopes where it also occurs within deformed quartz-sulfide stringers. In



Photo 5. Typical appearance of well developed sheeted veinlets with more widely spaced rusty-brown weathering sheeted veins along the west wall of the Gibraltar East pit between the 278 and 3050 foot intervals (individual benches are spaced at 45 foot intervals).



Photo 6a. Exceptionally wide banded sulphide-rich quartz vein with well developed sericitic envelopes. 3320 foot level, northwest



Photo 6b. Banded sulphide-rich quartz vein with both pyrite and molybdenite. 3140 foot bench, west wall Pollyanna pit.

addition to the dominant pyrite and lesser, molybdenite these veins have also been noted (Drummond *et al.*, 1973, 1976) to contain minor amounts of pyrrhotite, magnetite and chalcopyrite.

Petrographic examination of the sheeted vein envelopes indicates that they consist of two alteration types, one dominated by sericite the other by quartz. Sericite-rich envelopes consist of strongly flattened and stretched, very fine-grained, anastomosing and strongly fissile zones of sericite (70-90%), quartz (10-20%), epidote (5-10%), chlorite (1-5%) and trace to several percent sulphides. These zones bound flattened, augen-shaped, discontinuous aggregates of deformed, fine-grained quartz (85%), epidote (7-10%), sericite (5-10%) chlorite (5%) and sulphides (1-10%). These quartz-rich components of the vein envelopes may represent deformed and hydrothermally altered portions of the surrounding sheeted veinlets. Very fine-grained, recrystallized quartz and subhedral to euhedral fine-grained epidote aggregates form in the pressure shadows of the augen-shaped aggregates which may suggest that there was an episode of epidote formation during the time of deformation of the sheeted vein envelopes.

Sericite-rich envelopes of the sheeted veins commonly display well-developed S-C fabrics commonly suggesting an apparent dextral sense of shear. The 'c' fabric is defined by fine-grained sericite and quartz-rich laminae that are slightly discordant to and wrapped around flattened, augen quartz-rich aggregates of fine-grained quartz, chlorite and epidote, which locally contain sulphides. These augen of quartz-rich aggregates define the 's' fabric. This schistosity usually dissipates within a short distance from the sheeted veins. Intervening panels of relatively massive tonalite with sheeted quartz-sulfide veinlets may develop a weak parallel foliation proximal to the vein defined by the flattening and alignment of chlorite. A regionally consistent counter-clockwise oblique angle of about 10° between the vein-marginal schistosity (mean of 135/25) and the sericite-rich quartz-sulfide sheeted veins (mean of 145/45) further implies an apparent dextral sense of shear along these deformed sheeted veins. A conspicuous mineral stretching lineation defined by the alignment of stretched sulphides, sericite and chlorite grains is developed on these sheared surfaces. Millimetre-scale crenulations are also locally developed in the schistose margins of these sericite-rich sheeted veins. Stretching mineral lineations and fold axes are slightly scattered with a weak cluster that plunges sub-horizontally towards 155°, while the stretching mineral lineations show a cluster with a mean plunge of 50° towards 140°. In a few instances, the fold axes and stretching lineations are parallel, which may imply localized high strain, intense shearing and development of sheath folds.

### **Sheeted Veinlets**

Sheeted veinlets are the dominant planar feature throughout the mine and are characterized by semi-continuous, sub-parallel 1 to 3 millimetre wide veins. Vari-

ability in vein density is a notable feature throughout the pits. Zones of sheeted veinlets with vein spacing from 1 to 10 centimetres (Photo 5), form panels usually on the order of several tens of metres in thickness between broad intervals with more widely spaced veinlets. In these intervening panels of relatively massive tonalite veinlets are present but spacing is significantly increased, generally on the order of several tens of centimetres or greater. There are also areas containing several vein sets (2 to 4 in number) with varying orientations in contrast to the consistent and uniform orientation of the higher density sheeted zones.

Sheeted veinlets show some degree of variability in terms of vein morphology. Most often they are dominated by grey quartz (Photo 7) but in some areas, usually where closely associated with sulphide-rich sheeted veins, the sheeted veinlets are often dominated by pyrite. In other areas these sheeted features are defined by highly chloritic slip surfaces with little vein material. Dominant quartz veinlets consist of fine-grained, recrystallized smoky-gray quartz (65-70%), subhedral to anhedral chlorite (15-20%), epidote (5-10%), pyrite and chalcopyrite (5-10%), sericite (1-5%) and iron oxides (trace - 1%). Chlorite and epidote in sheeted veinlets produce the dark green colour in the veins.

Microscopic observations suggest sulphides in quartz-rich sheeted veinlets are commonly associated with quartz-chlorite-epidote aggregates and form as inclusions in chlorite and epidote. Inclusions of epidote, chlorite, quartz, sericite and iron oxides are also common in sulphides. Chalcopyrite forms in the interstices of epidote-epidote and epidote-quartz grains and may be flattened sub-parallel to the vein walls. Chalcopyrite partially and completely replaces pyrite cubes forming pyrite pseudomorphs. Pyrite may have chalcopyrite inclusions and iron oxide replacement rims. Quartz is recrystallized along chlorite-chlorite contacts as well as in the rest of the vein. Sericite replaces chlorite in the sheeted veinlets. Veinlet compositional variations which include magnetite, molybdenite and pyrrhotite are less common.



Photo 7. Detailed character of sheeted veinlets.

Sheeted quartz veinlets commonly develop micaceous envelopes in proximity to later hydrothermally altered shear zones. Where envelopes are not developed, discrete sericite-rich fissile zones, which are parallel to the foliation in the rock, cross cut relatively uniform sheeted veinlets at oblique angles. Where envelopes are developed, sericite-rich envelopes wrap around augen-shaped and boudinaged sheeted veins. Envelopes comprise very fine grained, flattened and stretched sericite (50-55%), quartz (30-35%), epidote (10-15%), chlorite (2-5%) and trace amounts of sulphides.

### **SCHISTOSE TONALITE**

Schistose tonalite is locally developed along hydrothermally-altered, high-strain zones within the Gibraltar mine. On the basis of structural relationships two distinct ages of schistose tonalite are recognized. These include an earlier series of undulating, sub-horizontal shear zones and a later, sub-vertical, high-strain zone. Both are associated with high-grade Cu ore at the Gibraltar mine. The earlier sub-horizontal shear zones cause folding and shearing of the sheeted veins and their intervening host rocks. The later, sub-vertical zone causes shearing and folding of the older sheeted veins and early sub-horizontal shear zones (Figure 4b).

#### **Early Sub-Horizontal Shear Zones**

Sub-horizontal shear zones are manifest in two forms, occurring as several discrete zones and as a broad, roughly 100 metre wide zone with numerous thinner discontinuous anastomosing shears. The most prominent type consists of relatively continuous, discrete, 1 to 2 metre wide, strongly foliated, fissile, phyllosilicate-rich, carbonate-altered shear zones. These high strain zones deform all previously described vein types. At least three and possibly four distinct, shallow to sub-horizontal continuous shear zones are recognized in the Gibraltar East pit and are repeated vertically at roughly 100 metre intervals. Rocks within the zone vary from schistose tonalite to a phyllonitic schist and are characterized by penetra-



Photo 8. Discontinuous bull-white quartz vein in shallow westerly dipping shear zone between the 3150 and 3225 levels, west wall, Gibraltar East pit. Quartz veined shear zone goes from bottom left to top right.

tive zones of sericite-rich, anastomosing laminations that wrap around flattened, augen-shaped quartz-rich aggregates. Discontinuous white, bull quartz veins with locally concentrated coarse-grained aggregates of chlorite, carbonate and Cu-sulphide minerals are a characteristic feature of these zones (Photos 8 and 9). Quartz-chlorite-carbonate-Cu veins are deformed in the schistosity of this unit and also crosscut the schistosity in these shear zones.

These shear zones are also typified by pervasive iron-carbonate alteration, which is largely restricted to the schistose tonalite between the well-defined bounding surfaces of the shear zones (Photo 10). This addition of iron-carbonate results in a distinctive orange-brown weathering colour. Iron-carbonate forms in the interstices of quartz, relict plagioclase and chlorite grains, in quartz-chlorite aggregates, and in ribbons in quartz grains. These carbonate ribbons are crosscut by phyllosilicate-rich fissile zones. These carbonate-altered zones are also characterized by penetrative, centimetre-scale crenulations and a crenulation cleavage. Proximal to the footwall of these shallow shear zones, sheeted veins are commonly openly to tightly S-asym-



Photo 9 Detail of coarse-grained aggregates of chalcopyrite and chlorite in quartz vein shown in sub-horizontal shear zone. 3320 foot bench level, west wall Gibraltar East pit.



Photo 10. Sub-horizontal carbonate altered and quartz-carbonate veined shear zone cross cutting sheeted veinlets. 2870 foot bench, west wall Gibraltar East pit.

metrically folded, with axial planes that have consistent moderate dips to the east. In the hanging wall of these shear zones the sulphide-rich sheeted veins are mechanically rotated into the shear zone. Geometric relationships most often suggest an apparent sinistral sense of shear along these high-strain zones, but this is not everywhere consistent. Eastwood (1970) indicates that the original Pollyanna showing, referred to as the Pollyanna shear zone, consisted of quartz lenses and copper minerals in a quartz-muscovite schist zone trending 055 degrees.

Less conspicuous, though economically significant is a broader zone with numerous 2 to 10 centimetre-wide shears spaced over several tens of centimetres that contain discontinuous quartz-chlorite-Cu sulphide veins (Photo 11). The general trend of this broad zone, as well as the individual shears, conforms to the same general trend of the underlying discrete continuous shear zone (Figure 4b). Iron-carbonate is less conspicuous in quartz veins and sheared tonalite throughout this zone of anastomosing shears.

The nature of the Cu-sulphide minerals present in these white bull-quartz veins varies as a function of depth in the Gibraltar East pit. Chalcopyrite dominates. However above the 3140-foot pit level it is partially to completely replaced by a fine-grained, dark-gray to black mineral, possibly covellite and/or chalcocite, which imparts a distinctive indigo-blue colour on oxidized surfaces.

The transition from relatively massive to schistose tonalite involves an increase in the intensity of schistosity (Photo 12) and by increased amounts of sericite and quartz (Figure 5). Increased amounts of sericite are concentrated along discrete to penetrative, anastomosing, fissile zones of mainly stretched sericite (70-90%) with lesser fine-grained, stretched quartz, epidote and chlorite. Fine sericite also partially (30-60%) to completely replaces relict plagioclase laths. An increase in the content of secondary quartz is demonstrated by quartz occurring as impregnations in the interstices of quartz and relict plagioclase grains, in addition to quartz replacing chlorite, sericite and altered plagioclase. Deformed anhedral grains to subhedral cubes of pyrite are associ-



Photo 11. Discontinuous anastomosing shear zones (for scale the individual benched 45 feet high).



Photo 12. Flattening fabric in schistose tonalite.

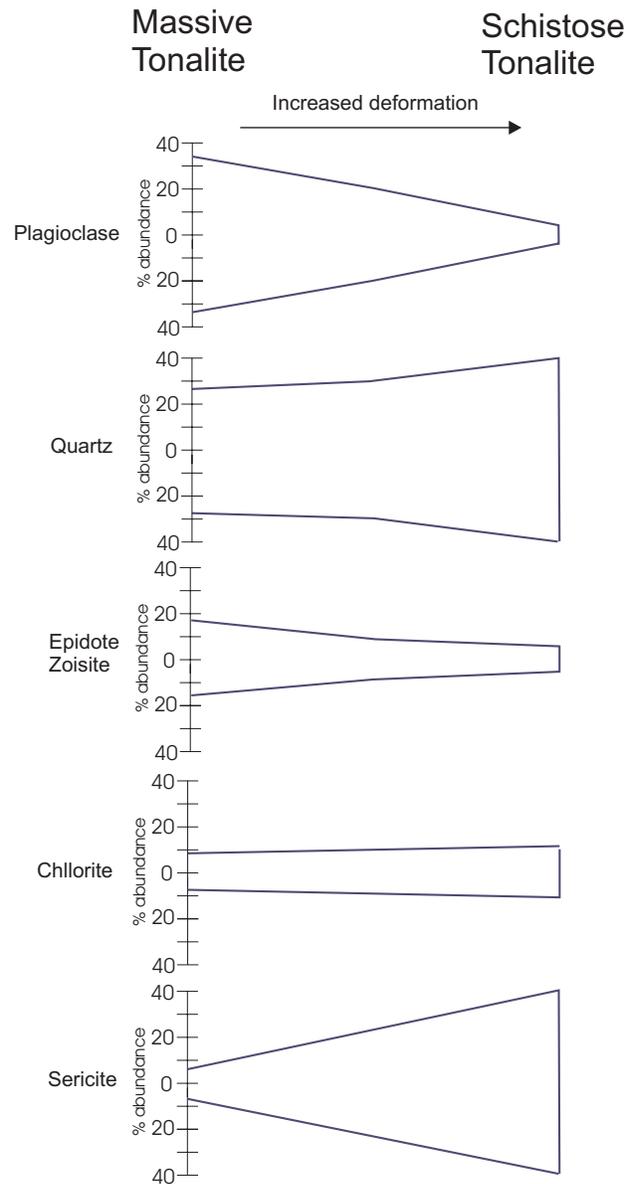


Figure 5. Relative mineralogical variation in mine phase tonalite as a function of progressive deformation, going from least deformed massive tonalite to schist.

ated with moderately flattened augen-shaped aggregates of quartz, epidote and chlorite. Anhedral chalcopyrite grains are concentrated along the phyllosilicate-rich zones, while very fine (recrystallized) subhedral pyrite is disseminated throughout the unit. Anhedral to subhedral pyrite also forms inclusions in and replaces the margins of chalcopyrite.

### Sub-Vertical Schistose Tonalite Zone

A major, sub-vertical high deformation zone, several metres wide, cuts the northwest portion of the Gibraltar East pit (Figure 4). Towards this zone, sheeted veins and veinlets, low-angle shear zones and contained veins become progressively deformed, from openly folded to tightly crenulated (Photo 13a,b) to transposed. All major and minor fold axes plunge at shallow angles (5-20°) to the southeast. Clockwise rotation of planar features on the southwest side of this zone combined with asymmetrical Z-folding of steeply southwesterly dipping sheeted veins where entering this zone on the northeast side (Photo 14) indicate relative movement on this structure (Figure 4b). Strongly sheared rocks within the zone are chlorite-rich and dark in colour and are associated with pervasive sericite and carbonate alteration. Copper sulphide minerals are significantly enriched and are typi-

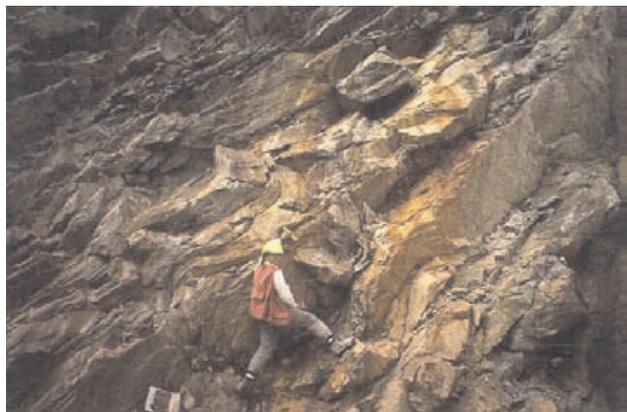


Photo 13a. Open folding of sheeted veins and veinlets along the southwest side of the Sub-vertical shear zone.



Photo 13b. Nature of folded, chloritic, Cu-rich schistose tonalite within the sub-vertical shear zone.



Photo 14. Asymmetrically z-folded, Fe-sulphide-rich sheeted vein on northeast side of sub-vertical shear zone.

cally smeared out along chloritic slip surfaces within the schistosity.

### Structure

Deformation of the Gibraltar mine was localized along discrete high-strain zones in a relatively massive and unfoliated tonalite. No extensive or pervasive foliations were recognized in the mine. The intensity of folding of veins and planar fabrics generally varies as a function of scale. On the regional scale, folds are open warps. At the local scale, in particular in proximity to discrete high deformation zones, folds are tight to transposed. The majority of folds plunge shallowly to the southeast (Figure 4). The orientation of mineral stretching lineations on foliation and shear surfaces varies from shallowly to moderately plunging to the southeast. A detailed synopsis and kinematic interpretation of the structural data from the Gibraltar mine will be given elsewhere (Ash *et al.*, in preparation).

### LATE BRITTLE FAULTING

A late, major northeast-trending steeply northwest dipping brittle fault cuts across the Gibraltar East pit through the middle of the area mapped (Figure 4a). It is characterized by a distinctive purplish-red stain and it cross-cuts all previously described map units and consists of hematite-rich incoherent clay gouge zones from 5 to 15 centimetres wide. Zones of hematite-rich alteration and minor hematite-stained fractures and faults marginal to the main gouge zones range from several decimetres to over a metre wide. Fault surfaces have horizontal to obliquely-plunging slickensides, which suggest strike-slip to oblique-slip movement on the faults. Although no obvious offsets were observed there is a subtle change in character in the rocks on either side of the fault. In the hanging wall, strongly deformed and sericite-altered rocks appear to be more prevalent than in the footwall. Sutherland Brown (1974) interpreted these faults to cause pit-wall instability and groundwater movement. He observed displacements of less than 10

metres along the faults in the Gibraltar East pit. Drummond and others (1976) suggest regional-scale, late, steep north to northeast-trending faults that cut the Gibraltar area have a net throw of 300 m.

## SUMMARY

On the basis of structural style, morphology and relative age relationships, three generations of veining are recognized at the Gibraltar Mine. The earliest are random stockwork to weakly planar quartz veins that are locally restrictive and largely unmineralized. The second generation includes two types of heterogeneously developed sub-parallel, sheeted veins and veinlets that pervade the mine area. The thicker sericite-enveloped, Fe-sulphide-rich, banded quartz veins contain concentrations of molybdenite. Cu-sulphide minerals are less conspicuous. Both of these generations of veins appear to be prekinematic and formed prior to development of any penetrative foliation fabrics within the batholith. The sericite enveloped, sheeted veins have accommodated significant amounts of later shearing but this is also largely non-penetrative and restricted to vein marginal shears.

The third generation of veining is compositionally distinct for earlier vein types containing quartz, chlorite,

carbonate, and abundant Cu-sulphide minerals. These are syn to late kinematic and associated with and developed along high-strain deformation zones. No molybdenite mineralization was noted in these veins. The general schistose character of high-grade copper ore at the Gibraltar mine resulted in its ease of crushing and milling or low work index.

## Regional Considerations

The syn kinematic high-strain, sub-vertical shear zone controls the overall geometry and setting of copper ore in the Gibraltar East pit. It is mimicked on the mine and regional scale. The shear zone which localizes high-grade ore in the northwestern portion of the Gibraltar East pit is also well defined at the western end of the Pollyanna pit. Towards the southeast, this northwesterly-trending shear zone bends to the east and is consistent with a comparable change in orientation of all planar (sheeted veins) and linear (fold hinges and mineral stretching lineations) structural elements at both the mine and regional scale (Ash *et al.*, 1999a).

Two distinct sub-vertical parallel zones are attributed to ore control, a northerly zone related to ore at the Gibraltar East and Pollyanna pits and a southern zone controlling mineralization at the Gibraltar West and Granite Lake pits (Figure 6). A similarly oriented shear zone with asso-

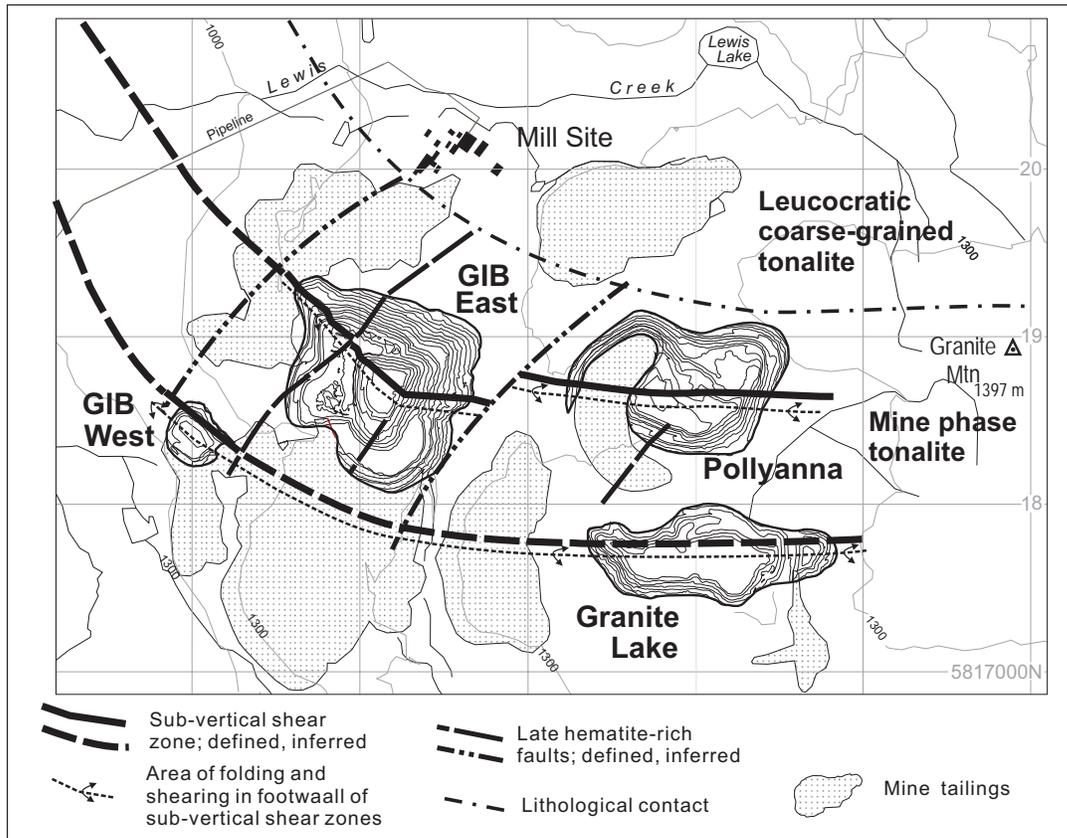


Figure 6. Mine scale distribution of sub-vertical high-strain shear zones relative to the position of Cu-ore at Gibraltar.

ciated schistose quartz diorite and tonalite along the southern margin of the Granite Mountain Batholith is associated with Cu-mineralization at the Sawmill Zone (Figure 2). The overall trend of these zones is also consistent with the orientation of contacts between specific phases of the pluton.

A series of 28 soil samples were collected by Sutherland Brown (1966) at roughly 150-meter intervals in a general east-northeasterly direction from across the Gibraltar Mine area and mercury concentrations were determined. It is significant that samples collected above the major sub-vertical, mineralized shear zones have elevated mercury concentrations that are 2 to 3 times background values. These data, although limited, suggest that mercury concentrations in soils may be useful in identifying similarly mineralized shear zones. No mercury analysis were undertaken in this study.

## CONCLUSIONS

Copper ore at the Gibraltar mine is structurally controlled. Ore grade mineralization is localized along high-strain shear zones that are associated with significant sericite enrichment.

Two major parallel northwest to east-trending sub-vertical shear zones control the distribution of copper mineralization at the mine. Regionally similar parallel zones appear to control occurrences of anomalous Cu mineralization.

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