11. THE GEOLOGY OF THE ENFIELD BELL MINE AND THE JERRITT CANYON DISTRICT, ELKO COUNTY, NEVADA[1]

by Donald J. Birak and Robert B. Hawkins

INTRODUCTION

The discovery of the disseminated gold deposits in the Jerritt Canyon district and development of the Enfield Bell mine have contributed greatly to the resurgence in exploration for disseminated gold deposits in Nevada and the western United States. The Jerritt Canyon project and Bell mine is a 70/30 joint venture between Freeport Gold Company and FMC Gold Incorporated which are wholly owned subsidiaries of their parent companies, Freeport-McMoRan Incorporated and FMC Incorporated, respectively.

The Jerritt Canyon district lies within the Independence Mountains in north-central Elko County, Nevada, approximately 80 km north of Elko (fig. 57). The Bell mine is located in the center of the Independence Range in the Jerritt Canyon Window of the Roberts Mountains Thrust. Ore is mined from carbonaceous and oxidized portions of the Roberts Mountains and Hanson Creek Formations, and is treated in a standard cyanidation mill, located approximately 12.8 km east of the mine.

HISTORY AND PRODUCTION

The discovery of gold mineralization in the Jerritt Canyon district was preceded by an antimony exploration program initiated by FMC in 1971, based upon antimony occurrences in the area reported by Lawrence (1963). Exploration emphasis shifted to gold when geologists recognized similarities

[1]Published with the permission of Freeport Gold and Freeport Exploration Companies.

Figure 57.--Location and general geology of the Jerritt Canyon district and the Enfield Bell mine area. Exposures of upper plate rocks are denoted by diagonal lines, while areas of lower plate rock exposure are unpatterned.

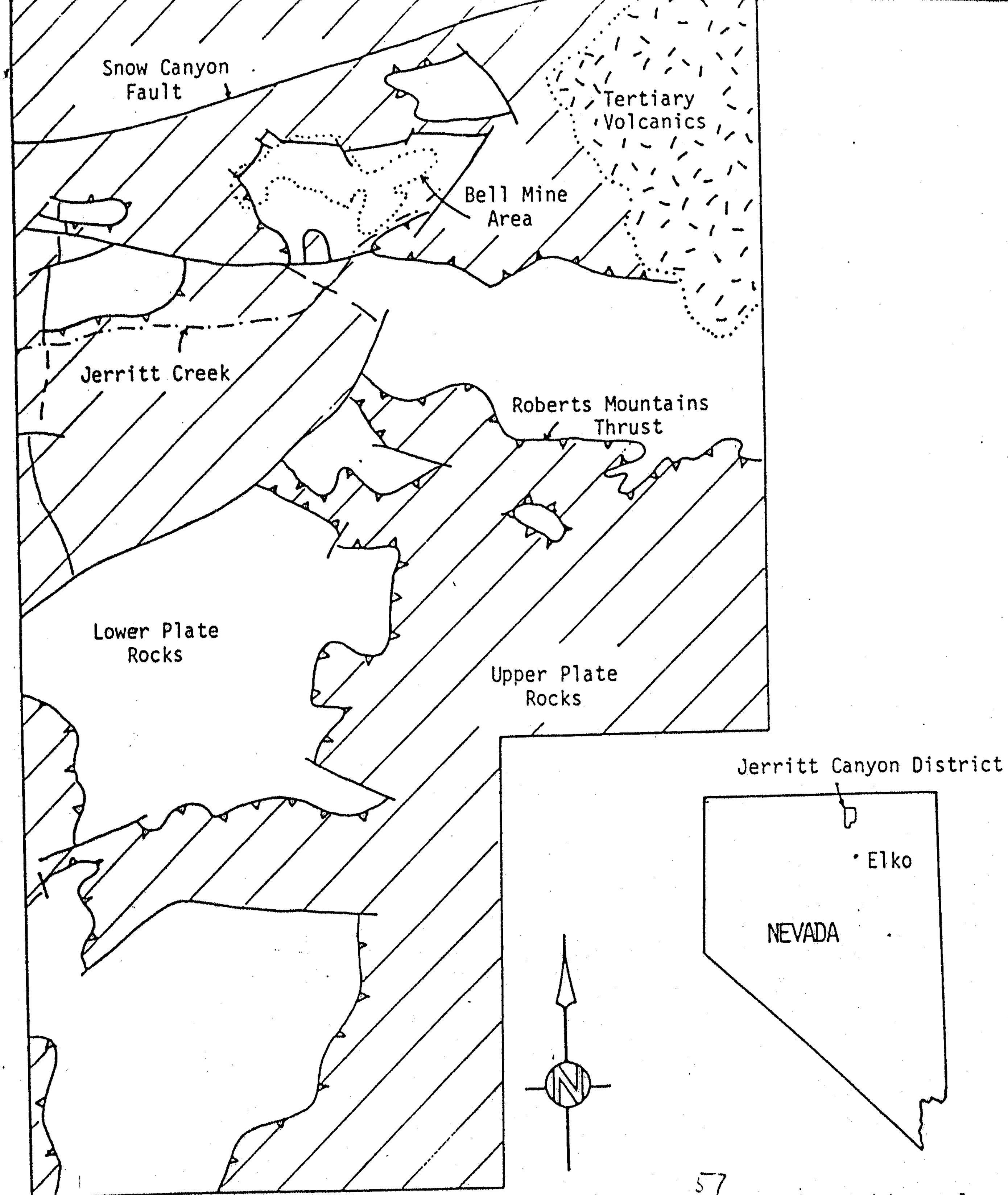


Figure 1. Location and general geology of the Jerritt Canyon District and the Enfield Bell Mine Area. Exposures of upper plate rocks are denoted by diagonal lines, while areas of lower plate rock exposure are unpatterned.

between this area and the Carlin orebodies. Mapping, sampling, and geochemical analyses led to the discovery of a gold anomaly along the north fork of Jerritt Creek. Drilling of this anomaly in 1973 revealed significant grades and thicknesses of gold mineralization in the lower portions of the Roberts Mountains Formation. Based upon this discovery, additional drilling was performed that delineated several small pods of low-grade gold mineralization. The mineralization was significant but not sufficient to constitute a mineable discovery.

In 1976, Freeport Exploration Company assumed management of the project through a joint venture agreement with FMC and began an expanded program of geologic mapping and geochemical sampling that led to a new understanding of the geology of the district. Several new geochemical anomalies and drill targets were defined including the Marlboro Canyon orebody, which is now part of the Bell Mine. Although a classic "bullseye" geochemical target was the clue that led to the initial discovery in the north fork of Jerritt Canyon, the bulk of current reserves were found beneath a cover of colluvium and soil that was geochemically barren.

A decision to proceed with the construction of a mine and mill was made in 1979 and full-scale mill production began in July of 1981. Current reserves are in four orebodies designated as the Marlboro Canyon, North Generator Hill, West Generator Hill, and Alchem deposits. Mining has proceeded for the last three years within the Marlboro Canyon deposit and part of the North Generator Hill deposit referred to as Lower North Generator Hill. Milling proceeds at a design rate of 3200 short tons per day (2900 metric tons per day) of oxidized and carbonaceous ore.

REGIONAL GEOLOGY

The geology of the Jerritt Canyon district (Hawkins, 1973) is similar to that of the Lynn window (Radtke and others, 1980) insofar as much of the district is composed of Paleozoic sedimentary and volcanic rocks of the upper and lower plates of the Roberts Mountains thrust fault (fig. 57). The upper plate is an Ordovician eugeosynclinal sedimentary and volcanic assemblage composed of shales, argillites, cherts, quartzites, and intermediate to mafic flows with lesser amounts of limestones and bedded barite. Basinal miogeosynclinal rocks comprise the lower plate and consist of Ordovician through Lower Devonian siltstones, limestones, cherts, and quartzites. Deformation during the late Devonian Antler orogeny moved the eugeosynclinal rocks (allochthon) eastward over the miogeosynclinal assemblage (autochthon), along the Roberts Mountains thrust fault (Merriam and Anderson, 1942). Good exposures of the thrust are not common in the Jerritt Canyon district. Where it is exposed, the thrust contact may be very undulatory. Folding of the lower and upper plate rocks is recognized locally as a manifestation of this thrusting. A major southwest plunging assymetrical anticline, referred to as the Map anticline, is believed to have formed at this time.

Contemporaneous with the Robert Mountains thrust, several imbricate low-angle normal and reverse faults within the upper and lower plates were formed. These faults are important insofar as they caused locally significant truncations of stratigraphy, providing excellent pathways for hydrothermal fluids. Several of these structures have been recognized within the lower plate rocks in the mine area.

Tertiary igneous activity in the district produced several different extrusive and intrusive rocks, none of which are found in the immediate mine area. A granodioritic to tonalitic pluton, measuring approximately 4,000 square meters in outcrop, was emplaced in the southwest portion of the district. While no age determinations have been made on this pluton, it is possibly as old as 120 million years and equivalent in age to the Gold Strike stock north of the Carlin mine (Hausen and Kerr, 1968) or as young as 38 million years and equivalent in age to the Mount Neva stock near the town of Tuscarora, Nevada (Coats and McKee, 1972). Perhaps contemporaneous with granitic plutonism was the formation of several intermediate to mafic dikes and sills. These intrusives are widely scattered across the district and are relatively small; their outcrops usually measuring less than 10 m wide and 30 m in length.

Deposition of andesitic and rhyolitic flows and ash-flows occurred about 43 to 34 million years ago (Stewart, 1980). Deposition of andesitic volcanics is interpreted, from mapping evidence, to be the older of the two events. Subsequent faulting and erosion have limited exposure of the volcanics to the extreme northeast corner of the district.

Basin and Range associated tectonism during the Miocene (Stewart, 1980, p. 110) produced a steep block-faulted terrain. Three prominent Basin and Range fault sets trend east-west, northwest, and northeast within the district. Hawkins (1982) postulated that the east-west fault set may have been active during the Mesozoic, and was followed by the development of northeast and northwest trending faults during the Basin and Range event. The Snow Canyon Fault is one of the major east-west faults and occurs just north of the Jerritt Canyon Window (fig. 57). Similar but smaller scale east-west faults in the mine are are the Marlboro Canyon and Bell faults (fig. 58), which may have also formed first in the Mesozoic.

Figure 58.--Preliminary geologic map of the Enfield Bell mine, Jerritt Canyon district, Elko County, Nevada.

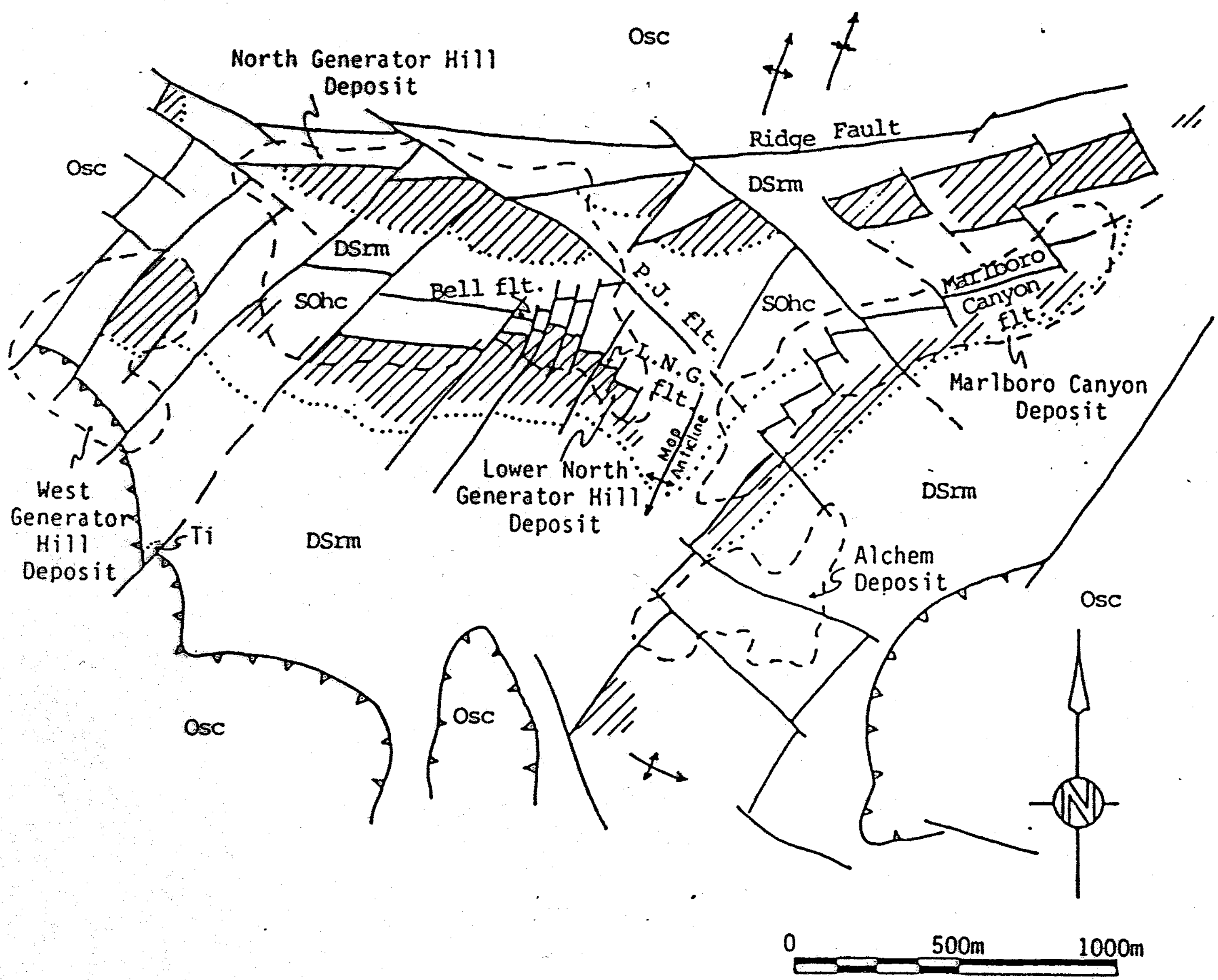


Figure ~~2~~ 58. Preliminary geologic map of the Enfield Bell Mine, Jerritt Canyon District, Elko County , Nevada.

LEGEND

- silicification
- ore deposit
- contact
- fault (dashed where approx.)
- thrust fault
- plunging fold

Osc - Snow Canyon Fm.
DSrm - Roberts Mountains Fm.
SOhc - Hanson Creek Fm.
Ti - Tertiary Intrusive

Erosion of uplifted blocks along these faults locally removed the upper plate rocks exposing the lower plate as windows in the Roberts Mountains thrust (fig. 58). In most areas the contact between the upper and lower plate rocks in the Jerritt Canyon district is thought to be a high-angle fault. Exposure of the Roberts Mountains thrust is limited. Continued erosion resulted in a steep terrain and locally thick alluvial and colluvial cover found in the district.

REGIONAL STRATIGRAPHY

The majority of the rocks in the Jerritt Canyon district are Paleozoic sedimentary and volcanic rocks that have been assigned to the upper and lower plates of the Roberts Mountains thrust (Hawkins, 1973).

Lower Plate Rocks

Lower plate stratigraphy within the Independence Mountains has been described by Kerr (1962), Hawkins (1973), Collord (written commun., 1979), and Birak (written commun., 1979). While a continuous undisturbed stratigraphic section has not been recognized, sufficient exposures are present to enable the reconstruction of a complete section from the base of the Eureka Quartzite through the Roberts Mountains Formation (table 8).

The Eureka Quartzite of Middle Ordovician age (Langenheim and Larsen, 1973) is recognized throughout most of Central Nevada as a prominent cliff-forming member of the autochthonous assemblage. Exposures of the formation in the district are limited to the southern portions of the Jerritt Canyon window, where it is composed of thick bedded orthoquartzite. Fresh rock is generally light grey with scattered grains of oxidized pyrite. Weathered surfaces may be slightly yellow-brown. Quartz grains are cemented by silica except near the contact with the overlying Hanson Creek Formation where carbonate cement may also occur. While bedding is indistinct, it is

Table ~~1~~ 8. Stratigraphic section of the Jerritt Canyon District.

Age	Rock Type or Formation		
Tertiary	Andesitic and Rhyolitic Volcanics Intermediate to Mafic Dikes and Sills (age uncertain)		
Cretaceous	Granodiorite to Tonalite Intrusive (age uncertain)		
Devonian			
Silurian		Roberts Mountains Thrust	Roberts Mountains Fm. (Llandoverian - Gedinnian)[2]
Ordovician	Jacks Peak Fm. (Caradocian)[1] McAfee Quartzite (Llandeilian - Caradocian)[1] Snow Canyon Fm. (Argenian - Llandeilian)[1]		Hanson Creek Fm. (Caradocian - Llandoverian)[3,4] Eureka Quartzite (? - Caradocian)[2,5]

1. Ages from Churkin and Kay, 1967.
2. Ages from Merriam and McKee, 1976.
3. Ages from Matti and others, 1975.
4. Ages from Forrest and Poole, 1972.
5. Ages from Langenheim and Larson, 1973.

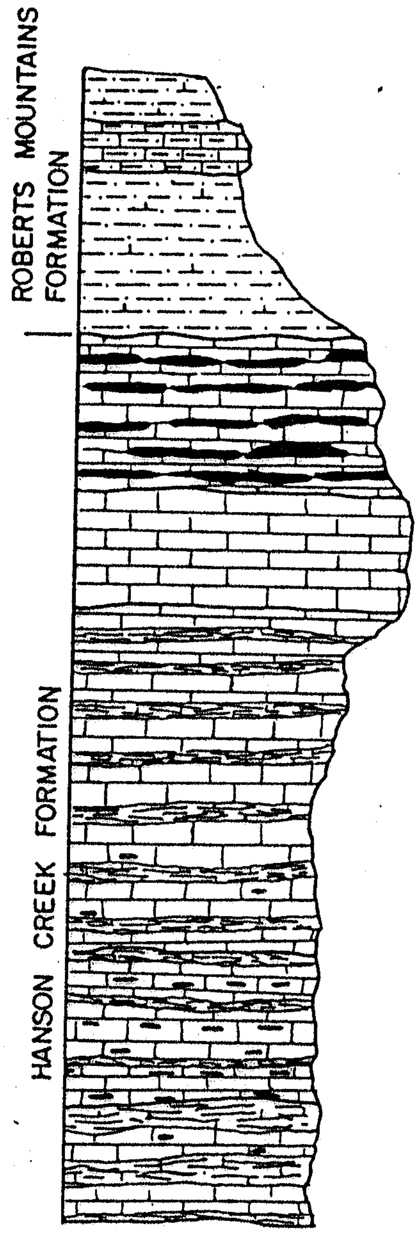
generally massive and in excess of 3 m thick. Fossils are rare but local exposures yield graptolite molds. Measured thicknesses of the Eureka Quartzite range from 150 to 190 m. While the base of the formation has not been well studied, the upper contact is interpreted to be gradational with the Hanson Creek Formation.

The Hanson Creek Formation of late Ordovician to early Silurian age, (Matti and others, 1975) is the major host rock at the Bell mine and is exposed in many parts of the Jerritt Canyon window. Using surface and subsurface data, Birak (written commun., 1979) has subdivided the Hanson Creek Formation into five lithologic units (fig. 59) designated as SOhc-I (youngest) through SOhc-V (oldest) (fig. 59). Since the upper parts of the Hanson Creek Formation are much more well known and occur more commonly in outcrop than the lower units, it was decided to number the units, consecutively from the top down.

The lower three units of the Hanson Creek Formation (SOhc-III, -IV, and -V) are carbonaceous, banded limestones. The banding is the result of alternating beds of micritic limestone and laminated, dolomitic limestone in which the laminated beds are the most carbonaceous. Pyrite occurs in both beds although it is more abundant in the laminated beds.

The basal unit, (SOhc-V), as measured, contains as 5 to 30 m of interbedded dolomitic limestone and thin-bedded micritic limestone with some silty parts near the basal contact. Fossils recognized are crinoidal, brachiopod, bryozoan, and radiolarian fragments. Near the top of the SOhc-V, an intraclastic layer has been recognized in which the intraclasts contain fossil debris mixed with carbon stringers and pods and carbonate cement. Locally, lenses and pods of black, carbonaceous chert have been recognized.

Figure 59.--Generalized stratigraphic section of the lower plate rocks in the Bell mine area.



DSrm – Variably calcareous or dolomitic laminated siltstone and one bed of silty laminated limestone. Major host to gold mineralization.

DISCONFORMITY

SOhc I – Interbedded chert and limestone. Minor host to gold mineralization.

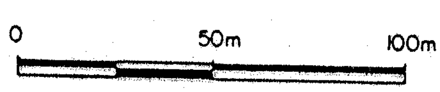
SOhc II – Thick-bedded limestone with wavy-bedded or nodular, oolitic, and laminated parts. Minor host to gold mineralization.

SOhc III – Interbedded micritic and laminated carbonaceous limestone with minor chert nodules and lenses near base. Major host to gold mineralization.

SOhc IV – Interbedded micritic and laminated carbonaceous limestone with abundant chert nodules and lenses within the micrite beds. Micrites may be faintly laminated.

SOhc V – Interbedded laminated and micritic carbonaceous limestone. Laminated beds predominate minor chert nodules and lenses.

Figure 57 Generalized stratigraphic section of the lower plate rocks in the Bell Mine area.



The overlying SOhc-IV is a 30 to 40 m thick sequence of carbonaceous banded limestone with abundant black chert nodules and lenses 5 to 25 cm long oriented parallel to bedding. Laminated beds are less well developed than in either the SOhc-V or SOhc-III. Fossil fragments are similar to those found in the basal unit.

The middle unit of the Hanson Creek Formation (SOhc-III) is a sequence of alternating carbonaceous, micritic limestone beds and laminated, carbonaceous, dolomitic limestone beds. The unit is the main host for gold mineralization in the Bell mine (fig. 59), and has been measured in excess of 90 m thick in exposures in the southern portions of the district. Chert beds, generally less than 10 cm long and 2 cm thick, occur sporadically in the lower portions of the unit. Studies have shown that gold mineralization favors the more permeable laminated beds, occurring locally in quantities 10 times greater than in the micrite beds.

Overlying SOhc-III is a variably textured 30 m thick limestone, SOhc II. Four different rock types have been recognized: (1) thick-bedded limestone, (2) wavy, thin-bedded to nodular limestone, (3) oolitic limestone, and (4) wavy-laminated limestone. The SOhc-II is weak to non-carbonaceous, weakly pyritic, and is locally entirely composed of dolomite. Fossils encountered are fairly evenly distributed and similar to those recognized in the lower three units.

The uppermost unit of the Hanson Creek Formation (SOhc-I) is composed of 3 to 40 m of interbedded black chert and carbonaceous limestone. Chert beds are more consistent than in the SOhc-IV and may exceed 100 cm in length and 5 cm in thickness. Pinching and swelling of the chert as a result of soft sediment deformation is common. Sponge spicules, radiolaria, and the lack of diagenetic replacement textures suggest a sedimentary, non-diagenetic origin for the chert. The limestone beds are thicker than the chert beds, comprising up to 75-percent of a measured thickness near the base of the unit. Laminated and non-laminated portions in the limestone beds have been recognized.

The contact between the Roberts Mountains and the Hanson Creek Formations appears to be disconformable. This contention has also been supported by the work of Matti and others, (1975). While previously published reports (Merriam and McKee, 1976; and Mullens and Poole, 1972) have placed the SOhc-I as part of the overlying Roberts Mountains Formation, Freeport geologists cite the sharp nature of the contact between the SOhc-I and Roberts Mountains siltstones, and the similar textures and mineralogy within the five Hanson Creek units as evidence that the SOhc I more properly belongs within the Hanson Creek Formation.

The Roberts Mountains Formation of Middle Silurian to Early Devonian age (Matti and McKee, 1977) is exposed throughout the Jerritt Canyon district. The basal 30 m of this formation is host to gold mineralization in the mine (fig. 59). The estimated thickness of the Roberts Mountains Formation is 300 m, however, the uppermost portions have been truncated by the Roberts Mountains thrust, which forms the upper contact of the formation. The major rock type of the Roberts Mountains Formation is a laminated, fissile, variably calcareous to dolomitic siltstone. The rock is composed of well-rounded, well-sorted quartz silt grains with carbonate as cement. Accessory minerals include illite/sericite, chlorite, anastamosing carbon filaments, disseminated pyrite, and a distinctive heavy mineral suite. Black lenses composed of carbon, pyrite euhedra, and fibrous chalcedony, .5 cm thick and 2 to 5 cm long oriented parallel to bedding, are common in the basal portions of the formation. Fossils are rare and are limited to graptolite molds on parting surfaces.

A 10 to 15 m thick bed of laminated to thin-bedded silty limestone occurs near the base of the formation. The more fissile siltstones tend to weather into small, platy fragments, forming steep slopes, while the silty limestone unit is more resistant and can be traced in outcrop for hundreds of meters along strike.

Upper Plate Rocks

The upper plate rocks (western facies) in the Independence Mountains, have been correlated with eugeosynclinal rocks of the Ordovician Valmy Group (Churkin and Kay, 1967). Three formations of Ordovician age are recognized locally (table 8). In ascending order, they are the Snow Canyon Formation, McAfee Quartzite, and Jacks Peak Formation.

While exposures of the McAfee Quartzite and Jacks Peak Formation are limited to the northern-most portion of the district, rocks of the Snow Canyon formation can commonly be found flanking lower plate rocks throughout the district. Only the Snow Canyon Formation is described here.

The rocks that comprise the Snow Canyon Formation in the Jerritt Canyon district are predominantly siliceous sedimentary rocks that are estimated to be 350 m thick (Churkin and Kay, 1967). With the exception of the more resistant members, Snow Canyon rocks do not crop out well and form smooth talus-covered slopes.

Shales, fissile siltstones, and argillites form the bulk of the Snow Canyon section. They are carbonaceous and much less calcareous or dolomitic than the rocks of the Roberts Mountains Formation. Weathered exposures show a characteristic orange-brown staining. Bedding is often very wavy and contorted and soft sediment compaction features are common. Graptolite molds are locally abundant.

Interspersed with the clastic rocks are multi-colored, wavy-bedded cherts that exhibit a knobby texture on their bedding planes, referred to locally as cobblestone texture. Bedding is generally less than 10 cm thick. Bedded grey barite locally occurs with the chert.

Discontinuous layers of grey to brownish quartzite, usually less than 3 m thick, occur within the finer-grained clastic sequence. A thicker quartzite unit, with scattered shale horizons, apparently caps the Snow Canyon Formation. Both types of quartzites are composed of quartz sand grains and scattered pyrite cemented with silica or carbonate. Carbon and random quartz veinlets are recognized locally. Cross bedding, while not abundant, has been observed in the thinner quartzite and siltstone beds.

Mafic pillow lavas occur within the Snow Canyon Formation, sandwiched between argillaceous rock sequences. Chert and limestone can be found sporatically within the lavas. The limestones occur between successive pillow structures. Alteration of these lavas has changed the primary minerals to chlorite, sericite, and carbonate. Pheoncrysts of plagioclase and pyroxene often are totally altered to calcite.

Limestone is the least continuous rock type in the Snow Canyon Formation. Besides occurring within altered mafic lavas, limestones have been recognized interspersed with laminated cherts, shales, and siltstones. A section of shaly, carbonaceous limestone capped by a cliff-forming, intraformational limestone breccia apparently occurs near the base of the formation on the western margins of the Bell mine area.

GEOLOGY OF THE BELL MINE

The Enfield Bell mine is located in the northern portion of the Jerritt Canyon Window. This area is approximately 3,300 m long in an east-west direction and 1,200 m wide in a north-south direction (fig. 58) and contains four known ore deposits. In order of decreasing size these deposits include the Marlboro Canyon, North Generator Hill, Alchem, and West Generator Hill deposits. Current reserves are 13.7 million short tons (12.5 million metric tons) at an average grade of .205 troy oz per ton (7.03 gm per metric ton) occurring in both oxidized and carbonaceous sedimentary rocks. Mineralization is structurally and lithologically controlled within the upper banded limestone of the Hanson Creek Formation (SOhc-III) and lower siltstones of the Roberts Mountains Formation (fig. 59). Lesser amounts of ore occurs in silicified sections of both formations. Small slices of geochemcially barren upper plate rock have been recognized in the Marlboro Canyon pit. Gold currently is being mined from Marlboro Canyon and a portion of North Generator Hill known as Lower North Generator Hill (fig. 58).

Structure

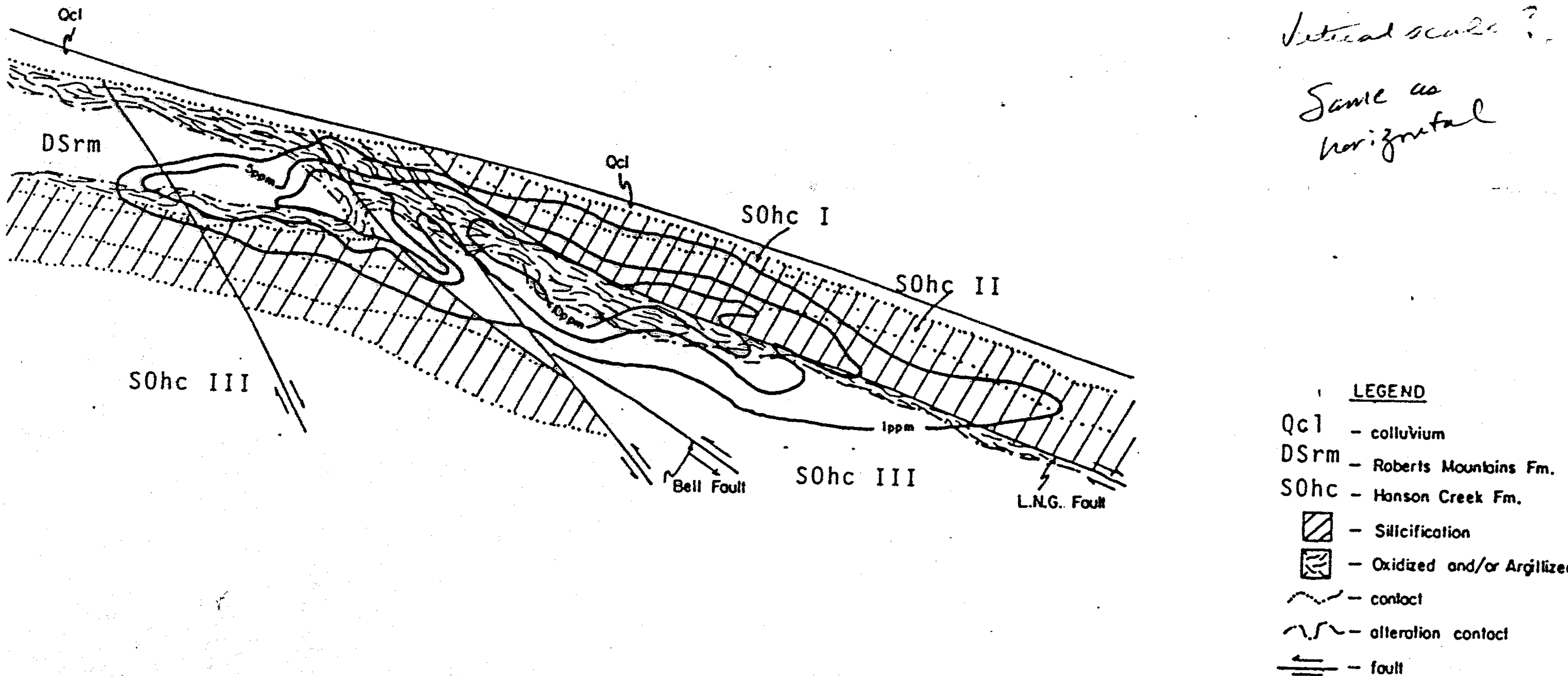
Faulting is common in the Bell mine area and is the most important structural feature related to mineralization; folding may have been contemporaneous with a pre-mineral set of faults. There are four sets of faults in the Bell mine area ranging in age from Devonian to Tertiary. The oldest faults are the Roberts Mountains thrust fault and sympathetic, subparallel low-angle normal and reverse faults within the upper and lower plate assemblages. The presence of imbricate, low-angle faults became evident when detailed mapping revealed reversals and truncations of stratigraphy along brecciated low-angle shears.

East-west-trending faults are the next younger set of major faults in the mine area. These are cut by younger northwest and northeast trending faults, respectively. The ages of these three fault sets is somewhat equivocal. However, it is postulated that the east-west system may have formed first during the Mesozoic with an overprint of Tertiary motion. One such fault is the Snow Canyon fault (Hawkins, 1982), which occurs immediately north of the mine area (fig. 57). Smaller scale, east-west faults within the mine area are the Marlboro Canyon and Paycheck faults within the Marlboro Canyon ore-body, the Bell and L.N.G. faults in the Lower North Generator Hill ore body, and the Ridge Fault which forms the northern boundary of the Jerritt Canyon window (fig. 58).

Figures 60 and 61 are typical cross sections through the Lower North Generator Hill and Marlboro Canyon deposits. They show the characteristics of the Bell and Marlboro Canyon faults, which are the main conduits for mineralization in their respective orebodies. In each case Roberts Mountains and Hanson Creek rocks form the footwall block (north) against Hanson Creek rocks in the hanging wall (south). Estimated relative vertical displacement on these faults is 100 m. Both faults dip steeply south but change dip and strike direction over short vertical and horizontal distances. The Marlboro Canyon Fault changes strike in the west portion of the Marlboro Canyon ore body to more northeasterly, while the Bell Fault changes to a northeasterly strike in the east end of the Lower North Generator Hill orebody (fig. 58)

The L.N.G. and Paycheck faults are also east-west trending faults that formed as a result of uplift along the Bell and Marlboro Canyon faults respectively. These faults dip gently to the south and are believed to have formed as a result of slippage along the boundary between silicified and unsilicified portions of the Hanson Creek Formation. The amount of displacement on the Paycheck and L.N.G. faults is estimated to be less than 30 m. Mineralization is localized in both of these faults. The Paycheck fault changes to a more northeasterly strike at the western edge of the Marlboro Canyon ore-body, while the LNG fault changes to a northwesterly strike on the east side of the Lower North Generator Hill ore body (fig. 58).

Figure 60.--North-south cross section through the central portion of the Lower North Generator Hill deposit. Contours of gold grade are 1, 5, and 10 ppm.



Vertical scale? Same as horizontal

Figure ~~4~~ 68. North-South cross section through the central portion of the Lower North Generator Hill Deposit. Contours of gold grade are 1, 5, and 10ppm.

APPROXIMATE HORIZONTAL and VERTICAL SCALE

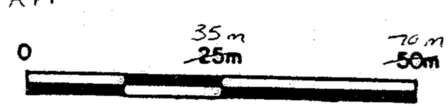


Figure 61.--North-south cross section, looking east, through the central portion of the Marlboro Canyon orebody. Gold mineralization is strongly structurally controlled with greater vertical than horizontal continuity. Contours of gold grade are 1, 5, and 10 ppm.

Vertical scale ?
Same as horizontal

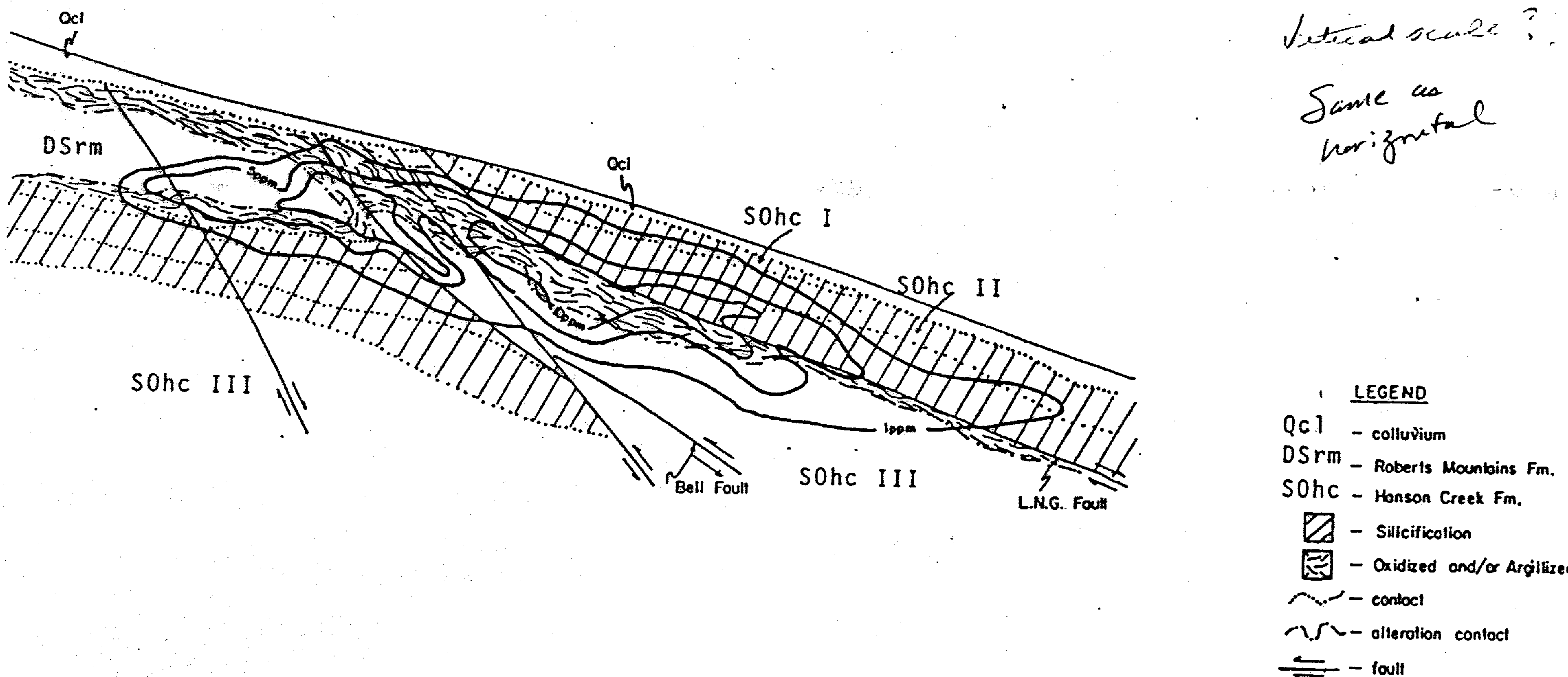
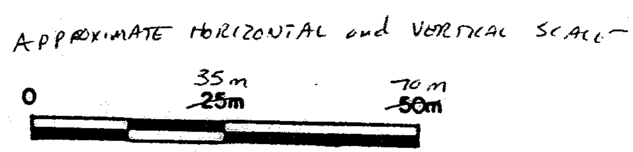


Figure ~~4~~ 6.8: North-South cross section through the central portion of the Lower North Generator Hill Deposit. Contours of gold grade are 1, 5, and 10ppm.



Following formation of the Marlboro Canyon and Bell faults the high-angle northwest and northeast trending faults were formed during Basin and Range tectonism. Mapping evidence of active mine faces suggests that northeast faults are younger than northwest faults. However, the northwest-trending P. J. fault in the North Generator Hill deposit cuts both east-west and northeast faults, indicating that some of the northwest faults formed later than northeast faults. While the genetic relationships of the faulting in the mine area is still equivocal, all faults are interpreted to be pre-gold mineralization. Ore is coincident with faults and blossoms at fault intersections. Figure 62, a geologic map of a typical ore bench in the Lower North Generator Hill pit, shows the relationships of these structures.

The Map anticline, a southwest plunging, asymetrical fold occurs between the North Generator and Marlboro Canyon orebodies (fig. 58) and is believed to have formed as a result of thrusting. The western limb of this fold strikes west-northwest and dips to the south-southwest, while the east limb strikes north-northeast dipping to the east-southeast. Dips on each limb range from 25° to 65°; the eastern limb being the steepest. The fold limbs are delineated by dipping beds of jasperoid, which can be readily seen in aerial photographs.

Orebody morphology

The ore in the Bell mine occurs in two distinctly different modes. The largest, possessing the most continuous and highest grades of gold, are elongate, steeply-dipping, tabular zones (Marlboro-type ore zones), which are typical sites for ore deposition in North Generator Hill and most of Marlboro Canyon. The second type of ore zone (Alchem-type ore zone) is also tabular but is associated with low-angle faults, and often with stratiform

Figure 62.--Geologic map of a typical mine level in the Lower Generator Hill orebody.

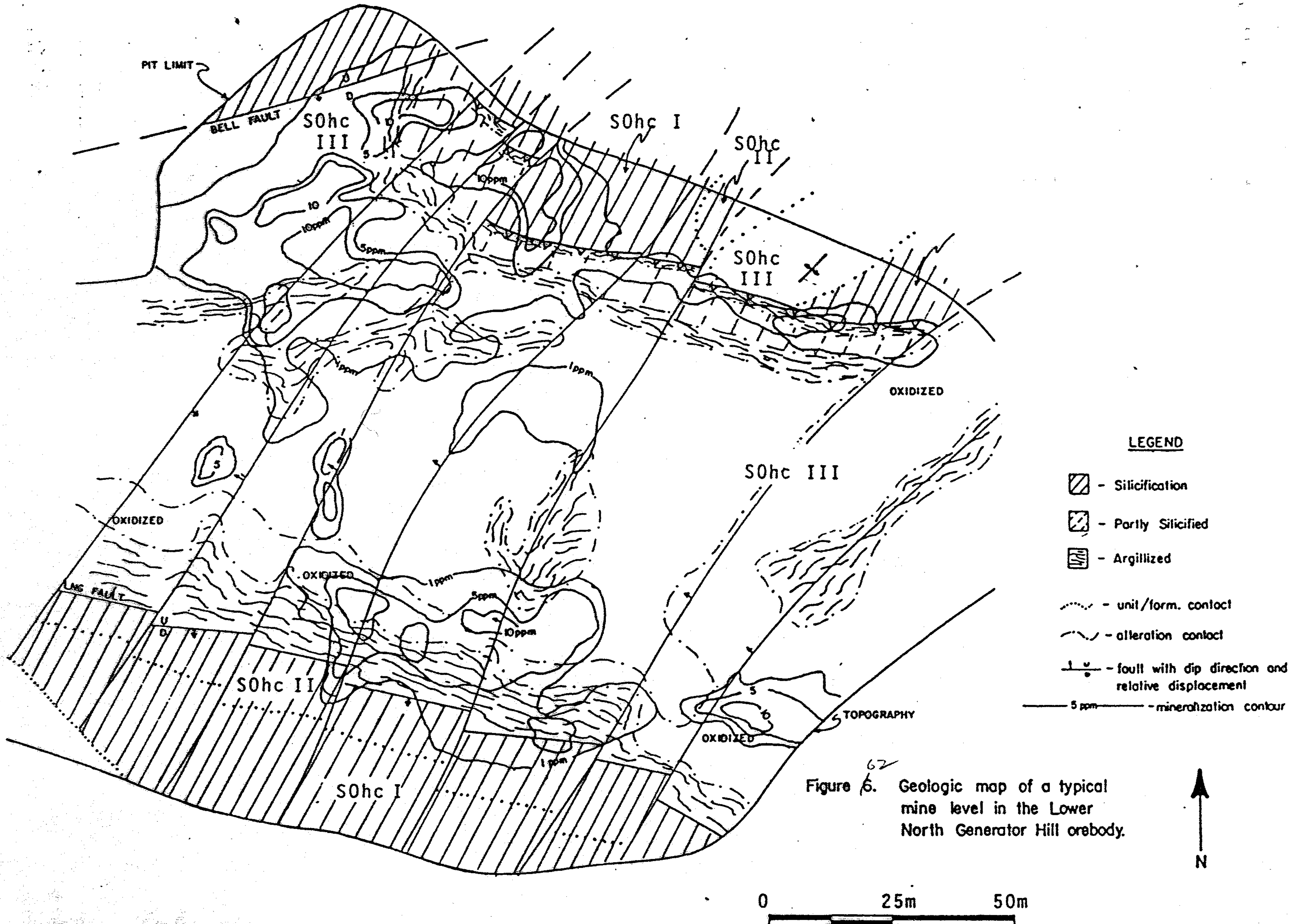


Figure 6. Geologic map of a typical mine level in the Lower North Generator Hill orebody.

jasperoids. The bulk of the ore tonnage in western Marlboro Canyon, Alchem, and West Generator Hill deposits are from Alchem-type ore zones.

The cross section in figure 61 shows a typical Marlboro-type ore zone. A mushroom-like appearance is created by ore values increasing in large increments from the surface down, tapering off more gradually below the main ore intervals. Figure 63 shows a typical cross sectional view of an Alchem-type ore zone. The ore occurs in both unsilicified and silicified portions of the Roberts Mountains Formation and in silicified sections of the underlying Hanson Creek Formation. The contact between the two formations is interpreted to be, in part at least, a low-angle fault. The best ore-grades occur in the Roberts Mountains rocks, and the ore zone may be very undulatory.

Gold in both types of ore zones occurs as micron and submicron grains disseminated in the rock quite typical of ore zones observed in other deposits, such as Carlin. Gold grains observed in thin section may exceed 5 microns in diameter. Generally the gold is less than 2 microns in size and can be observed only with the aid of an electron microscope.

Alteration

Three major hydrothermal events have altered the rocks of the Bell mine: (1) silicification, (2) oxidation and argillization, and (3) carbonization. Silicification, the most prominent event, resulted in alteration of limestones to hard, dense, vari-colored jasperoids. The jasperoids in the mine area stand out in strong relief from the surrounding terrain and are roughly tabular in shape. Approximately 35 to 40 percent of the rocks in the mine area are jasperoids, but constitute less than 10% of the ore. The degree of silicification recognized in the mine area is variable, ranging from scattered quartz veining to complete replacement of the carbonate fraction. Silicification affected rocks of both the Roberts Mountains and

Figure 63.--North-south cross section through the western portion of the Marlboro Canyon orebody showing the stratiform nature of gold mineralization in an Alchem-type ore zone. Contours of gold grade are 1, 5, and 10 ppm.

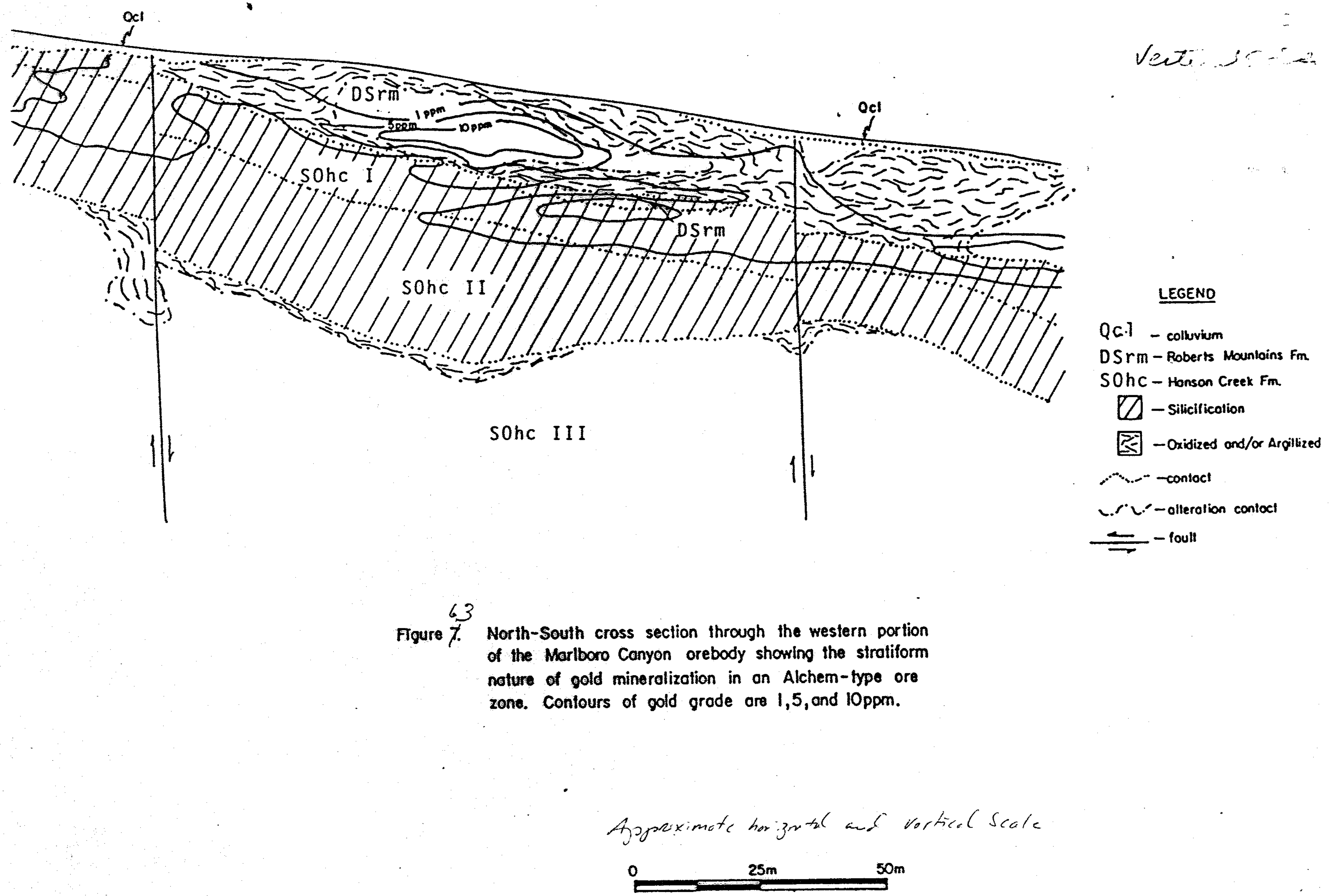


Figure 7. 63 North-South cross section through the western portion of the Marlboro Canyon orebody showing the stratiform nature of gold mineralization in an Alchem-type ore zone. Contours of gold grade are 1,5, and 10ppm.

Hanson Creek Formations, but is more intense in limestones of the Hanson Creek Formation. Mine mapping suggests that all but perhaps the latest phase of silicification occurred prior to Tertiary block faulting. Jasperoids can be seen in razor-sharp contact against unsilicified rocks, horizontally juxtaposed along high-angle faults. It is interpreted that the roughly stratiform nature of the jasperoids is the result of silicification along low-angle faults. The major stage of silicification that formed the jasperoids is also believed to be pre-gold. Gold values are found in silicified and unsilicified rocks on either side of high-angle faults. Gold mineralization does not normally occur in ore-grade concentrations in jasperoids and is usually homogeneously distributed and of lower grade relative to the range of values found in the main ore zones. Locally, jasperoids may host gold mineralization in excess of 30 ppm but generally it ranges from .1 to 1.5 ppm.

Oxidation and argillization are perhaps the most eonomically important alteration events to have taken place in the Bell mine area; the oxidized and argillized rocks contain the highest gold values and are relatively easy to treat with conventional cyanidation techniques of gold recovery. These two types of alteration are spatially coincident and are believed to have similar but not necessarily contemporaneous genesis. Oxidation of the Roberts Mountains Formation produced a tan to light orange-brown, semi-friable siltstone. Pyrite grains are well-oxidized to limonite, and carbon is generally absent. The rock may also be non-calcareous due to associated but limited decalcification. Oxidation within the Hanson Creek Formation is similar to that recognized in the Roberts Mountains Formation. Notable exceptions are; (a) the local oxidation of black, carbonaceous chert lenses and beds to light-brown chert or black chert with brown rims, and (b) the preferrential oxidation of the more-permeable, laminated beds of the third Hanson Creek unit. Again, as in the Roberts Mountains Formation, oxidation of the Hanson Creek Formaiton may be accompanied by decalcification.

Argillization of the Bell mine rocks took place along structurally controlled zones and is considered an advanced, more localized, stage of the oxidation process. This alteration produced clay-rich zones within the Hanson Creek and Roberts Mountains Formations. The clay-rich zones are very tabular with greater vertical than horizontal continuity. This shape is due to their formation along high-angle structures such as the Marlboro Canyon and Bell faults where argillized Hanson Creek limestones occur against argillized Roberts Mountains siltstones (figs. 60 and 61). Argillization is also recognized in rocks directly above and below jasperoids. One such occurrence is along the L.N.G. fault, where argillized and oxidized Hanson Creek limestone forms the footwall of the fault against unargillized jasperoids in the hanging wall (fig. 60). While primary rock textures are often preserved in the argillically altered rock, primary minerals are not. Dominant alteration minerals are kaolinite, sericite, illite, smectites, alunite, jarosite, quartz, and iron oxide. Carbonate, pyrite, and carbon are rarely present. Gold values encountered in argillized and oxidized rocks range from .1 ppm to over 150 ppm. The highest gold value encountered to date occurred within argillized Roberts Mountains siltstone, assaying 685 ppm.

Most of the observed effects of oxidation and argillization are believed to have formed nearly contemporaneously after silicification. Argillized rock grades into oxidized rock, whereas razor-sharp contacts between argillized and silicified or carbonaceous rock have been observed. Some oxidation may have occurred prior to argillization and silicification as evidenced by oxidized, decalcified, unsilicified beds of limestone occurring interbedded with silicified limestone. Replacement of carbonate by silica normally results in a very impermeable rock that would resist the effects of oxidation and argillization.

Carbonization of the rocks in the Bell mine area is strongly controlled by structure. Carbonization produced black, sooty carbonaceous zones within much less carbonaceous or oxidized rock. High-angle and low-angle fault zones may localize the carbon. Often the carbonized rock is sheared and may be host to realgar and orpiment. It is believed that primary sedimentary hydrocarbons migrated or were concentrated in the highly permeable fault zones, possibly through the action of oxidation and/or argillization. Gold values within the remobilized carbon zones may be high along main ore trends, ranging from .1 to 35 ppm. Locally, values in excess of 100 ppm have been detected.

Accessory mineralogy

Several gangue minerals occur in the rocks of the Bell Mine, some of which locally are excellent indicators of gold mineralization. Others are simply indicative of hypogene activity on a district-wide scale. The most reliable mineralogical indicators of gold mineralization are realgar and orpiment. Realgar is by far the most abundant arsenic mineral encountered, while orpiment occurs as an oxidation of realgar. Minor arsenopyrite has been detected through x-ray diffraction. Realgar and orpiment are found in carbonaceous rock in veins intermixed with white, sparry calcite, as veins in carbonaceous rocks, and as small, scattered grains with remobilized carbon along fractures and shears. While arsenic minerals have not been recognized in completely oxidized or argillized rock, significant arsenic values have been detected. District-wide geochemical arsenic values range from trace values to over 1000 ppm. Higher concentrations are usually associated with higher grade gold values.

Cinnabar is also a good indicator of gold mineralization, though far less abundant than the arsenic minerals. Dull, blood-red grains of cinnabar have been found disseminated in high-grade ore zones. District wide geochemical analyses have yielded mercury values from trace values to over 50,000 ppb (parts per billion). The highest mercury values are invariably associated with high arsenic values in remobilized carbon zones where cinnabar may be found finely disseminated with realgar and orpiment.

Barite and stibnite constitute the remainder of the volumetrically important accessory minerals. Although they are not reliable indicators of gold mineralization, they are abundant in the mine area where they are almost entirely restricted to jasperoids. Barite occurs as euhedral encrustations on fractures or in vugs, as thin, white veins, or as massive, mosaic-textured pods in jasperpoids. Euhedral dipyramidal barite crystals, up to 10 cm long, have been found in vuggy zones in jasperoids. While barite may be locally abundant, geochemical data for barium distribution is inconclusive.

Stibnite forms euhedral, acicular crystals in radiating clusters or vein fillings of anhedral to subhedral grains. Veins of stibnite range from less than 1 to over 15 cm in width. Stibnite and barite are often found intermixed, and some occurrences show stibnite mantled with barite, which indicates a slightly earlier deposition for stibnite. Alteration of stibnite through hypogene and supergene processes formed three common antimony oxides as rims or complete replacements of stibnite crystals. These oxides are stibiconite, $H_2Sb_2O_5$, valentinite, Sb_2O_3, and kermesite, Sb_2S_2O. Geochemical antimony values from trace values up to 500 ppm have been detected district wide. Native sulfur crystals occur occasionally with stibnite, presumably as a more advanced oxidation product of stibnite.

Other accessory minerals that have been recognized either megascopically, microscopically, or with x-ray diffraction are calcite, jarosite, variscite, dolomite, lepidocrocite, collophane, and possibly scorodite, $FeAsO_4 \cdot 2H_2O$, and dusserite, $Ca_3(AsO_4)_2 \cdot 3Fe(OH)_3$. With the exception of calcite and jarosite, these minerals are not abundant, and it is equivocal whether they formed through hypogene processes. Calcite is most commonly found as white, blocky veins in Hanson Creek limestones, and with lesser amounts in Roberts Mountains siltstones or jasperoids. Botryoidal encrustations of calcite occur in vugs in oxidized limestones or jasperoids and can contain gold in concentrations up to 1.5 ppm. Jarosite is fairly common constituent of argillized rock and is also found as small, cinnamon-brown crystals on fracture surfaces in silicified and unsilicified rock.

Base metal sulfides have not been observed in the Bell mine area. However they have been reported from other disseminated gold deposits (Harris and Radtke, 1976). Anomalous geochemical values of copper, lead, and zinc, have been obtained from surface samples in the Bell mine area.

Silver values in the Bell mine are typical of those in other disseminated systems and range from less than .05 to 1.5 ppm. Typically the ratio of gold to silver is in excess of 20:1. Data on other common trace elements such as manganese, tungsten, or thallium are inconclusive.

SUMMARY AND CONCLUSIONS

Gold mineralization in the Jerritt Canyon district and the Enfield Bell mine is hosted within carbonaceous and oxidized portions of autochthonous, lower plate rocks of the Roberts Mountains thrust. Thrusting and associated imbricate, low-angle faults provided excellent pathways for the movement of hydrothermal fluids, especially when intersected by high-angle faults. These conduits allowed the gold-bearing fluids to migrate upward into structurally, and chemically favorable horizons. Alteration events such as silicification, oxidation, argillization, and carbonization occurred during the hypogene history of the deposit although not necessarily contemporaneously with gold mineralization. A preliminary genetic sequence for the Bell mine ore-bodies is proposed as follows:

1) Deposition of Paleozoic miogeosynclinal and eugeosynclinal rocks in separate basins.
2) Thrusting and folding of eugeosynclinal rocks over the miogeocline during Antler tectonism.
3) High-angle faulting during the Mesozoic.
4) Small-scale oxidation of portions of the lower plate rocks.
5) Silicification of the lower plate rocks, forming jasperoids.
6) High-angle block fualting during the Tertiary, possibly contemporaneously with intrusive activity.
7) Deposition of gold.
8) Oxidation and argillization of carbonaceous rocks locally enriching gold values and causing formation of remobilized carbon zones.
9) Deposition of stibnite, barite, realgar, and orpiment.

Although many questions on the hydrothermal history of the Jerritt Canyon district remain to be answered, continued production and exposure of the orebody continue to add to the knowledge gained thus far.

ACKNOWLEDGEMENTS

The management of Freeport Gold and Freeport Exploration are gratefully acknowledged for permission to publish this manuscript. Critical review of this manuscript and stimulating discussions over the complex geology of the deposit with Freeport geologists are gratefully appreciated and have contributed greatly to the current level of understanding of the history of the Jerritt Canyon district and Enfield Bell mine.

REFERENCES CITED

Churkin, M., Jr., and Kay, M., 1967, Graptolite-bearing Ordovician siliceous and volcanic rocks, northern Independence Range, Nevada: Geological Society of America Bulletin, v. 78, p. 651-684.

Coats, R. R., and McKee, E. H., 1972, Ages of plutons and types of mineralization, northwestern Elko County, Nevada: U.S. Geological Survey Professional Paper 800C, p. C165-C168.

Harris, Michael, and Radtke, A. S., 1976, Statistical study of selected trace elements with reference to geology and genesis of the Carlin gold deposits, Nevada: U.S. Geological Survey Professional Paper 960, 21 p.

Hausen, D. W., and Kerr, P. F., 1968, Fine gold occurrences at Carlin, Nevada, in Ridge, J. D., ed., Ore deposits of the United States 1933-1967 (Graton-Sales vol.): New York, American Institute of Mining and Metallurgy Petroleum Engineers, v. 1, p. 908-940.

Hawkins, R. B., 1973, The geology and mineralization of the Jerritt Creek area, northern Independence Mountains, Nevada: Pocatello, Idaho, Idaho State University, M.S. thesis, 104 p.

_____1982, Discovery of the Bell gold mine--Jerritt Canyon district, Elko County, Nevada: Mining Congress Journal, v. 68, p. 28-32.

Kerr, J. W., 1962, Paleozoic sequences and thrust slices of the Seetaya Mountains, Independence Range, Elko County, Nevada: Geological Society of America Bulletin, v. 73, p. 439-460.

Langenheim, R. L., Jr., and Larsen, E. R., 1973, Correlation of Great Basin stratigraphic units: Nevada Bureau of Mines and Geology Bulletin 72, 36 p.

Lawrence, E. F., 1963, Antimony deposits of Nevada: Nevada Bureau of Mines Bulletin, v. 61, 248 p.

Matti, J. C., and McKee, E. H., 1977, Silurian and lower Devonian Paleogeography of the outer continental shelf of the Cordilleran miogeocline, Central Nevada, in Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Paleozoic Paleogeography in western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium, p. 181-25.

Matti, J. C., Murphy, M. A., and Finney, S. C., 1975, Silurian and lower Devonian basin and basin-slope limestones, Copenhagen Canyon, Nevada: Geological Society of America Special Paper 159, 48 p.

Merriam, C. W., and Anderson, C. A., 1942, Reconnaissance survey of the Roberts Mountains, Nevada: Geological Society of America Bulletin, v. 53, p. 1675-1727.

Merriam, C. W., and McKee, E. H., 1976, The Roberts Mountains Formation, a regional stratigraphic study with emphasis in rugose coral distribution: U.S. Geological Survey Professional Paper 973, 51 p., 12 plates

Mullens, T. E., and Poole, F. G., 1972, Quartz-sand-bearing zone and early Silurian age of upper part of the Hanson Creek Formation in Eureka County Nevada: U.S. Geological Survey Professional Paper 800B, p. B21-B24.

Radtke, A. S., Rye, R. O., and Dickson, F. W., 1980, Geology and stable isotope studies of the Carlin gold deposit, Nevada: Economic Geology Bulletin, v. 75, p. 641-672.

Stewart, J. H., 1980, Regional tilt patterns of late Cenozoic basin-range fault blocks, western United States: Geological Society of America Bulletin, v. 91, p. I460-I464.