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The Geology of the Enfield Bell Mine and the Jerritt Canyon District, Elko County, Nevada

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CONTENTS

INTRODUCTION

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

The Jerritt Canyon district lies within the Independence Mountains in north-central Elko County, Nev., approximately 80 km north of Elko (fig. 57). The Enfield 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 parts 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.

Acknowlegments.—We gratefully acknowledge the management of the Freeport Gold Co. and the Freeport Exploration Co. for permission to publish this report. We thank Freeport geologists, especially those of the Jerritt Canyon District Office, for their critical reviews of the manuscript and stimulating discussions of the complex geology of the deposit; these reviews and discussions have contributed greatly to our current level of understanding of the history of the Jerritt Canyon district and the Enfield Bell mine.

HISTORY AND PRODUCTION

The discovery of gold mineralization in the Jerritt Canyon district was preceded by an antimony-exploration program initiated by FMC Inc. in 1971, on the basis of the antimony occurrences in the area reported by Lawrence (1963). Exploration emphasis shifted to gold when geologists recognized similarities between this area and the Carlin ore bodies. 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 part of the Roberts Mountains Formation. On the basis of this discovery, additional drilling was performed that delineated several small pods of low-grade gold mineralization; the mineralization was significant but not in sufficient amounts to constitute a minable discovery.

In 1976, the Freeport Exploration Co. assumed management of the project through a joint-venture agreement with FMC Inc. 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 drilling targets were defined, including the Marlboro Canyon ore body, which is now part of the Enfield Bell mine. Although a classic "bull's-eye" geochemical target was the clue that led to the initial discovery in the north fork of Jerritt Creek, the bulk of current reserves were found beneath a cover of colluvium and soil that was geochemically barren.

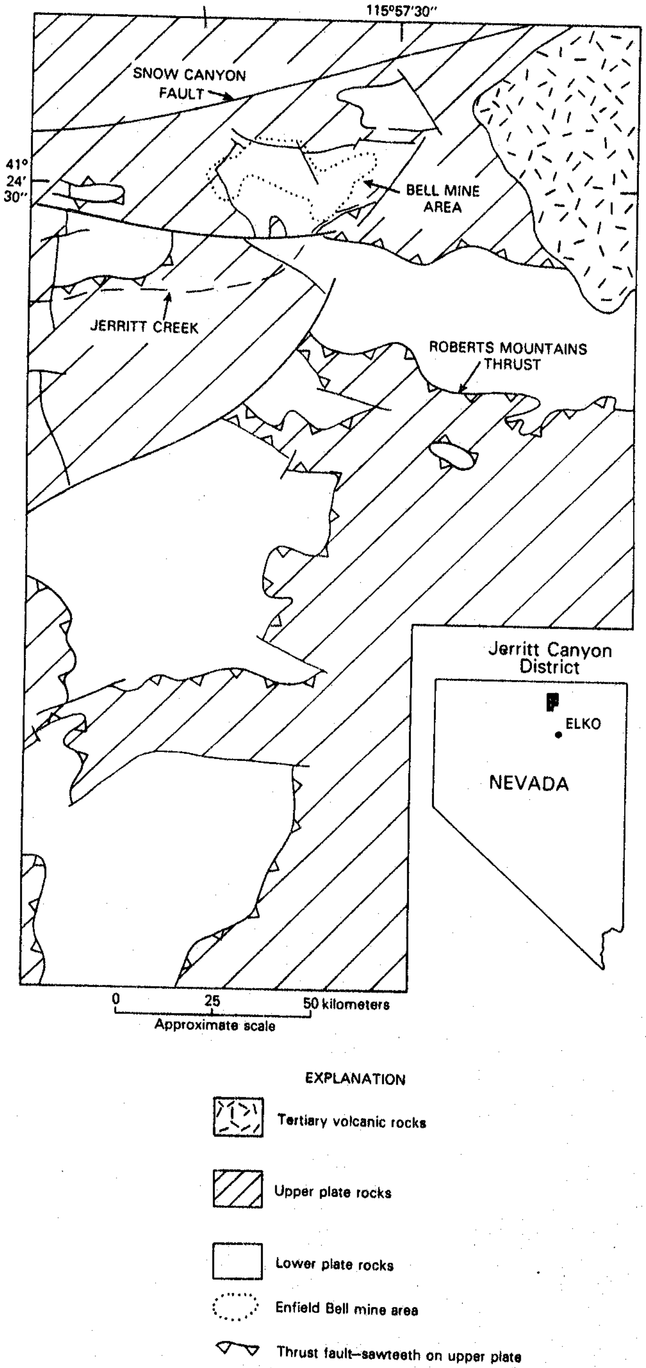

Figure 57. Location and general geology of the Jerritt Canyon district and the Enfield Bell mine area. Diagonal lines, exposures of upper-plate rocks; unpatterned, exposures of lower-plate rocks.

A decision to proceed with the construction of a mine and mill was made in 1979, and full-scale mill production began in July 1981. Current reserves are in four ore bodies, designated the Marlboro Canyon, North Generator Hill, West Generator Hill, and Alchem deposits. Mining has proceeded for the past 3 years within the Marlboro Canyon deposit and in part of the North Generator Hill deposit, referred to as Lower North Generator Hill. Milling proceeds at a design rate of 3,200 tons per day (2,900 t/d) 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 (fig. 57). The upper plate consist of an Ordovician eugeosynclinal sedimentary and volcanic assemblage composed of shale, argillite, chert, quartzite, intermediate to mafic flows, and lesser amounts of limestone and bedded barite. Basinal miogeosynclinal rocks compose the lower plate and consist of Ordovician and Silurian siltstone, limestone, chert, and quartzite. Deformation during the Late Devonian Antler orogeny moved the eugeosynclinal rocks (allochthon) eastward over the miogeosynclinal assemblage (autochthon), along the Roberts Mountains thrust (Merriam and Anderson, 1942). Good exposures of the thrust are uncommon in the Jerritt Canyon district. Where it is exposed, the thrust contact may be highly undulatory. Folding of the lower- and upper-plate rocks is recognized locally as a manifestation of this thrusting. A major southwest-plunging asymmetric anticline, referred to as the Map anticline, may have formed at that 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 that provided excellent pathways for hydrothermal fluids. Several of these structures have been recognized within the lower-plate rocks in the Enfield Bell mine area.

Tertiary igneous activity in the district produced several extrusive and intrusive rock types, none of which are found in the immediate mine area. A granodioritic to tonalitic pluton, measuring approximately 4,000 m^2 in outcrop area, was emplaced in the southwestern part of the district. Although no age determinations have yet been made on this pluton, it maybe as old as 120 m.y., equivalent in age to the Gold Strike stock north of the Carlin mine (Hausen and Kerr, 1968), or as young as 38 m.y., equivalent in age to the Mount Neva stock near the town of Tuscarora, Nev. (Coats and McKee, 1972). Possibly contemporaneous with granitic plutonism was the formation of several intermediate to mafic dikes and sills. These intrusive bodies are widely scattered across the district and are relatively small; their outcrops generally measure less than 10 m wide by 30 m long.

Deposition of andesitic and rhyolitic flows and ash flows occurred about 43 to 34 m.y. B.P. (Stewart, 1980). Deposition of the andesitic volcanic rocks is interpreted, from mapping evidence, to be the earlier of these two events. Subsequent faulting and erosion have limited exposures of the volcanic rocks to the extreme northeast corner of the district. Regional magnetic data suggest that these volcanic rocks continue beneath valley-fill gravel to the east.

Basin-and-range-associated tectonism during the Miocene (Stewart, 1980) created a steep block-faulted terrain. Three conspicuous basin-and-range fault sets trend east-west, northwest, and northeast within the district. Hawkins (1982) postulated that the east-west-trending 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, one of the major east-west-trending faults, occurs just north of the Jerritt Canyon window (fig. 57). Similar but smaller scale east-west-trending faults in the Enfield Bell mine are are the Marlboro Canyon, Bell, and Ridge faults (fig. 58), which may have also formed first during the Mesozoic.

Erosion of uplifted blocks along these faults has locally removed the upper-plate rocks and exposed the lower plate as windows in the Roberts Mountains thrust (fig. 58). In most areas, the contact between 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 has resulted in a steep terrain and the locally thick alluvial and colluvial cover in the district.

REGIONAL STRATIGRAPHY

Most 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).

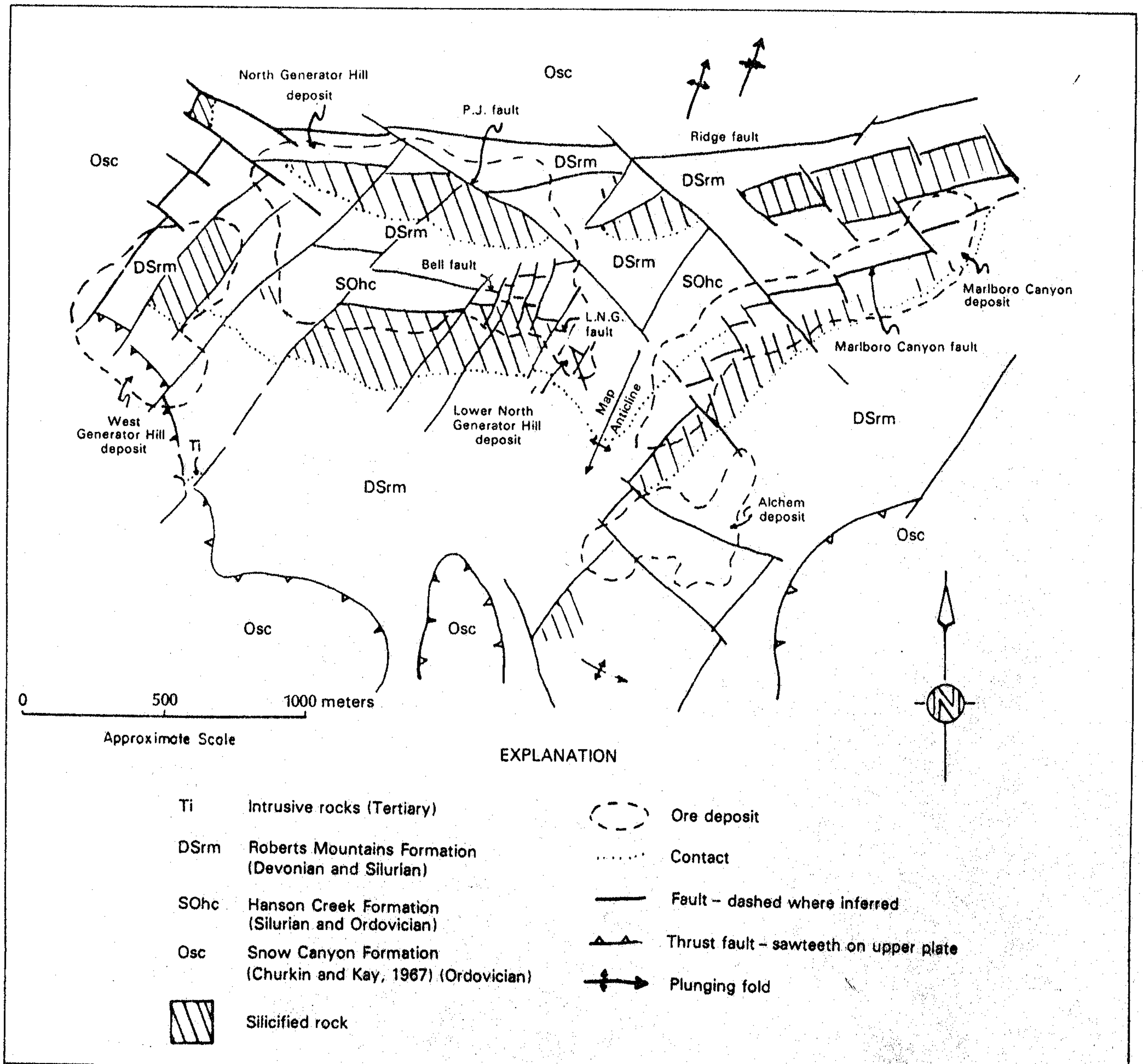

Figure 58. Preliminary geologic map of the Enfield Bell mine, Jerritt Canyon district, Elko County, Nevada.

Lower-plate rocks

Lower-plate stratigraphy within the Independence Mountains was described by Kerr (1962) and Hawkins (1973). Although a continuous, undisturbed stratigraphic section has not yet 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 (fig. 59).

The Eureka Quartzite of Middle Ordovician age 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 parts 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. Although bedding is indistinct, beds are generally massive and more than 3 m thick. Fossils are rare, but local exposures yield graptolite molds. Measured thicknesses of the Eureka Quartzite range from 150 to 190 m. Although the base of the formation has not been well studied, the upper contact is interpreted to be gradational with the Hanson Creek Formation.

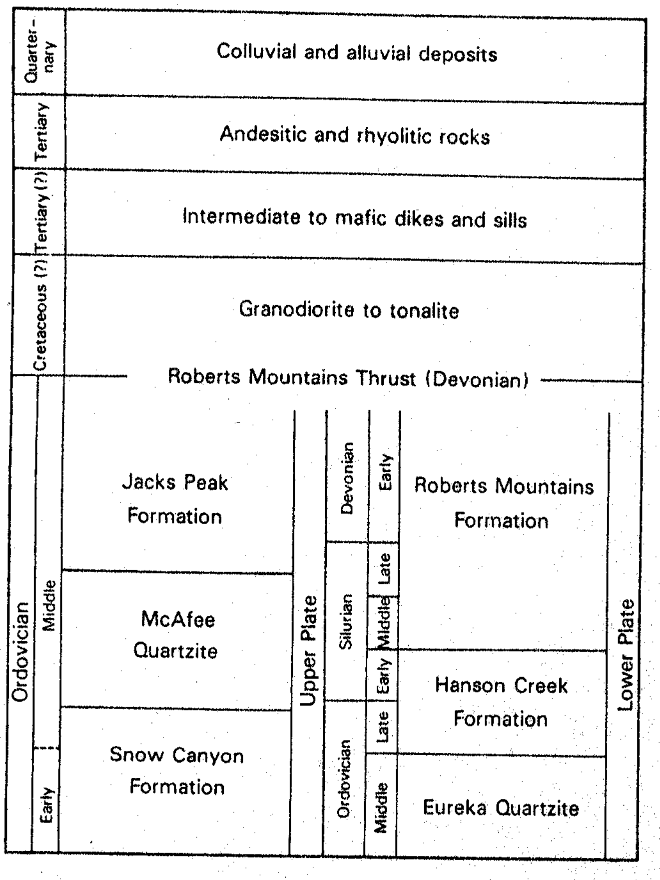

Figure 59. Stratigraphic section of the Jerritt Canyon district. Stratigraphy for upper-plate rocks from Churkin and Kay (1967), and for lower-plate rocks from Mullens and Poole (1972), Matte and others (1975), and Merriam and McKee (1976).

The Hanson Creek Formation, considered to be of Late Ordovician and Early Silurian age by Matti and others (1975), is the major host rock at the Bell Enfield mine and is exposed in many parts of the Jerritt Canyon window. On the basis of surface and subsurface data, the Hanson Creek Formation is here subdivided into five lithologic units—unit 1 (youngest) through unit 5 (oldest) (fig. 60). Because the upper parts of the Hanson Creek Formation are much better known and occur more commonly in outcrop than the lower units, the units are numbered consecutively from the top down.

The lower three units of the Hanson Creek Formation, units 3 through 5, are carbonaceous banded limestones. The banding, best developed in unit 3, results from alternating beds of micritic limestone and laminated dolomitic limestone, in which the laminated beds are the most carbonaceous. Pyrite occurs in both types of beds, although it is more abundant in the laminated beds.

The basal unit, unit 5, as measured, consists of 5 to 30 m of dolomitic limestone and thin-bedded micritic limestone, with some laminated calcareous siltstone near the basal contact. Fossils recognized throughout are crinoidal, brachiopod, bryozoan, and radiolarian fragments. Near the top of unit 5, an intraclastic layer has been recognized in which the intraclasts contain fossil debris mixed with carbon stringers and pods and sparry calcite cement. Locally, lenses and pods of black, carbonaceous chert have been recognized.

The overlying unit 4 is a 30- to 40-m-thick sequence of carbonaceous banded limestone containing abundant black chert nodules and lenses, 5 to 25 cm long, oriented parallel to bedding. Micrite beds may be faintly laminated, whereas laminated dolomitic limestone beds are locally absent. Fossil fragments are similar to those found in the basal unit.

The middle unit of the Hanson Creek Formation, unit 3, is a sequence of alternating carbonaceous micritic limestone beds and laminated carbonaceous dolomitic limestone beds. This unit, which is the main host for gold mineralization in the Enfield Bell mine (fig. 60), has been measured at more than 90 m thick in exposures in the southern part of the district. Chert beds, generally less than 0.1 m long and 2 cm thick, occur sporadically in the lower part of the unit. Fossils recognized in this unit are similar to those in the lower two units, with the addition of trilobite fragments. Studies have shown that gold mineralization favors the more permeable laminated beds, which occur locally in tenfold greater abundance than in the micrite beds.

Overlying unit 3 is a varyingly textured, 30-m-thick unit of limestone—unit 2. Four different rock types have been recognized in this unit: (1) thick-bedded limestone, (2) wavy thin-bedded to nodular limestone, (3) oolitic limestone, and (4) wavy-laminated limestone. The rock is weak to noncarbonaceous, weakly pyritic, and locally is entirely composed of dolomite. Fossils are fairly evenly distributed and resemble those recognized in the lower three units; however, trilobite fragments have not been recognized in this unit.

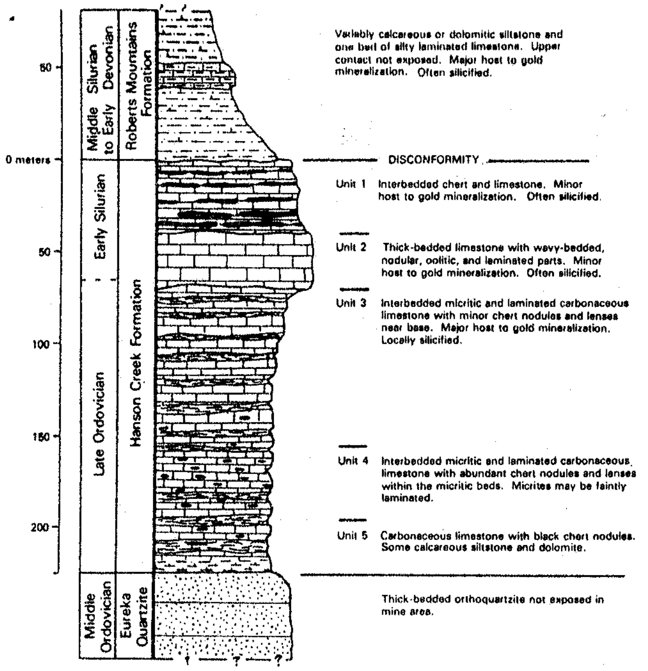

Figure 60. Generalized stratigraphic section of lower-plate rocks in the Enfield Bell mine area.

The uppermost unit of the Hanson Creek Formation, unit 1, is composed of 3 to 40 m of interbedded black chert and carbonaceous limestone. Chert beds are more consistent than in units 3, 4, or 5, and may exceed 1 m in length and 5 cm in thickness. Pinching and swelling of the chert as a result of soft-sediment deformation is common. Sponge spicules, radiolarians, and the absence of diagenetic-replacement textures suggest a sedimentary, nondiagenetic origin for the chert. The limestone beds, which are thicker than the chert beds, compose as much as 75 percent of a measured thickness near the base of the unit. Both laminated and nonlaminated limestone beds have been recognized.

The contact between the Roberts Mountains and Hanson Creek Formations appears to be disconformable, a contention that was also supported by the work of Matti and others (1975). Whereas previously published reports (Mullens and Poole, 1972; Merriam and McKee, 1976) placed the uppermost unit of the Hanson Creek Formation as part of the overlying Roberts Mountains Formation, Freeport Gold Co. geologists cite the sharpness of the contact between this uppermost unit and siltstone of the Roberts Mountains Formation, as well as the similar textures and mineralogy within the five units of the Hanson Creek Formation, as evidence that the uppermost unit, 1, 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 Enfield Bell mine (fig. 60). The estimated thickness of the Roberts Mountains Formation is 300 m; however, the uppermost part has 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, varyingly 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, 0.5 cm thick and 2 to 5 cm long, oriented parallel to bedding, are common in the basal part 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 siltstone beds commonly weather into small platy fragments and form gradual slopes, whereas 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, in ascending order: The Snow Canyon Formation (Early and Middle Ordovician), the McAfee Quartzite (Middle Ordovician), and the Jacks Peak Formation (Middle Ordovician).

Whereas exposures of the McAfee Quartzite and the Jacks Peak Formation are limited to the northernmost part of the Jerritt Canyon district, the Snow Canyon Formation commonly flanks lower-plate rocks throughout the district. Only the Snow Canyon Formation is described here.

The rocks that compose the Snow Canyon Formation in the Jerritt Canyon district are predominantly siliceous sedimentary rocks, estimated at 350 m thick (Churkin and Kay, 1967). Except for the more resistant members, the Snow Canyon does not crop out well and forms smooth, talus-covered slopes.

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

Interspersed with the clastic rocks are multicolored, wavy chert beds 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 brown quartzite, generally 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 quartzite are composed of quartz sand grains and scattered pyrite, cemented with silica or carbonate. Carbon and random quartz veinlets are recognized locally. Crossbedding, though sparse, 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 sporadically within the lavas. The limestone beds occur between successive pillow structures. Alteration of these lavas has changed the primary minerals to chlorite, sericite, and carbonate. Phenocrysts of plagioclase and pyroxene commonly are totally altered to calcite.

Limestone is the least continuous rock type in the Snow Canyon Formation. Besides occurring within altered mafic lavas, limestone has been recognized interspersed with laminated chert, shale, and siltstone. A section of shaly carbonaceous limestone capped by a cliff-forming intraformational limestone breccia apparently occurs near the base of the formation on the west margin of the Enfield Bell mine area.

GEOLOGY OF THE ENFIELD BELL MINE

The Enfield Bell mine is located in the northern part of the Jerritt Canyon window, in an area approximately 3,300 m long east-west by 1,200 m wide north-south (fig. 58). The mine comprises four known ore deposits, in order of decreasing size: the Marlboro Canyon, North Generator Hill, West Generator Hill, and Alchem deposits. Current reserves are 13.7 million tons (12.5 million t) at an average grade of 0.199 troy oz Au per ton (7.03 g Au/t), occurring in both oxidized and carbonaceous sedimentary rocks. Mineralization is structurally and lithologically controlled within the upper banded limestone of the Hanson Creek Formation, unit 3, and the lower siltstone of the Roberts Mountains Formation (fig. 60). Lesser amounts of ore occur in silicified sections of both formations. Small slices of geochemically barren upper-plate rock have been recognized in the Marlboro Canyon pit. Gold currently is being mined from Marlboro Canyon and a part of North Generator Hill known as Lower North Generator Hill (fig. 58).

Structure

Faulting is common in the Enfield Bell mine area and is the most important structural feature related to mineralization; folding may have been contemporaneous with a premineral set of faults. The four sets of faults in the Enfield Bell mine area range in age from Devonian to Tertiary. The oldest faults are the Roberts Mountains thrust 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 faults are cut by younger northwest- and northeast-trending faults. The ages of these three fault sets is somewhat equivocal; however, the east-west-trending system is postulated to 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-trending faults within the mine area are the Marlboro Canyon fault in 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 north boundary of the Jerritt Canyon window (fig. 58).

Figures 61<u>A</u> and 61<u>B</u> show typical cross sections through the Lower North Generator Hill and Marlboro Canyon deposits that illustrate the characteristics of the Bell and Marlboro Canyon faults, which were the main conduits for mineralization in their respective ore bodies. In each deposit, rocks of the Roberts Mountains and Hanson Creek Formations form the footwall block (north) against rocks of the Hanson Creek Formation 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 directions over short vertical and horizontal distances. The Marlboro Canyon fault changes strike in the western part of the Marlboro Canyon ore body to more northeasterly, whereas the Bell fault changes strike to northeasterly in the east end of the Lower North Generator Hill ore body (fig. 58). Both faults became shallower in dip on progressively deeper mine levels.

The L.N.G. fault is also an east-west-trending fault that may have formed as a result of uplift along the Bell fault; it appears, for the most part, to be a bedding-plane fault. This fault, which dips gently south, is believed to have formed as a result of slippage along the boundary between silicified and unsilicified parts of the Hanson Creek Formation. The amount of displacement on the L.N.G. fault changes to a northwesterly strike on the east side of the Lower North Generator Hill ore body (fig. 58).

After 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 the northeast-trending faults postdate the northwest-trending faults. However, the fact that the northwest-trending P.J. fault in the North Generator Hill deposit cuts both east-west- and northeast-trending faults indicates that some of the northwest-trending faults postdate the northeast-trending faults. Although the genetic relations of faulting in the mine area is still equivocal, all the faults are interpreted to predate gold mineralization. Ore coincides 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 relation of these structures.

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

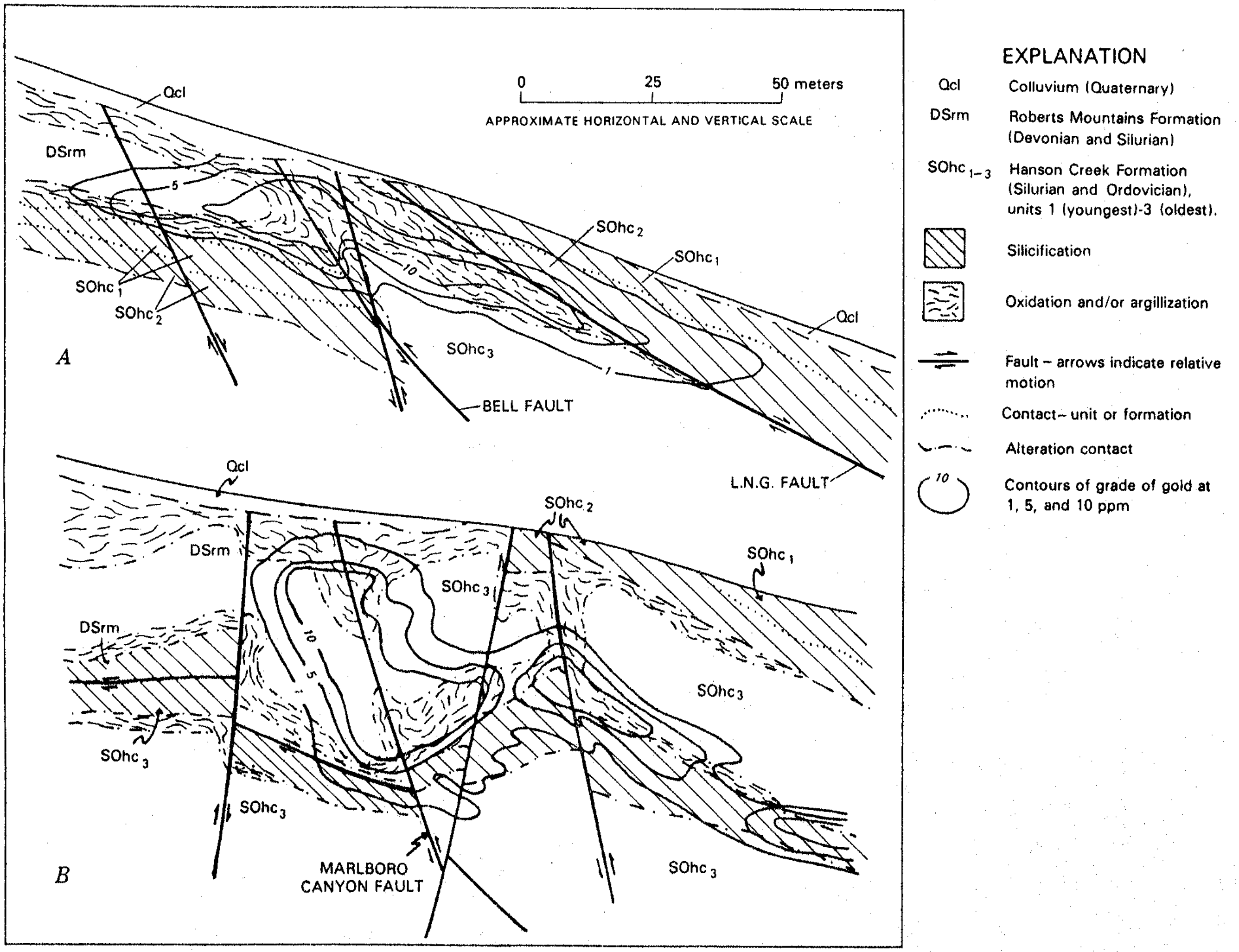

Figure 61. A, North-south cross section through the central part of the Lower North Generator Hill deposit. Contours of gold grade are 1, 5, and 10 ppm. B, North-south cross section, looking eastward, through the central part of the Marlboro Canyon ore body. Gold mineralization is strongly structurally controlled, with greater vertical than horizontal continuity. Contours of gold grade are 1, 5, and 10 ppm.

Ore-body morphology

The ore in the Enfield Bell mine occurs in two distinct modes. The largest ore zone, containing the most continuous and highest grades of gold, are elongate, steeply to moderately dipping tabular zones (Marlboro-type ore zones), which are typical sites for ore deposition in North Generator Hill and in most of Marlboro Canyon. The second type of ore zone (Alchem-type ore zone) is also tabular but is associated with low-angle faults, commonly containing stratiform jasperoid bodies. The bulk of the ore tonnage in the western Marlboro Canyon, Alchem, and West Generator Hill deposits are from Alchem-type ore zones.

Figure 61B shows a cross section of a typical Marlboro-type ore zone. A mushroomlike appearance is created by gold values increasing in large increments from the surface downward, 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 parts of the Roberts Mountains Formation and in silicified sections of the underlying Hanson Creek Formation. The contact between these two formations is interpreted to be, at least in part, a low-angle fault. The best ore grades occur in rocks of the Roberts Mountains Formation, and the ore zone may be highly undulatory.

Gold in both types of ore zones is 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 µm in diameter but are generally smaller than 2 µm. Where large enough to be observed petrographically, gold grains commonly are spatially associated with goethite, which may be pseudomorphic after pyrite.

Alteration

Three major hydrothermal events have altered the rocks of the Enfield Bell mine: (1) silicification, (2) oxidation and argillization, and (3) carbonization. Silicification, the predominant event, resulted in alteration of the limestone to hard dense varicolored jasperoid.

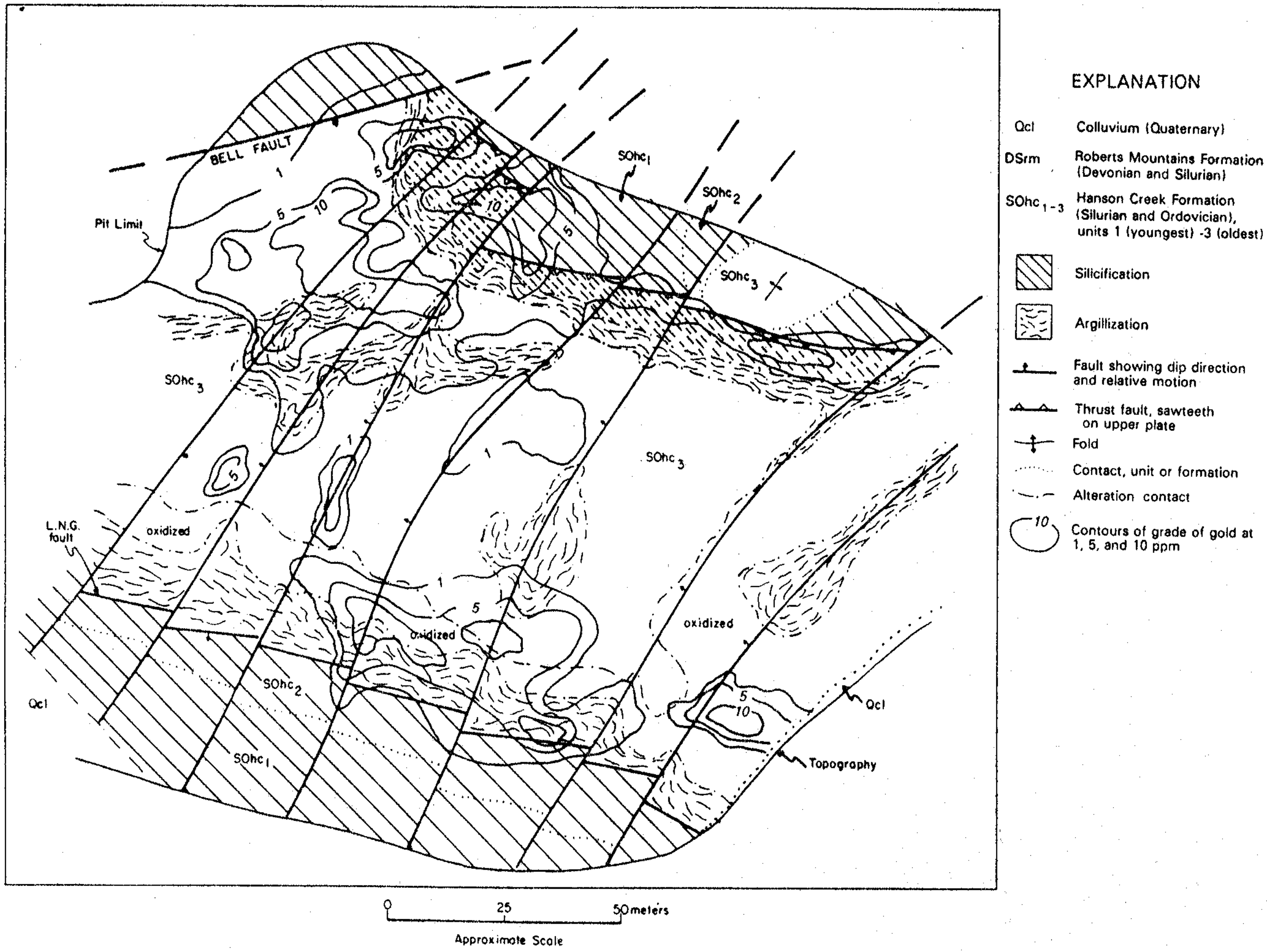

Figure 62. Geologic map of a typical mine level in the Lower Generator Hill ore body.

The jasperoid bodies in the mine area stand out in strong relief from the surrounding terrain and are approximately tabular in shape. Although about 35 to 40 percent of the rocks in the mine area are jasperoid, jasperoid constitutes less than 10 percent of the ore. The degree of silicification recognized in the mine area ranges from scattered quartz veining to complete replacement of the carbonate fraction. Silicification has affected rocks of both the Roberts Mountains and Hanson Creek Formations but is more intense in limestone of the Hanson Creek Formation. Mine mapping suggests that all but, possibly, the latest phase of silicification occurred before Tertiary block faulting. Jasperoid can be seen in razor-sharp contact against unsilicified rocks, horizontally juxtaposed along high-angle faults. The nearly stratiform appearance of the jasperoid bodies is interpreted to be the result of silicification along low-angle faults as well as replacement of chemically favorable rock types. The major stage of silicification that formed the jasperoid bodies is also believed to predate gold mineralization. Gold values occur in silicified and unsilicified rocks on either side of high-angle faults. Gold mineralization does not normally occur in ore-grade concentrations in jasperoid and generally is homogeneously distributed and of lower grade relative to the range of values found in the main ore zones. Locally, the jasperoid bodies may host gold mineralization higher than 30 ppm, but generally it ranges from less than 0.05 to 1.5 ppm.

Oxidation and argillization may be the most economically important alteration events to have taken place in the Enfield 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 coincide spatially and are believed to have similar, but not necessarily contemporaneous, genesis. Oxidation of the Roberts Mountains Formation produced a tan to light-orange-brown semifriable siltstone. Pyrite grains are well oxidized to limonite and goethite, and carbon is generally absent. The rock may also be noncalcareous, owing to associated but limited decalcification. Oxidation within the Hanson Creek Formation is similar to that recognized in the Roberts Mountains Formation, except for (1) local oxidation of black, carbonaceous chert lenses and beds to light-brown chert or black chert with brown rims, and (2) preferential oxidation of the more permeable laminated beds of unit 3 of the Hanson Creek Formation. Again, as in the Roberts Mountains

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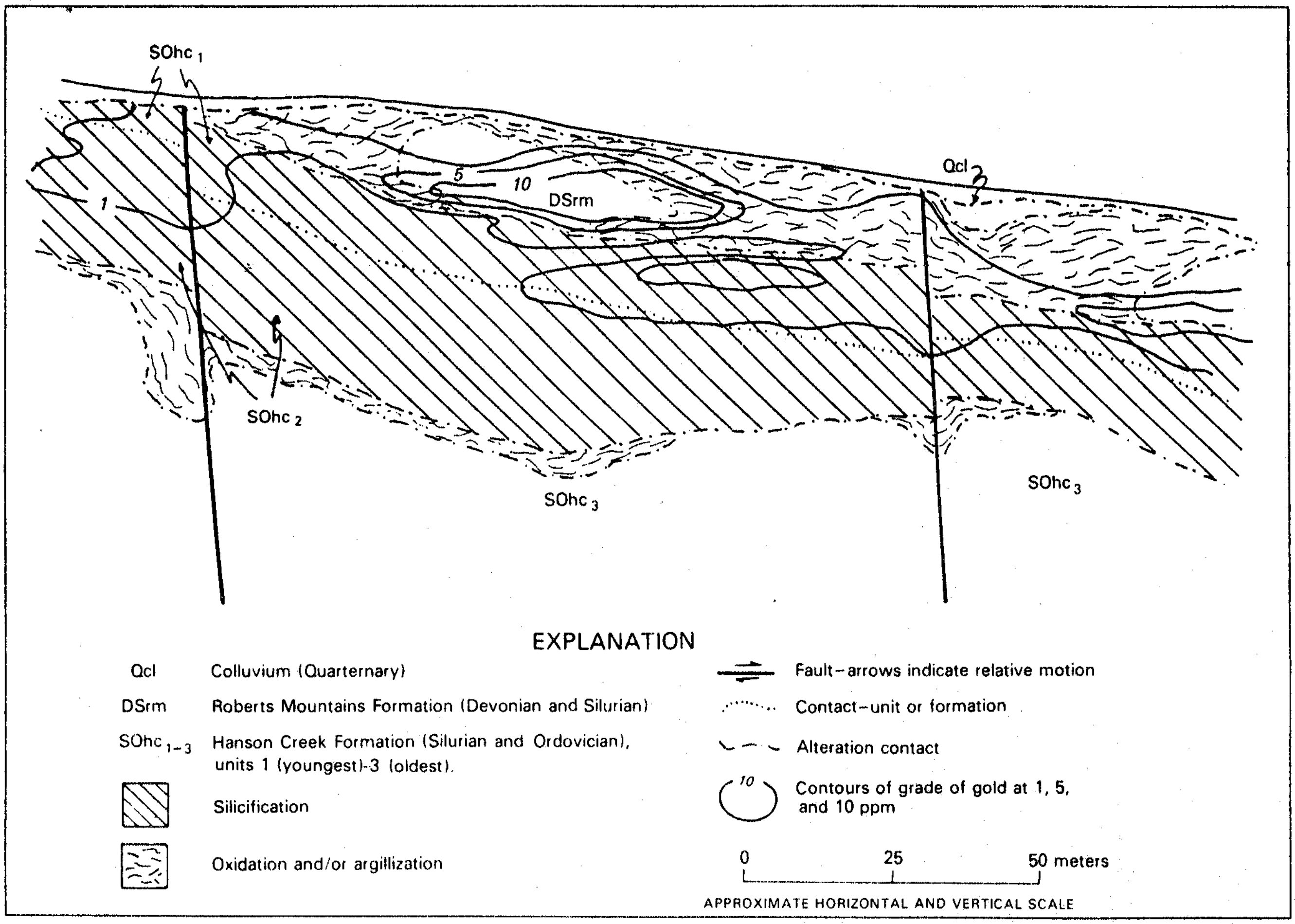

Figure 63. North-south cross section through the western part of the Marlboro Canyon ore body, showing the stratiformity of gold mineralization in an Alchem-type ore zone. Contours of gold grade are 1, 5, and 10 ppm.

Formation, oxidation of the Hanson Creek Formation may have been accompanied by decalcification.

Argillization of the Enfield 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 that are highly tabular, with greater vertical than horizontal continuity. Their shape is due to formation along high-angle structures, such as the Marlboro Canyon and Bell faults, where argillized Hanson Creek limestone occurs against argillized Roberts Mountains siltstone (fig. 61A, 61B). Argillization is also recognized in rocks directly above and below jasperoid bodies. 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 jasperoid in the hanging wall (fig. 61A). Whereas primary rock textures are commonly 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 rare. Gold values in the argillized and oxidized rocks range from less than 0.05 to more than 150 ppm; the highest gold value measured to date was 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 before argillization and silicification, as evidenced by oxidized, decalcified, unsilicified beds of limestone interbedded with silicified limestone. Replacement of carbonate by silica normally results in a highly impermeable rock that would resist the effects of oxidation and argillization.

Carbonization of the rocks in the Enfield Bell mine area is strongly controlled by structure. Carbonization produced black, sooty carbonaceous zones within much less carbonaceous or oxidized rock. High- and low-angle fault zones may have localized the carbon. Commonly 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 large-scale pressure solution. Gold values within the remobilized carbon zones may be high along main ore trends, generally ranging from less than 0.05 to 35 ppm. Locally, values of more than 150 ppm have been detected.

Accessory mineralogy

Several gangue minerals occur in the rocks of the Enfield Bell mine, some of which locally are excellent indicators of gold mineralization, whereas others are simply indicate hypogene activity on a districtwide scale. The most reliable mineralogic indicators of gold mineralization are realgar and orpiment. Realgar is by far the most abundant arsenic mineral, whereas 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. Although arsenic minerals have not been recognized in completely oxidized or argillized rock, significant arsenic values have been detected. Districtwide geochemical arsenic values range from traces to more than 1,000 ppm; higher concentrations are generally associated with higher gold grades.

Cinnabar is also a good indicator of gold mineralization, although it is far less abundant than the arsenic minerals. Dull blood-red grains of cinnabar have been found disseminated in high-grade ore zones. Districtwide geochemical analyses have yielded mercury values from traces to more than 50,000 ppb. 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 rest of the volumetrically important accessory minerals. Although they are not reliable indicators of gold mineralization, these two minerals are abundant in the mine area, where they are almost entirely restricted to jasperoid bodies. Barite occurs as euhedral encrustations on fractures or in vugs, as thin white veinlets, or as massive mosaic-textured pods and veins in jasperoid bodies and, less commonly, in oxidized siltstone. Euhedral dipyramidal barite crystals, as much as 10 cm long, have been found in clay-filled vuggy zones in jasperoid. Although barite may be locally abundant, the geochemical data for barium distribution are 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 more than 15 cm in width. Stibnite and barite are commonly found intermixed, and mantling of stibnite with barite in some occurrences 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: Stibiconite ($H_2Sb_2O_5$), valentinite (Sb_2O_3), and kermesite (Sb_2S_2O). Both stibnite and antimony oxides have been observed as coatings and encrustations on euhedral quartz crystals. Geochemical antimony values from traces to as much as 500 ppm have been detected district wide. Some native sulfur crystals occur with stibnite, presumably as a more advanced oxidation product of the stibnite.

Other accessory minerals that have been recognized either megascopically, microscopically, or with x-ray diffraction are calcite, jarosite, alunite, variscite, dolomite, lepidocrocite, collophane, possibly scorodite ($FeAsO_4 \cdot 2H_2O$), and dusserite ($Ca_3(AsO_4)_2 \cdot 3Fe(OH)_3$). Except for calcite and jarosite, these minerals are only sparse, and it is equivocal whether they formed through hypogene processes. Calcite is most commonly found as white blocky veins in Hanson Creek limestone and in lesser amounts in Roberts Mountains siltstone or in jasperoid bodies. Botryoidal encrustations of calcite (travertine?) occur in vugs in oxidized limestone or jasperoid bodies and can contain as much as 1.5 ppm Au. Jarosite, which is a fairly common constituent of argillized rock, also occurs as small cinnamon-brown crystals on fracture surfaces in silicified and unsilicified rock.

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

Silver values in the Enfield Bell mine are typical of those in other disseminated systems and range from less than 0.05 to 1.5 ppm. Typically the Au/Ag ratio exceeds 20:1. Data on other common trace elements, such as Mn, Tl, or W, are inconclusive.

SUMMARY AND CONCLUSIONS

Gold mineralization in the Jerritt Canyon district and the Enfield Bell mine is hosted within carbonaceous and oxidized parts 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 where 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, though not necessarily contemporaneously with gold mineralization. A preliminary genetic sequence for the Enfield Bell mine ore bodies is 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 parts of the lower-plate rocks; (5) silicification of the lower-plate rocks to form jasperoid bodies; (6) high-angle block faulting during the Tertiary, possibly contemporaneously with intrusive activity; (7) formation of zones of remobilized carbon; (8) deposition of gold; (9) oxidation and argillization of carbonaceous rocks; and (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 ore body are still adding to the knowledge gained thus far.