Asamera writings
on the Cannon
Mine - This was
all it had in
Reference to Lovitt
+ the "J Reef"

North-trending faults

Early workers (Lovitt and McDowall, 1954; Lovitt and Skerl, 1958; Patton, 1967; Patton and Cheney, 1971) recognized a prominent post-mineralization north-trending fault pattern in the L-D mine at "D" reef. These faults are near vertical and have dextrally offset the silicified lens that constitutes "D" reef into a series of partially and completely detached blocks. Three main faults have been identified at "D" reef: The North-South fault, the 49 fault, and an unnamed fault that defines the northwestern boundary of "D" reef (Plate 1). The North-South fault has been traced by drilling and geophysical data, and forms the western margin of the rhyodacite at Rooster Comb. The unnamed fault on the the western boundary of Block 3 has been traced by drilling to the western margin of Wenatchee Dome. There, it defines the boundary between the "B" reef complex and the perlite and rhyodacite of Wenatchee dome (Plate 1).

Other north-trending faults are shown on Plate 1. These include the fault between Old Butte and Saddle Rock, and a fault west of the andesite outcrop adjacent to "C" reef. The location of these structures is based largely on inference from very limited drill-hole information. Lovitt and Skerl (1958, p. 966) show ten north- to northwest-trending faults in a zone extending from "D" reef to "G" reef, a remarkably perceptive interpretation, considering the limited amount of subsurface data at that time.

The north-trending fault pattern appears to be confined to rocks of uncertain age in the central portion of the district. This may merely reflect either the benefits of underground exposures and detailed drill-hole information in these rocks, in contrast with the paucity of outcrops elsewhere in the district, or it may represent a more complex tectonic history for rocks in the central portion of the district.

Pitcher syncline

Sedimentary beds of the Oligocene-aged Wenatchee Formation have been folded into a northwest-trending syncline in the western part of the district. This structure is well exposed on the north side of Squilchuck Canyon where the fold profile has continuous curvature and a well defined vertical axial plane (Figure 14). The axis of the Pitcher syncline plunges gently to the northwest, but becomes poorly defined at Dry Gulch. Where it crosses Dry Gulch, the fold profile is defined by a broad, flat-lying central area with sharply upturned edges at the eastern and western borders (Gresens, 1983, p. 55). Northwest of Dry Gulch the Pitcher syncline becomes even broader, but the structure cannot be traced beyond the northwesternmost exposure of the Wenatchee Formation.

INTRODUCTION TO THE ECONOMIC GEOLOGY OF THE WENATCHEE DISTRICT

The Wenatchee mining district is an unusual example of epithermal gold-silver mineralization in respect to the host lithology, tectonic setting, ore mineralogy, and style of mineralization. Shortly before its closure in 1967, the L-D mine was the 13th largest gold producer and 6th largest gold mine in the United States (Patton and Cheney, 1971, p. 9). Past and present proven reserves in the district total approximately 1.5 million ounces (46.7 metric tons) of gold, and nearly 2.25 million ounces (70.7 metric tons) of silver at an average grade of about 0.25 oz/ton (8.6 g/mt) Au, and 0.37 oz/ton (12.7 g/mt) Ag. Individual ore bodies in the Wenatchee district are described in the following sections of this thesis, with an emphasis on the recently discovered Cannon mine. The general characteristics of hydrothermally altered rocks in the Wenatchee district as exposed at the surface are described in this section to provide a background for later, more detailed discussions of the ore bodies.

Hydrothermally altered rocks that host gold and silver mineralization in the Wenatchee district are resistant to weathering and generally form rugged outcrops that contrast sharply with the surrounding colluvial slopes. Early prospectors in the district referred to these outcrops as "reefs", a term that is still used in the Wenatchee district, but one that is not intended to imply any systematic, geometric relationship between the location of hydrothermally altered rocks and district-scale structures. Various reefs, which have alphabetic designations, are shown on Plate 1 and in Figure 2. Except for "A" reef, all exposures of silicified rock in the Wenatchee district consist of tan to very light-gray, iron-stained, and brecciated sedimentary rocks that are cross-cut by quartz veins and veinlets. The matrix of feldspathic sandstone beds is replaced by fine-grained quartz, and this replacement process has produced a very competent rock that has a plutonic appearance. Early miners referred to "D" reef as the "bastard granite" in allusion to its plutonic appearance (Patton and Cheney, 1971, p. 8).

"A" reef, located on the north side of Dry Gulch (Plate 1) is distinctive in that it is the only place in the area under consideration that good underground and surface exposures of intensively silicified and veined Saddle Rock andesite occur. On the 1250 level of "A" reef, an exploration adit developed by Anaconda, the Saddle Rock andesite is strongly silicified and argillized, and cut by a northeast-trending vein set. Locally, these veins contain up to 0.2 oz./ton (6.9 g/mt) gold. Diamond drilling information indicates that the Saddle Rock andesite is also altered west of the "B" reef complex.

"F" and "G" reefs are the only zones of alteration on Plate 1 that are west of the Saddle Rock andesite. These reefs are poorly exposed except for several small trenches excavated by early prospectors. "E" reef, located about 150 meters west of "D" reef (Plate 1), may also be west of andesite equivalent to the Saddle Rock andesite, but current information is insufficient to make this determination.

"C" reef is located between "D" reef and "B" reef along the main trend of mineralization extending from "D" reef to "A" reef. "C" reef forms a small but distinct ridge, but does not crop out well. A small exploration adit was driven on the 1575-foot level at "C" reef but was not accessible during the course of this investigation. Geologic and assay maps of the adit indicate that sedimentary rocks at "C" reef are extensively silicified, but not well mineralized. A jagged outcrop of hornblende andesite cut by small northeast-striking hematite-chalcedony veins is located immediately west of "C" reef (Plate 1). The andesite does not appear to be appreciably altered, and the hematite-chalcedony veinlets are not mineralized with gold.

Economic mineralization has been identified only at "D" reef and the "B" reef complex (Plate 1). "D" reef is the best surface exposure of hydrothermally altered rocks in the district as it forms a rugged outcrop of silicified coarse-grained feldspathic sandstone on the north side of Squilchuck Canyon (Plate 1). Northwest-striking quartz veins are well-developed in the "D" reef outcrop, and stand out as 0.5 to 1 meter-thick quartz-filled fractures cutting the silicified and oxidized cliffs (Figure 16). Surface exposures of silicified sedimentary rocks at "D" reef extend continuously to the northwest from the contact of undifferentiated alluvial sediment at Methow Street to about the 1800-foot elevation (Plate 1). Above this elevation, outcrops are sparse, but

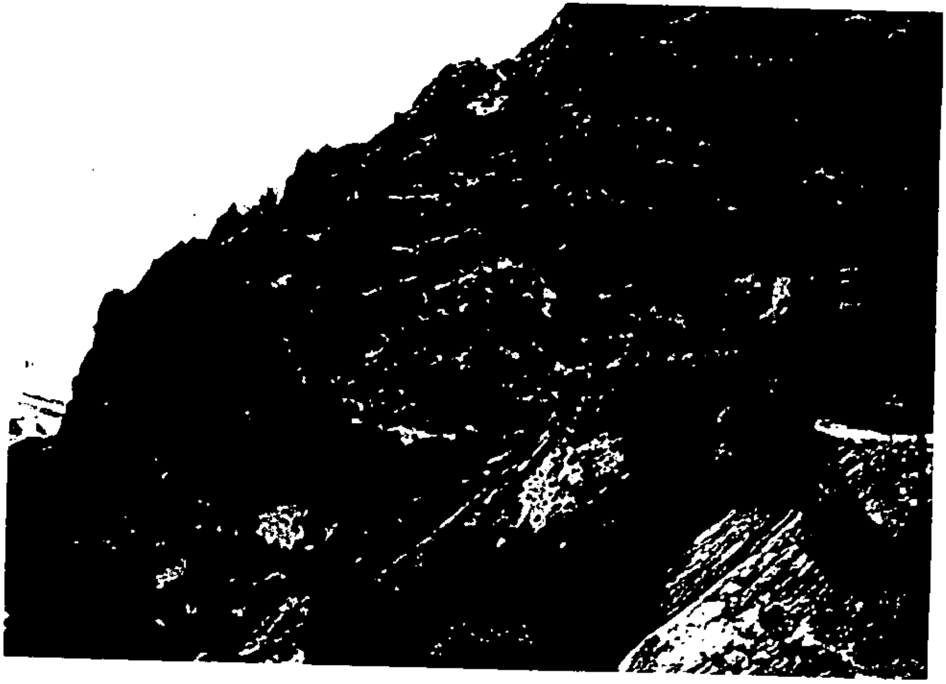


Figure 16. Silicified, veined sedimentary rocks at the "D" reef. View is looking west. Note the well developed north and south-dipping veins.

exposures in road cuts indicate that the sedimentary rocks are argillized (Plate 1).

"B" reef forms a small outcrop of silicified sedimentary rocks west of Wenatchee Dome on the south side of Dry Gulch (Figure 17). The surface exposure of "B" reef contains few quartz veins and is only weakly mineralized with gold. Other ore bodies at the "B" reef complex are overlain by up to 100 meters of surficial deposits, such that, there is no surface exposure of ore-grade rock. Ore bodies of the "B" reef complex will be discussed in the next section.

Mineralization at "D" reef and the "B" reef complex is both disseminated and vein and veinlet controlled. Ore bodies at both reefs consist of widely spaced quartz-adularia veins in pervasively mineralized and silicified wall-rock. The southeasternmost part of "D" reef contains veins that are wide enough that they could be mined as separate entities. However, most of the economic mineralization at "D" reef, and all of the ore bodies in the "B" reef complex require employment of bulk mining techniques, as mineralized veins, although they may be very high grade, are small and discontinous. Wallrock between the veins contains lower grades of disseminated mineralization. Local hydrothermal breccias and quartz-veinlet stockworks are also mineralized at both "D" reef and in ore bodies of the "B" reef complex.

Both pre-mineralization and post-mineralization faulting and folding are important in localizing these bodies of alteration and mineralization. On a district scale, stratigraphy appears to exert little control over the location of altered and mineralized zones, except that most, if not all, hydrothermal activity was apparently confined to the belt of complexly deformed sedimentary rocks in the central portion of the district. On a more detailed scale, individual stratigraphic horizons do exert significant local control over the boundaries of alteration and mineralization. Rhyodacite and andesite intrusions have a close spatial relationship with hydrothermally altered rocks; radiometric dating indicates a close temporal relationship as well (Table 3).

GEOLOGY OF THE "D" REEF

The geology of the L-D mine at "D" reef has been described by Lovitt and McDowall (1954), Lovitt and Skerl (1958), Patton (1967), and Patton and Cheney (1971). Moody (1958), and Guilbert (1963) investigated the ore and gangue mineralogy at the L-D mine. Geologic investigations subsequent to these publications include an extensive diamond and rotary drilling program by Cyprus Mines Corporation, diamond drilling and geophysical investigations by Lovitt Mining Company (Folk, 1987), and surface mapping and drilling by Asamera Minerals Company and Breakwater Resources. During this investigation, the 1250 level of the L-D mine was rehabilitated and Block 1 was mapped in detail; a cursory examination of Blocks 2 and 3 was also made.

Distribution of Mineralized Rocks

"D" reef consists of an elongate lens of hydrothermally altered and mineralized sedimentary rocks. This lens of altered rock strikes northwest and dips 60° to 80° southwest, approximately parallel to the orientation of the sedimentary host rocks. A regular pattern of north-trending dextral strike-slip faults have offset the mineralized rocks, and produced en echelon of blocks of ore, shown in Figure 58 as Blocks 1, 2, and 3. Ore was mined at "D" reef between the elevations of 850 and 1600 feet; mineralization and alteration have been identified as deep as the 750-foot elevation.

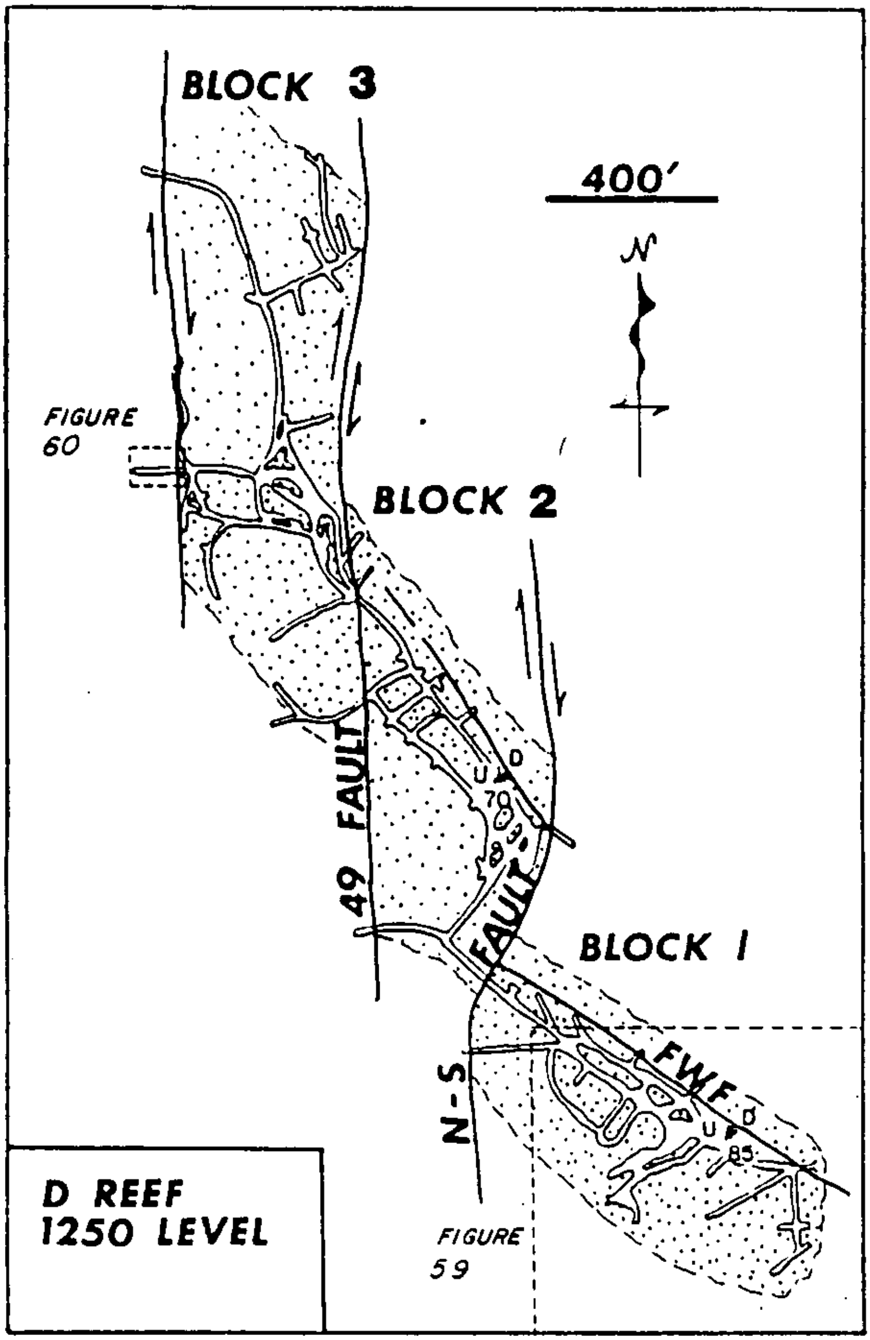


Figure 58. Plan map of the 1250 level of the L-D mine at "D" reef. FWF is the Footwall Fissure, stippled pattern indicates limit of silicification. Locations of Figures 59 and 60 indicated. Modified from Patton and Cheney (1971, figure 4).

Sructural Framework

The main structural feature in Blocks 1 and 2 is a northwest-striking, reverse fault known as the Footwall Fissure (Lovitt and Skerl, 1958, p. 966). The Footwall Fissure consists of two strands that dip steeply to the southwest, and are variably separated by 50 to 75 feet of intensively silicified and broken sedimentary rocks, the original character of which are not recognizable (Figure 58). Patton and Cheney (1971, p. 9) state that alteration and mineralization are restricted to the hangingwall side of the western strand. However, in Block 1 of the 1250 level, the section of rocks between the east and west strands of the Footwall Fissure is intensively silicified and weakly mineralized with gold. Also, the main access drift on the 1250 level of Block 1 was developed in silicified sedimentary rocks on the footwall side of the west strand (Figure 59, and Plate 8 of Patton, 1967). Patton and Cheney (1971, p. 7) also suggest that the Footwall Fissure is a pre-mineralization structure; however, the most recent movement on the Footwall Fissure post-dates mineralization, as is evidenced by the abrupt termination of northeast-trending veins in Block 1 (Figure 59). Sedimentary beds in the hangingwall of the west strand dip 75° to 85° to the southwest, approximately parallel to the plane of the fault. Progressing west into the hangingwall, the dip of bedding gradually decreases 50° to 60° (Figure 59). Sedimentary beds are poorly defined between the east and west strands, but where bedding can be recognized, it

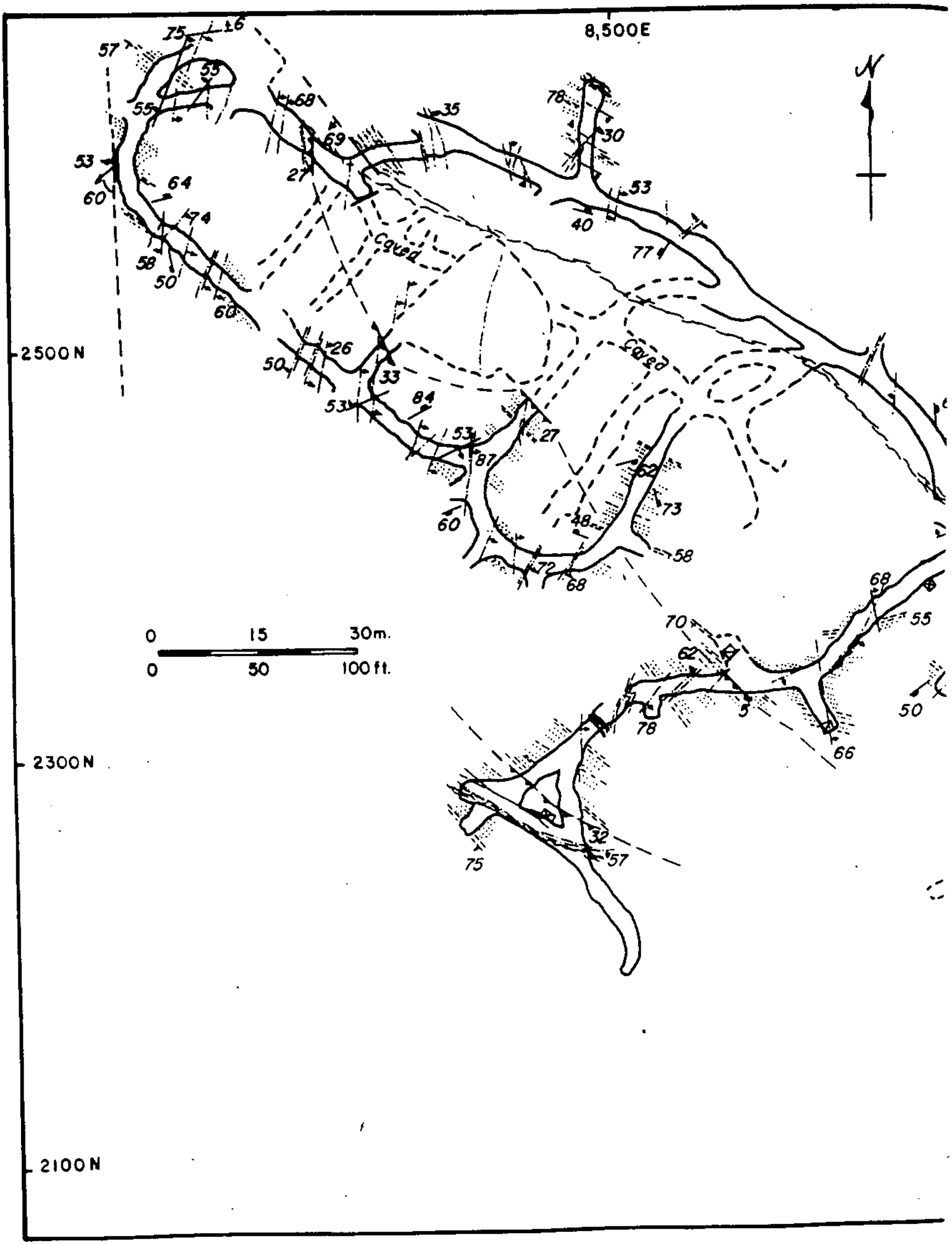
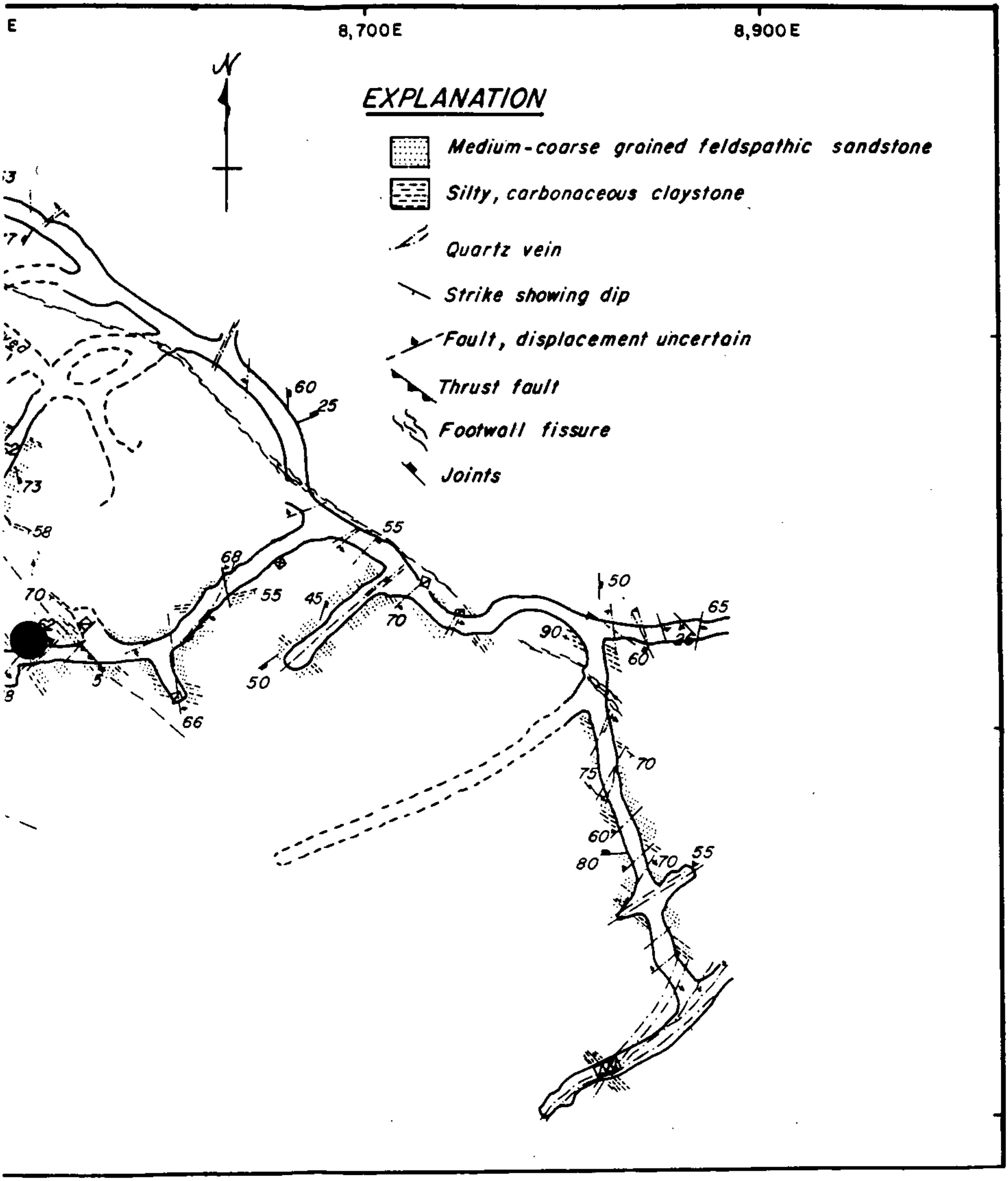


Figure 59. Geologic map of Block 1, 1250 level, L-D mi



1250 level, L-D mine.

dips steeply to the northeast.

The Footwall Fissure has been offset by three north-trending strike-slip faults that separate Blocks 1, 2, and 3. The North-South fault has laterally displaced mineralization as much as 300 feet and separates Blocks 1 and 2 (Figure 58). The amount of displacement on the 49 fault that separates Blocks 2 and 3, has not been determined, but is less than the displacement on the North-South fault. An unnamed north-trending strike-slip fault marks the western boundary of Block 3 (Figure 58). These three north-trending strike-slip faults also appear to have a component of oblique reverse displacement of undetermined magnitude. Minor folds in carbonaceous gouge of the unnamed fault on the western margin of Block 3 indicate a hangingwall movement direction of N20°E to N40°E (Figure 60). Patton and Cheney (1971, p. 9) cite several interpretive lines of evidence for oblique reverse movement on the north-trending faults.

At least three generations of vein development have been observed in Block 1, and presumably correspond to intra-mineralization fracturing. Early veins are developed along fractures parallel to bedding, and are cut by later northeast-trending vein filled fractures that dip 60° to 80° to the northwest (Figure 61). These northwest-dipping fractures are offset by northeast-striking veins that dip 80° to 85° to the south (Figure 59). Both the bedding-plane veins, and the northwest-dipping veins are mineralized, but the south-dipping veins are barren. The northeast-trending vein pattern is

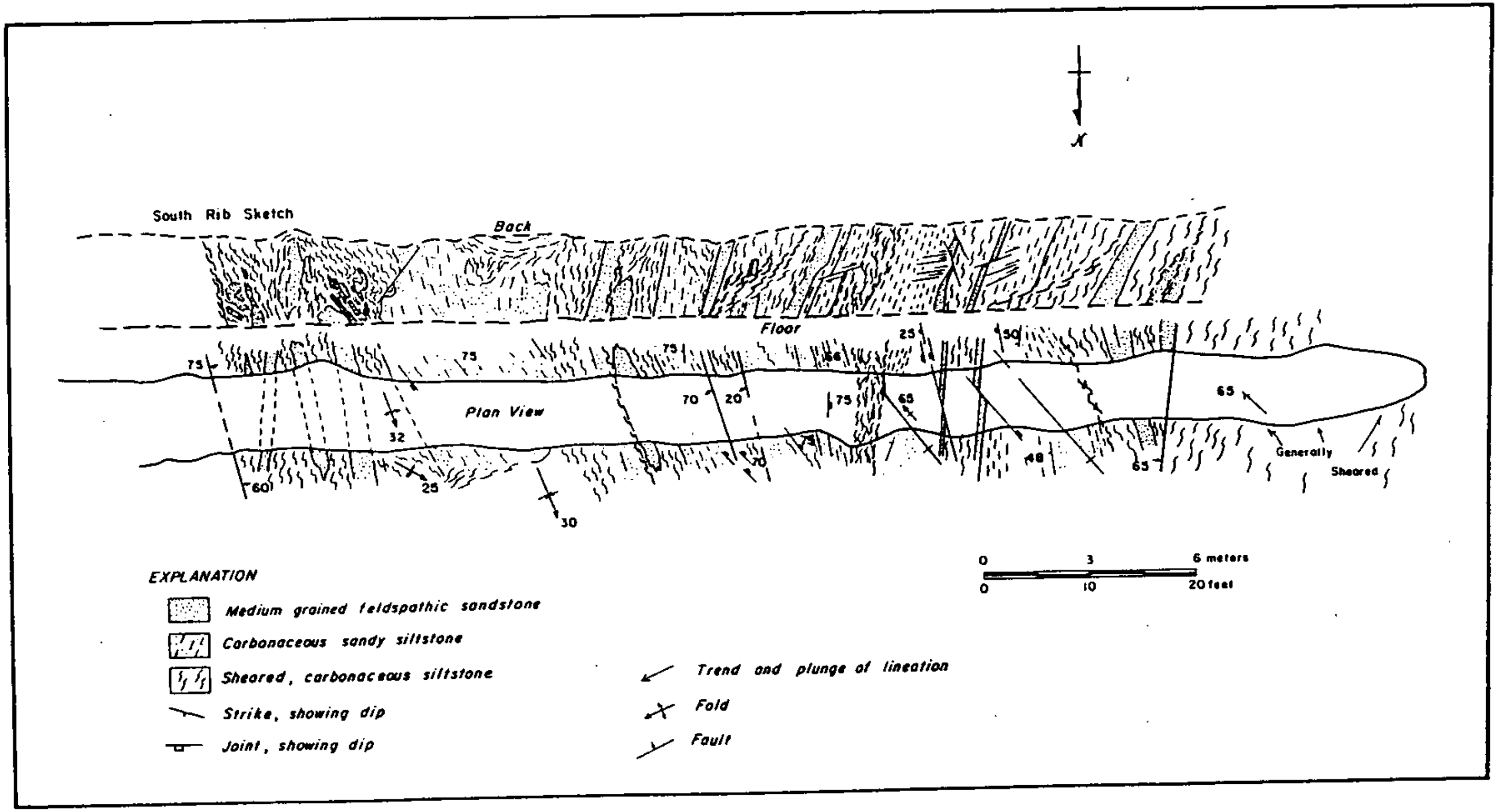


Figure 60. Detailed geologic map of carbonaceous gouge zone in unnamed fault on the western boundary of Block 3 on the 1250 level. Minor structures indicate that the slip direction is to the northeast.

consistent throughout Block 1, but it is only in the southeast portion of Block 1 that the width of the veins is sufficiently developed that they could be individually stoped (Figure 59). In Blocks 2 and 3, based on a brief examination, the pattern of veins approaches a stockwork, although the northeast strike remains the dominant orientation.

Detailed mapping in Block 1 has identified a series of regularly spaced, small thrust faults that offset both mineralized and barren quartz veins. These faults are typically less than 2 cm in width, they strike northwest and generally dip less than 20° to the southwest. Displacement is commonly on the order of 2 to 5 meters and the vertical spacing between thrust planes is commonly 1 to 5 meters (Figure 59). Patton (1967, Plate 7) noted a well-developed low-angle fault on the 1100 level in Block 2, which he referred to as the "Flat Fault".

Patton and Cheney (1971, p. 7) interpreted the Footwall Fissure to be part of an imbricate thrust zone. They correctly identified the structure as a reverse fault, and indicated that the dip of the Footwall Fissure decreased in the lower levels of the mine. An earlier observation by Patton (1967) is inconsistent with the latter observation. Patton's map of the 850 level, the deepest level in the mine, shows the Footwall Fissure to dip 75° to 85° to the southwest, essentially parallel to the dip of this structure on all levels of the mine (Patton, 1967, Plate 4). The decrease in dip on the Footwall Fissure suggested by Patton and Cheney

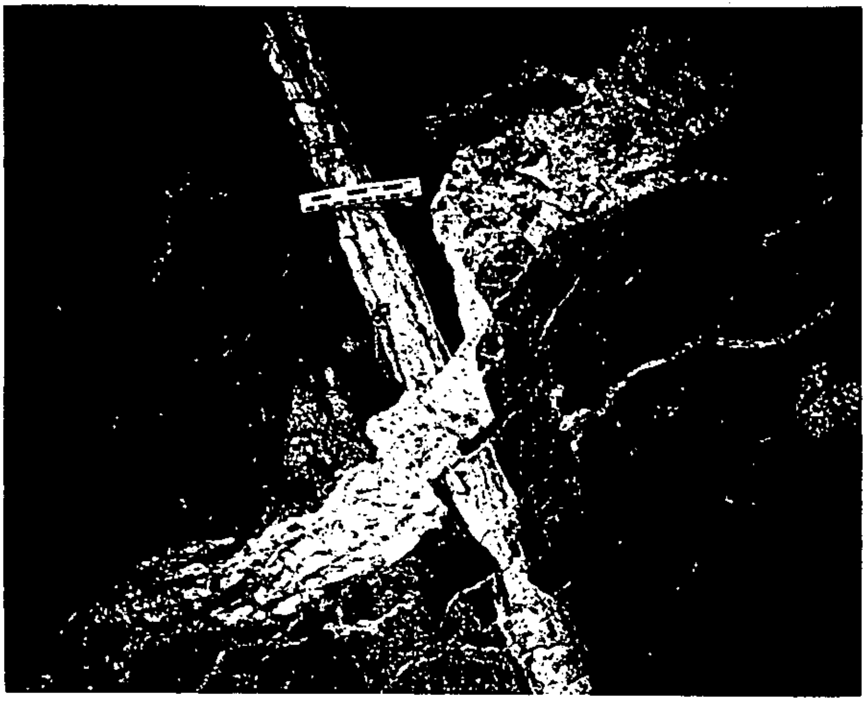


Figure 61. Bedding-plane vein crosscut by northeast-striking, north-dipping vein in Block 1. A later structural adjustment has offset the northeast trending vein. Viewed to the southeast, scale is in inches and centimeters.

(1971) is based on their interpretation that the Footwall Fissure is the same structure as the Flat Fault. The lower levels were not accessible during the course of this study, and this relationship could not be confirmed.

Stratigraphy of the Mineralized Section

Rocks in the footwall portion of the east strand of the Footwall Fissure consist of a cobble to boulder conglomerate at least 200 feet thick. Patton (1967) and Patton and Cheney (1971) correlated this conglomerate with conglomerates exposed on the western side of Rooster Comb. Where exposed east of the 1250 level portal (Plate 1) the conglomerate consists of cobbles and small boulders of volcanic rocks, quartz, and some biotite gneiss that are stained with red and yellow iron oxide minerals, in a weakly argillized matrix of feldspathic sandstone.

The stratigraphy between the east and west strands of the Footwall Fissure is not well defined due to intensive silicification and brecciation. Breccia fragments commonly consist of medium to coarse-grained feldspathic sandstone. Pebble conglomerate and laminated silty beds occur locally.

Three stratigraphic sections were measured in Block 1 in the hangingwall portion of the west strand and are shown in Figure 62. The hangingwall section of Block 1 consists largely of feldspathic sandstone beds, 0.5 to 1 meter thick, with thin interbeds of carbonaceous clayey siltstone. Distinctive pebble conglomerate beds that consists of 1 - 3

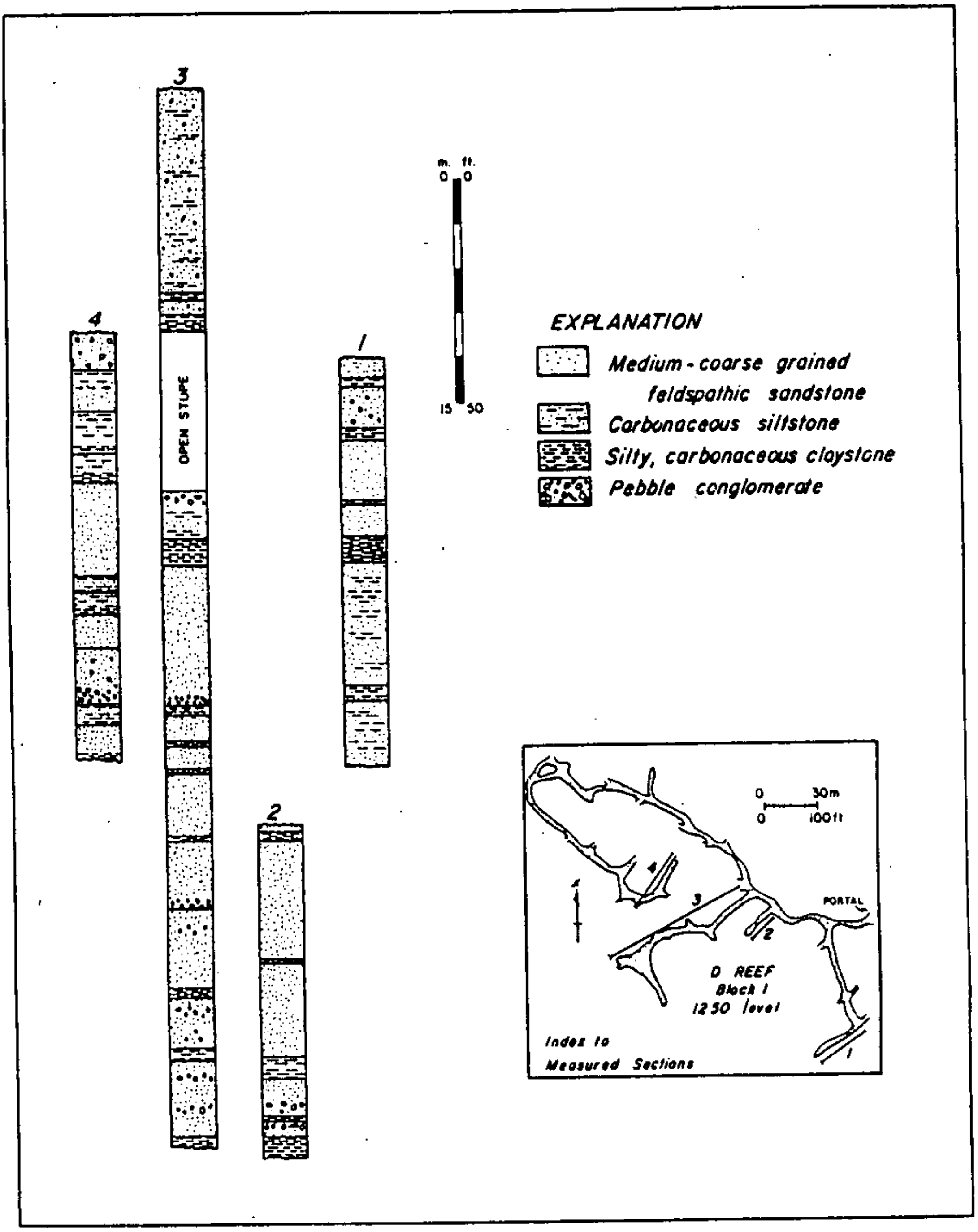


Figure 62. Measured stratigraphic sections in Block 1 of the 1250 level of the L-D mine. Measured by T. Roberts M. Klisch, and L. Ott.

centimeter diameter pebbles of biotite gneiss, granite, and volcanic rock supported by a feldspathic sandstone matrix, are locally useful for correlation purposes (Figure 62). Carbonized plant remains are common in all of the sedimentary beds and abundant in siltstone horizons.

The stratigraphic section in Blocks 2 and 3 has not been closely inspected. In general, Block 2 appears to contain more silty carbonaceous rocks than are present in Block 1. However, the intensity of silicification and veining in Block 2 is greater than in Block 1, and the original character of the sedimentary host rock is not as evident. Thickly bedded feldspathic sandstones are the principal rock type in Block 3; cross bedding and other useful sedimentary structures can be observed in the northwestern portion of this area of the 1250 level, where the intensity of alteration diminishes.

Sedimentary beds at "D" reef are thicker and contain a greater portion of medium- to coarse-grained feldspathic sandstone beds than the beds at the "B" reef complex. The thinly laminated interbeds of carbonaceous siltstone that are prevalent in units 1 and 2 in the "B" North ore body are not evident at "D" reef, and the distinctive pebble conglomerate beds in coarse-grained sandstones at "D" reef are not evident in the "B" reef complex. The two sequences of mineralized sedimentary rocks therefore cannot be directly correlated.

Mineralization and Hydrothermal Alteration

With the exception of the southeast part of Block 1, the style of mineralization at "D" reef is generally similar to the "B" reef complex. In Blocks 2 and 3, ore-grade rock consisted of discontinuous high-grade veins and veinlets in pervasively silicified feldspathic sandstone (Figure 63). In the southeast portion of Block 1, northeast-trending veins, up to 2 meters in width, were mined as separate entities. In Blocks 2 and 3, multiple periods of fracturing are manifest by complex cross-cutting vein relationships; however, the paragenesis of veining, particularly with regard to gold deposition, has not been deciphered. In Block 1, there are fewer veins, and the veins have greater continuity, enabling early workers to recognize a temporal relationship between mineralized and barren veins. Lovitt and Skerl (1958, p. 966) note that auriferous veins in Block 1 always dip 60° to 80° to the north, and are offset by barren south-dipping to near-vertical quartz veins.

Guilbert (1963) examined 23 ore specimens for Day Mines Co. and his work revealed that the principal ore minerals at "D" reef are electrum, native gold, and naumannite (Ag_2Se). Other sulfide minerals reported by Guilbert are pyrite, marcasite, chalcopyrite, and minor tetrahedrite, sphalerite, and stibnite. Moody (1958) unsuccessfully searched for the presence of telluride minerals. Neither stibnite nor any selenide minerals have been identified at the "B" reef complex.

Figure 63. Style of veining in the northeast part of the 1250 level of Block 1. Note the sinuous discontinuity of veins in the right portion of the photograph. The vein in the back, above the miner, is gold-bearing and dips steeply to the north. The south-dipping vein in the lower left part of the photograph is barren and offsets the north-dipping vein.

Guilbert (1963, p. 24) noted that precious metals were deposited in veins early during the period of fracture filling. Gold, electrum and naummanite were localized within approximately a millimeter of the vein wall in all the samples studied by Guilbert. Traces of chalcopyrite occurred between the vein wall and ore minerals in only a single specimen.

Non-sulfide gangue minerals identified by Guilbert include quartz, and calcite. Chappell (1936, p. 131) recognized adularia in an outcrop sample of vein material from the "D" reef. Guilbert (1963) identified three modes of silicification in samples from the L-D mine: (1) quartz flooding in feldspathic sandstone, (2) gray to milky white fine-grained, vuggy vein quartz, and (3) coarse-grained, clear coxcomb quartz. Guilbert emphasized that the flood silica and milky quartz modes are not necessarily representative of sequential silicification stages, and suggested that the two may be contemporaneous (Guilbert, 1963, p. 23).

Lamellar quartz with attendant calcite is common in veins at the L-D mine, particularly in Block 2. The lamellar quartz with infilling calcite is commonly in the inner portion of the veins, but some veins display this structure across the entire vein width. Only minor amounts of sericite and kaolinite are present in wall rocks of Blocks 1 and 2 of the 1250 level. Feldspathic sandstones in the northwest portion of Block 3 are argillized but still contain auriferous veins. Sedimentary rocks exposed in road cuts at the ridge crest between "D" reef and the "B" reef complex are moderately argillized.

OTHER MINERALIZED AREAS

No economic mineralization has been identified at "E" reef, "C" reef, "A" reef, "F" reef, or "G" reef, although each of these exposures has been prospected in varying degrees of detail. "A" reef is the largest of the subeconomic outcrops of mineralized rock and has been prospected thoroughly since 1952, when Anaconda drove approximately 500 feet of exploratory drifts at the 1250 foot elevation. A short exploration drift was also driven into the "C" reef outcrop, and numerous trenches and small pits have been excavated in the vicinity of "F" and "G" reefs. Subsequent to these early exploration efforts, intensive diamond drilling has been conducted at "A" reef and "C" reef by Cyprus Mines Corporation and Asamera Minerals and Breakwater Resources. To date, none of these efforts have been successful in locating any ore grade material in sufficient tonnage to be economic.

With the exception of "A" reef, all of the peripheral reef consist of silicified, veined sedimentary rocks, generally similar in appearance to the "B" reef and "D" reef. At "A" reef, the Saddle Rock andesite has been altered and weakly mineralized with gold. Figure 64 is a map of the 1250 exploration drift at "A" reef. Sedimentary rocks east of the andesite have been extensively brecciated, and bedding attitudes are not recognizable. The andesite is intensively silicified and not recognizable as andesite, except for a few relict hornblende "ghosts" in thin section. Petrographic examination of silicified andesite sampled from surface exposures at "A" reef reveal that the rock is pervasively silicified and argillized in a selectively pervasive style. Plagioclase grains are altered to pale-brown clay that has been tentatively identified by x-ray diffraction as kaolinite (R. Ashley, written communication, 1986). Hornblende phenocrysts are altered to pale-brown kaolinite(?) and pyrite. The groundmass of the andesite is completely altered to fine-grained quartz, and millimeter-size quartz veinlets cross-cut this pervasively silicified groundmass.

The highest grades of gold mineralization at "A" reef occur in quartz veins in the altered andesite. These veins have a dominant northeast strike, and dip 50° to 60° to the southeast (Figure 64). In contrast to veins in the "B" reef complex, the quartz veins at "A" reef do not have a crustified appearance, and consist mainly of white drusy quartz.

North of the "A" reef outcrop, two isolated blocks of silicified, veined feldspathic sandstone are exposed. Drilling and trenching indicate that these blocks are not connected to each other or to the "A" reef outcrop. Numerous drill holes in the vicinity of "A" reef indicate that alteration and veining do not persist below approximately the 950-foot elevation, and that the silicified zone is underlain by sheared carbonaceous claystone beds or gouge material. For this reason, "A" reef, and the blocks of mineralized rock to the north are interpreted to be down-dropped from "F" reef (Plate 2).

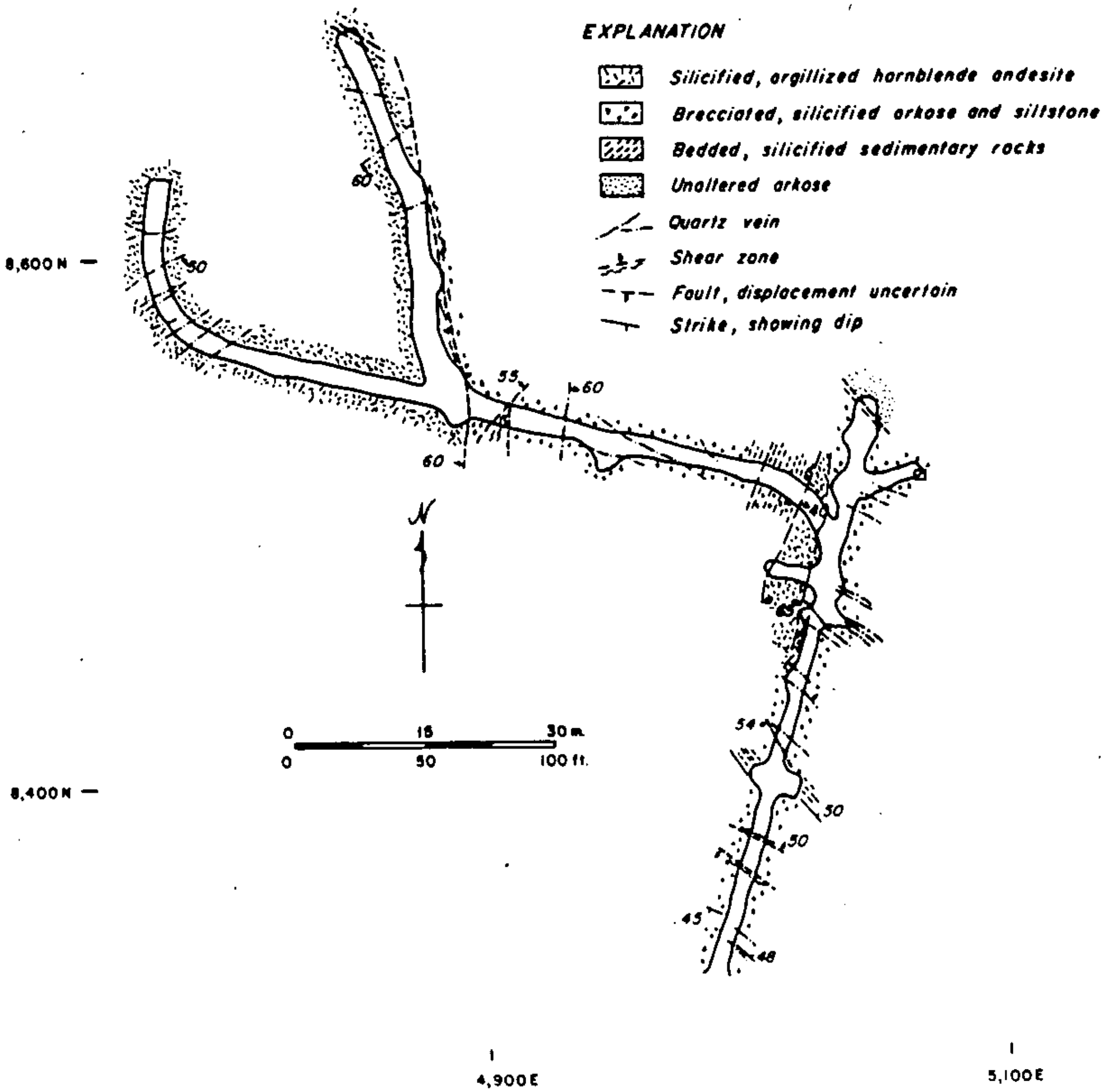


Figure 64. Geologic map of the 1250 level at "A" reef.

"F" and "G" reefs are of interest because they are the only zones of altered sedimentary rocks west of the Saddle Rock andesite. Unfortunately, there is a paucity of outcrop in the area and drilling is not extensive enough to make a very detailed interpretation of the subsurface. From the drill hole information available, there appears to be a diffuse zone of weakly to moderately argillized sedimentary rocks west of the Saddle Rock outcrop, extending from nearly the bottom of Dry Gulch, northwest to "G" reef. Within this zone of argillization are sparse zones of more intensively argillized and, uncommonly, silicified sedimentary rocks. Gold values are generally low, but some intercepts of silicified rock have produced assays in excess of 0.20 oz/ton over a five foot core run. "F" and "G" reefs are apparently larger silicified zones within the northwest-trending argillic zone, but an assessment of the full mineralization potential in this area will require additional subsurface information.

"C" reef appears to be a weakly mineralized extension of "D" reef, and can possibly be considered as Block 4 in the en echelon series (Plate 1). The exploratory drift into the "C" reef was not accessible during this investigation, but existing assay and geologic maps show low grades of gold in silicified, brecciated sedimentary rocks. The southernmost limit of drift at "C" reef is approximately 250 west and 350 feet above the northwesternmost limit of drifting in Block 3 of the 1250 level. This amount of displacement is within range of estimated displacement on the North South fault which separates Blocks 1 and 2.

Hornblende andesite, compositionally equivalent to, and on strike with the Saddle Rock andesite crops out immediately west of "C" reef. In surface exposure, this andesite exposure is not appreciably altered, but drilling shows the andesite to be weakly argillized at depth, similar to andesite intercepted by drilling along the western margin of the "B" reef complex. No drilling has been conducted west of the andesite exposure adjacent to "C" reef to investigate the potential presence of mineralized and altered rocks similar to the trend west of the Saddle Rock exposure.

"E" reef forms a small topographic high in the mouth of the drainage west of "D" reef (Plate 1). A limited amount of drilling has been conducted at "E" reef by Cyprus and, more recently, by the Lovitt Mining Company (Folk, 1987). Data are not sufficient to determine the relationship of "E" reef to "D" reef. "E" reef may be a structurally detached block that was initially part of "D" reef, but the required displacement would be inconsistent with known fault patterns in the district. Hornblende andesite has been encountered by drilling west of the "D" reef outcrop, between "E" reef and "C" reef and may continue southeast between "E" reef and "D" reef (Plates 1 and 2). "E" reef may represent a southeastern extension of the trend of altered sedimentary rocks extending from "G" reef to the bottom of Dry Gulch.

DISCUSSION

The mineralogical and textural characteristics of ore deposits in the Wenatchee district are typical of those found in epithermal precious metal deposits worldwide. The principal characteristics and occurrences of epithermal systems as well as conceptual models of the genesis of epithermal precious metal deposits, are reviewed in recent literature by Berger and Eimon (1983), Buchanan (1981), Durning and Buchanan (1981), Hayba and others (1985), and Heald and others (1987). Such models are either based on, or substantiated by, studies of active geothermal systems (Weissberg and others, 1979; White, 1981; Henley and Ellis, 1983), some of which are currently depositing ore-grade concentrations of gold and silver (Weissberg, 1969; Krupp and Seward, 1987; Hedenquist and Henley, 1985).

Ore deposits in the Wenatchee district can be classified in the gold-selenide category of epithermal deposits as proposed by Lindgren (1933). Other selenide-bearing epithermal precious metal deposits include Knob Hill, Golden Promise, and Seattle deposits in the Republic district of Washington (Dixon and Brackney, 1986; T. Devoe and R. Tschauder, oral communication 1988), the De Lamar-Silver City district, Idaho (Barrett, 1985; Bonnichsen, 1983; Pansze, 1975; Lindgren, 1900), the Hishikari gold deposit in Japan (Abe and Kawasaki, 1987), and Guanajuato, Mexico (Gross, 1975). The most common selenide minerals at these localities are aguilarite and naummanite, which were important ore minerals at the L-D mine.

Fluid inclusion analyses of veins from the "B" reef complex were unsuccessful, and light stable isotopes have not been investigated in the Wenatchee district; therefore, there is no quantitative data on the original chemistry of hydrothermal fluids responsible for mineralization. In this discussion, it is assumed that the general chemical characteristics of the mineralizing fluids were similar to other epithermal fluids, and fluids in active geothermal systems, that have been extensively analyzed. The fluids were probably dilute (Nash, 1972; Hayba, 1983), of meteoric origin (O'Neil and Silberman, 1974), temperatures ranged from 300^{0}C to 100^{0}C (Hayba, 1983), the principal solutes were SiO_2, Na, K, Ca, Cl, CO_2, H_2S, and CH_4 (Ellis, 1979), the pH range was slightly acidic to slightly alkaline (Henley, 1985), and gold transport was by means of either chloride or bisulfide and thiosulfide complexes (Seward, 1973, 1984; Cole and Drummond, 1986). Furthermore, sulfide and gangue mineral precipitation may have resulted from either fluid boiling or mixing with oxygenated waters (Buchanan, 1981; Berger and Eimon 1983; Drummond and Ohmoto, 1985; Reed and Spycher, 1985; Cole and Drummond, 1986).

Within these constraints, an interpretation of the geochemistry of the hydrothermal system responsible for mineralization in the Wenatchee district will be made. This interpretation will be based on ore and gangue mineralogy, vein and breccia textures, alteration patterns, trace element assemblage, and comparison of these data with similar characteristics in other epithermal deposits.

Davidson (1960) investigated the occurrence of selenium in some epithermal deposits hosted by volcanic rocks, and has suggested that selenium concentrations may be influenced by the degree of crystallinity of extrusive rocks. Davidson (1960, p. 14) has proposed that selenium is lost in the process of crystallization, and that rapidly cooled, noncrystalline volcanic rocks retain their selenium content. Coleman and Delevaux (1957, p. 525) have proposed that selenium enrichment in sedimentary rocks is suggestive of a volcanic provenance.

Similar ionic charge and radii permit ready substitution of selenium for sulfur in many common sulfide minerals, and Coleman and Delevaux (1957, p. 522) have proposed that a complete isomorphous series FeS_2-$FeSe_2$ may exist at moderately high temperatures. Isomorphous series for PbS-PbSe have been produced experimentally by Earley (1950, p. 356) and identified in nature by Coleman (1958, p. 1679). Wright and others (1965, p. 1814) produced continuous solid solutions for PbS and PbSe, and for ZnS and ZnSe at temperatures as low as 300^0C. Davidson (1960, p. 3) has proposed that a similar system may exist for Ag_2S-Ag_2Se. Petruk and others (1974, p. 369) determined from specimens from Guanajuato, Mexico and Silver City, Idaho, that acanthite composition can vary from Ag_2S to $Ag_2S_{0.85}Se_{0.15}$, aguilarite composition from $Ag_4S_{0.95}Se_{1.05}$ to $Ag_4S_{1.10}Se_{0.90}$, and naummanite composition from Ag_2Se to $Ag_2S_{0.12}Se_{0.88}$. They assumed a complete solid solution between argentite and naummanite above 176^{0}C (Petruk and others, 1974, p. 368). No naturally occurring gold selenide minerals have been reported, although various forms of AuSe have been produced experimentally (Cranton and Heyding, 1968), and fishchesserite (Ag_3AuSe_2) the selenium analog of petzite, has been reported in carbonate veins at Predborice, Czechoslovakia associated with native gold, naumannite, and clausthalite (Zdenek and others, 1972, p. 1554).

Trace amounts of Se associated with mineralization at the "B" reef complex are possibly an indication of limited substitution of Se for S in one or more of the sulfides present. However, microprobe analysis of these pyrargyrite, acanthite, and electrum did not detect any selenium.

Pyrargyrite and electrum are the principal ore minerals in the "B" reef complex. Most experimental studies on the stability of pyrargyrite have focused on its phase relations with other sulfosalts and argentite (Chang, 1963; Craig and Barton, 1973; Keighin and Honea, 1969). Barton and Skinner (1979, p. 383) point out that sulfosalts are not particularly good indicators of physical conditions of ore formation, as they represent a diverse group of minerals that require sophisticated analytical techniques for positive identification. Barton and Skinner also point out that sulfosalts are difficult to synthesize experimentally as they have undesirable quenching properties, and are compositionally complex.

Textural relations indicate that pyrargyrite has been partially replaced by electrum in vein samples from the "B" North ore body. This may indicate that sulfur activity decreased during the period of ore mineral deposition. Margolis (1987, p. 78) interpreted the paragenetic sequence of arsenopyrite to stibnite to native antimony in vein samples from the Wenatchee Heights area to be indicative of decreasing sulfur activity with time.

The nature of precious metal transport in solutions from which ore bodies in the Wenatchee district were deposited is uncertain. Experimental work by Cole and Drummond (1986, p. 53) indicates that $Au(HS)_2^-$ (and presumably similar sulfide complexes) is more stable than chloride complexes at relatively low temperatures (less than 250^0C), high pH (>5) and high total H_2S concentrations, and that the ratio of silver to gold in solution in these solutions is generally less than 10. Their work also predicts that deposits precipitated from solutions that transport gold as bisulfide complexes will contain argentite as the dominant silver mineral with subordinant native silver (and presumably silver as electrum), and that these deposits will have low Ag/Au ratios provided that the Ag/Au ratio in solution is not significantly changed during mineral precipitation (Cole and Drummond, 1986, p. 58). Solutions in which $AuCl_2^-$ is stable are characterized by relatively high temperatures ($>250^0C$), low pH (<5), lower H_2S concentration, and higher chloride concentration (Cole and Drummond, 1986, p. 53), and that the dominant silver mineral deposited from these solutions will be native silver, with subordinant argentite. Ag/Au ratios in solutions in which chloride complexes are dominant tend to be greater than 10 and typically are greater than 100.

The silver/gold ratio at both "D" reef and the "B" reef complex is between 1 and 2, and this may indicate metal transport as bisulfide complexes, and would be compatible with observed metal complexes in active geothermal systems (Seward, 1973; Krupp and Seward, 1987, p. 1127). Acanthite is not abundant, as would be expected in hydrothermal environments in which gold is transported as a bisulfide complex (Cole and Drummond, 1986, figure 3), but pyrargyrite, paragenetically earlier than electrum, may indicate comparatively high total H_2S concentrations. Precipitation of silver as electrum later in the period of ore deposition reflects decreasing sulfur activity, but does not necessarily suggest precious metal transport by chloride complexes (Cole and Drummond, 1986, p. 53).

The reasons for episodic variation in fluid chemistry, indicated by symmetric encrustations of quartz, chalcedony, and adularia, are not fully understood, but fluid boiling is a possibility. No direct evidence of fluid boiling was found in this investigation. Criteria described by Buchanan (1981) as evidence for fluid boiling include fluid inclusion data, the presence of very fine-grained quartz, ore shoots with flat bottoms, and the presence of a low-pH alteration assemblage overlying ore. The lower boundary of mineralization in the

"B" North and "B-4" zones is stratigraphically controlled but the nature of the lower boundary has not been identified in the "B" Neath zone. Elswhere in the district, the bottom of mineralization appears to be controlled by post-mineralization faults. Fine-grained quartz is abundant in all ore bodies in the district, and rocks overlying the "B" reef complex are argillized and wall-rock and vein breccias, and stockwork veining in massive feldspathic sandstone beds indicate excessive fluid pressures, and local, violent pressure release, with attendant boiling. Also, the spherical-clast breccias associated with many veins and breccia zones are indicative of grain abrasion in a vapor-dominated environment.

Numerous workers have cited evidence of fluid boiling in epithermal systems (Buchanan, 1981; Berger and Eimon, 1983). Drummond and Ohmoto (1985) and Reed and Spycher (1985) discuss important changes in fluid chemistry that are caused by boiling. Silicate precipitation, particularly quartz, is primarily a function of temperature in near-surface hydrothermal systems (Fournier, 1985, p. 55). Of particular interest is the work by Reed and Spycher (1985) on the stability of potassium silicate minerals in a boiling epithermal solution. Reed and Spycher (1985, p. 258) have shown that muscovite and K-feldspar precipitate because Al is liberated from $Al(OH)_4^-$ as temperature decreases. These silicate minerals, therefore, are not precipitated as a result of boiling. However, K-feldspar is more stable than muscovite in high pH solutions, as is indicated by the following

00^{0}C as quartz at about 220^{0}C
3.2); therefore, considerable cooling
red to precipitate opal. In veins in
opal(?) is minor, and occurs most
late, associated with fine-grained
lamellar boxworks, where quartz has
edony generally occurs as discontin-
the borders of fine-grained quartz
persaturation with respect to quartz
ny to precipitate (Fourneir, 1985, p.

71) has shown that, in most natural
te can be precipitated by heating or
cooling of solutions, without
tends to increase calcite solubility.
undant in the "B" reef complex, it
ior portions of veins; elsewhere, the
s are filled with hydrothermal breccia
quartz. One possible interpretation
that vein carbonate was precipitated
ling in the mineralizing fluids, but
ling of the hydrothermal system,
reased, and quartz solubilities
the replacement textures observed.
at the "B" reef complex are
tion patterns associated with
pithermal deposits as described by

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