CAROLIN MINE - COQUIHALLA GOLD BELT PROJECT

(92H/6, 11)

By G.E. RAY

INTRODUCTION

This project was initiated in June 1981, and has been centred around the Carolin gold mine (MDI No. 092H/NW/007), situated approximately 18 kilometres northeast of Hope. The main objectives are:

(1) Regional mapping to outline the relationship between the Coquihalla Serpentine Belt and the adjoining Ladner Group. The contact between these units is of economic interest because the Carolin mine, several former gold producers, and numerous gold occurrences lie close to it. Regional mapping during this initial season was confined to an area stretching 13 kilometres south and 5 kilometres east of the Carolin mine (Figure 1).

(2) Detailed mapping at the Carolin gold mine, with particular emphasis on interpreting the structural history of the rocks hosting the gold mineralization (Figures 2, 3, and 4; Table 1).

(3) Geochemical analysis and, where possible, microfossil identification on rock samples collected from the entire region. Mineralogical and trace element studies will be undertaken on underground ore samples taken from the Idaho Zone at Carolin mine and from other former gold mines in the area.

TABLE 1. STRUCTURAL HISTORY OF THE CAROLIN MINE AREA

F_3	Sporadically developed, minor conjugate folds associated with kink banding and crenulation cleavage.
F_2	Open to tight, disharmonic folds having sub-vertical to easterly dipping, southeast-striking axial planes and north-west to southeast, gently plunging axes. It is the dominant fold episode in the area and is associated with a widespread axial planar slaty cleavage and mineral lineation. Some disruption along fold limbs and axial planes.
F_1	Widespread structural inversion of the Ladner Group and greenstone volcanics, probably related to major recumbent folding. No associated axial plane fabric recognized.
Early to Middle Jurassic ?	Unconformable deposition of the Ladner Group sediments on a greenstone volcanic unit of unknown age.

HISTORY AND PREVIOUS WORK

By the early part of this century, numerous gold-bearing quartz veins had been discovered in rocks adjacent to the eastern edge of the Coquihalla

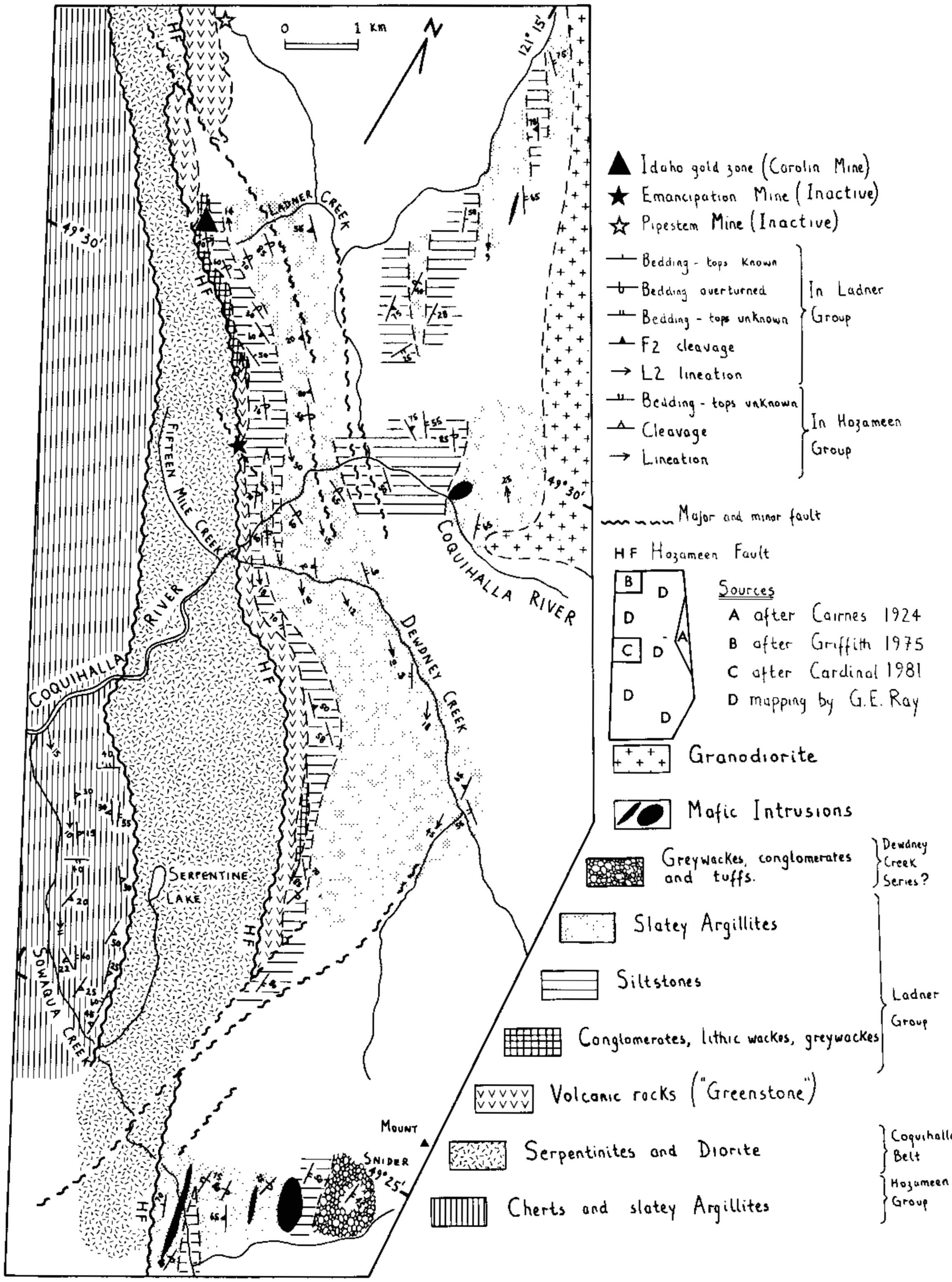

Figure 1. Regional geology of the Coquihalla River area.

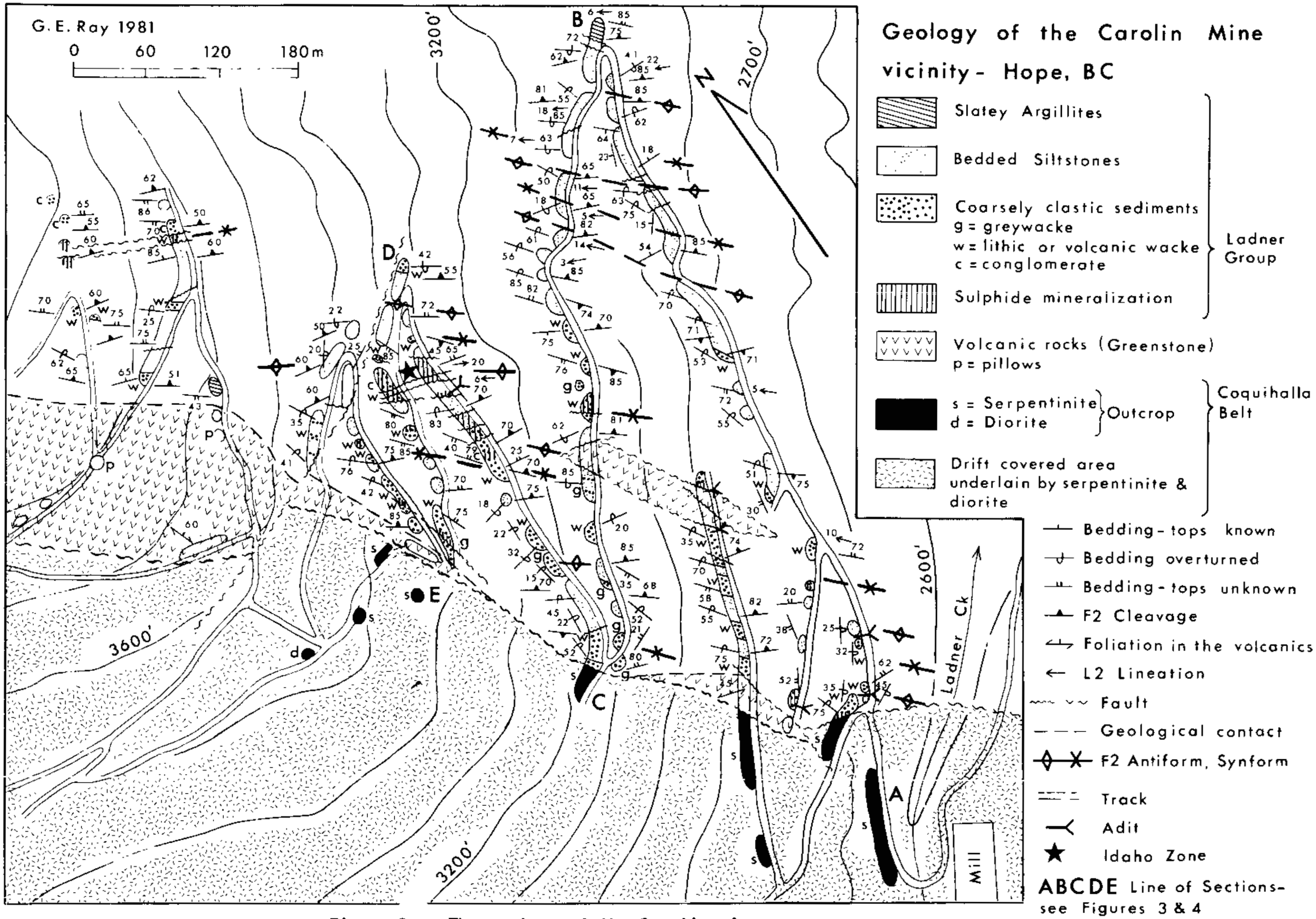

Figure 2. The geology of the Carolin mine area.

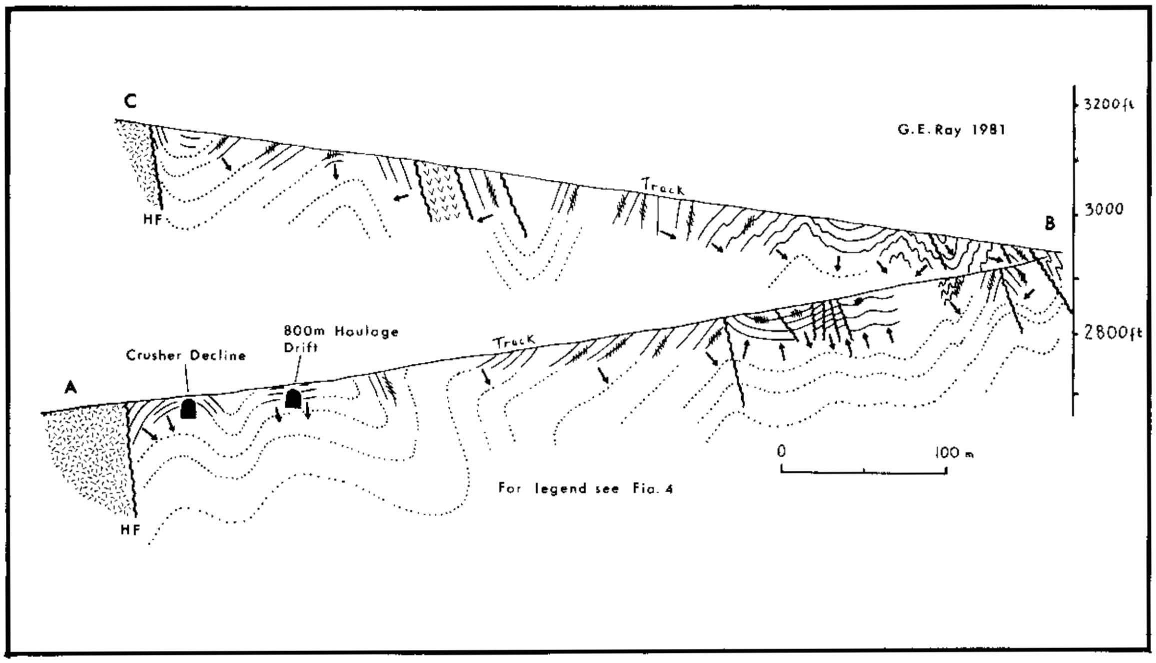

Figure 3. Geological sections AB, BC (see Figure 2) in the Carolin mine area.

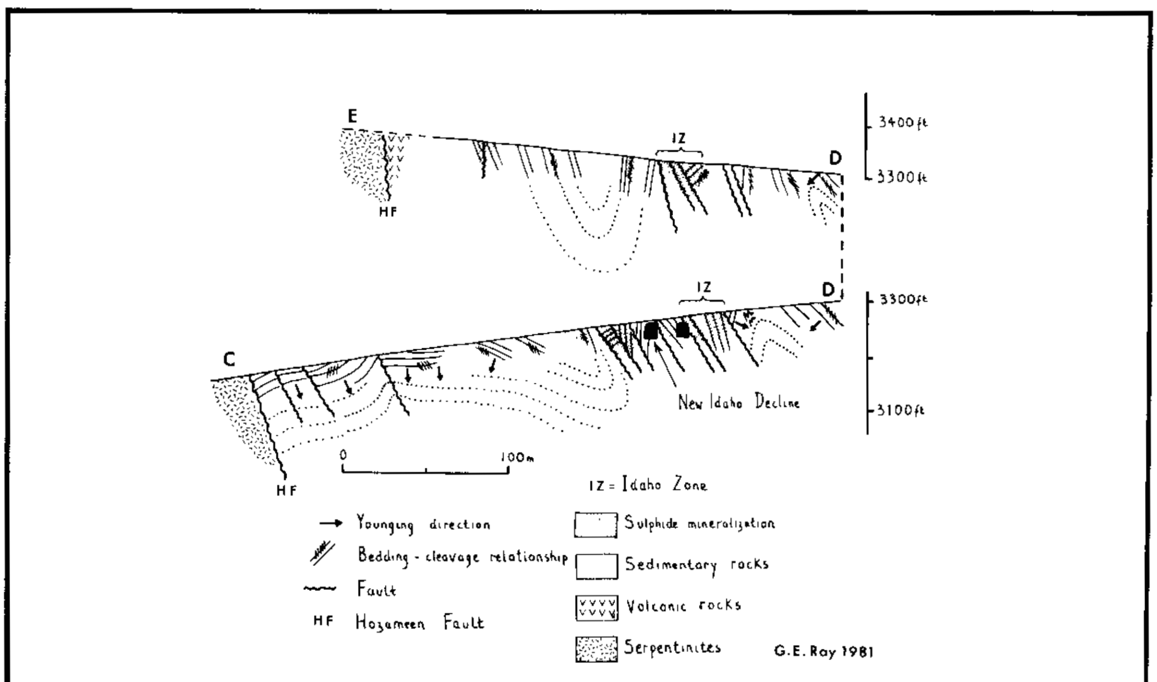

Figure 4. Geological sections CD, DE (see Figure 2) across the Idaho Zone, Carolin mine.

Serpentine Belt. These discoveries eventually led to underground production from three deposits, the Pipestem, Emancipation, and Aurum mines (Figure 1). All three properties are now closed and the mineralization and geology at these sites are described by Cairnes (1924, 1929). Mineralization at the Emancipation mine was in quartz veins cutting altered volcanic rocks whereas at Pipestem the gold-bearing veins cut sedimentary rocks of the Ladner Group. In both deposits gold is associated with silver, pyrite, and arsenopyrite, while pyrrhotite, chalcopyrite, and calcite are reported from the Emancipation property. The Emancipitation area was recently re-examined by Aquarius Resources Ltd. (Cardinal, 1981).

In 1927, the Aurum gold mine was discovered just south of the Idaho Zone. Spectacular values of free gold, hosted in a talcose shear, were found in the Hozameen fault which is a major fracture marking the eastern margin of the Coquihalla Serpentine Belt. At Aurum, gold is associated with pyrrhotite, pyrite, chalcopyrite, arsenopyrite, and possibly millerite (Cairnes, 1929).

Surface exposures of the Idaho Zone (Figure 4), the gold deposit which comprises the current Carolin mine operation, were originally described by Cairnes (1929). At that time the gold values were not economic but the increased price of gold in the early 1970's led Carolin Mines Ltd. to conduct a major exploration and development program on the property. Current outlined ore reserves are as follows:

Tonnes	Oz./tonne	Cut-off Grade
2 000 000	0.128	0.05 oz./ton Au
1 500 000	0.141	0.08 oz./ton Au

Carolin mine started production in December 1981, and the mill should handle approximately 1,500 short tons of ore per day.

Brief details on the geology of the Idaho Zone were given by Barr (1980), but most work on the deposit is in unpublished form; this includes work by Cochrane, et al. (1974), Griffiths (1975), and a mineralogical and petrographic study on the ore zone by Kayira (1975).

The regional geology, involving early major work by Cairnes (1924, 1929), was compiled by Monger (1970). Additional work relevant to the area includes that by McTaggart and Thompson (1967), Coates (1970, 1974), and Anderson (1976).

REGIONAL GEOLOGY

In the Carolin mine vicinity, the Coquihalla Serpentine Belt forms an elongate north-northwest-trending unit that separates rocks of the Ladner and Hozameen Groups to the east and west respectively (Figure 1); both margins of the belt appear to represent major long-lived tectonic fractures. In the Coquihalla River area, the belt exceeds 2 kilometres in width, but it gradually thins to the north and south until in the

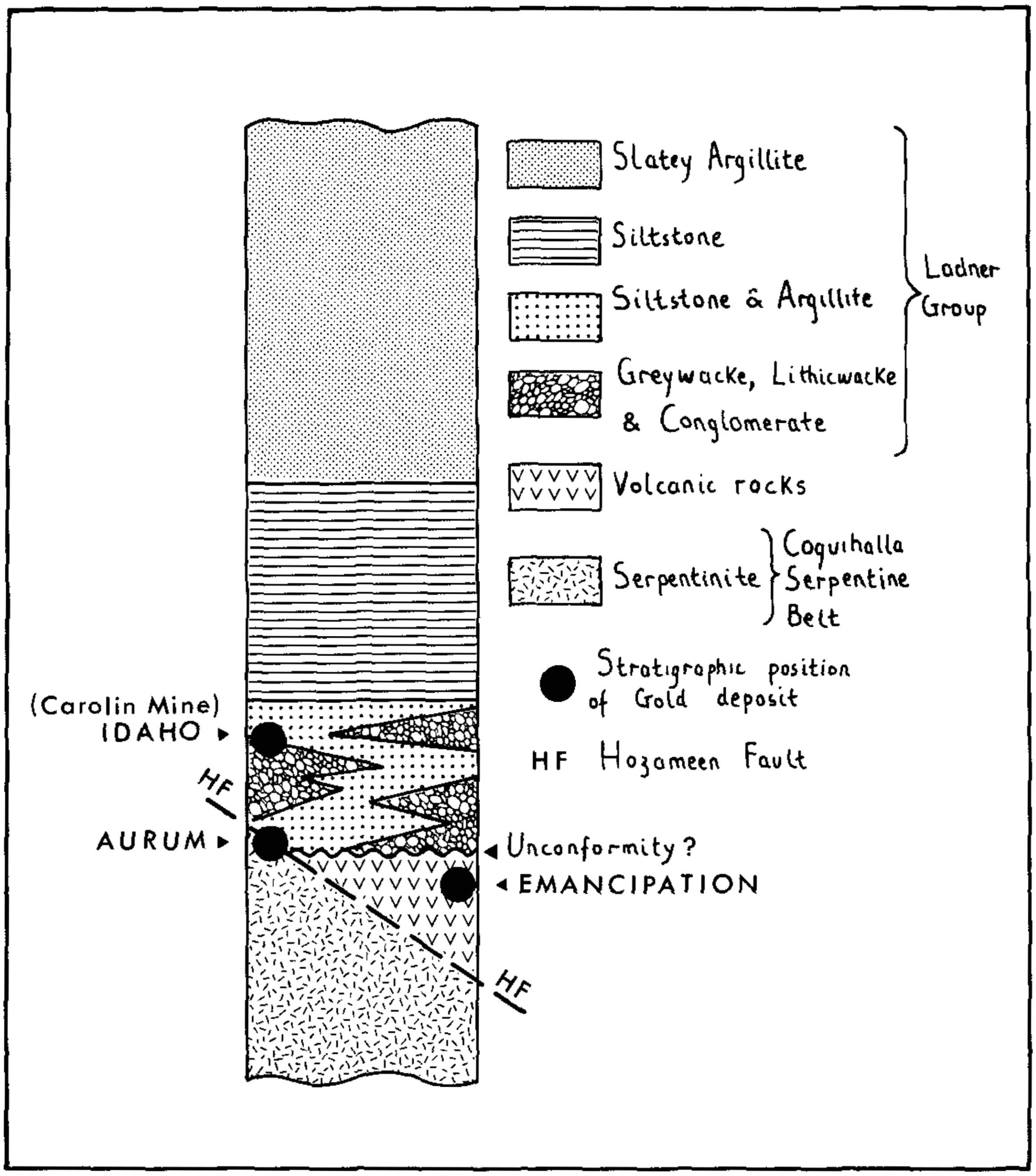

Figure 5. Schematic stratigraphic succession in the Carolin mine area (not to scale): (1) F_2 folding of the Ladner Group sedimentary rocks containing carbonaceous argillites (black); (2) late F_2 high-angle reverse faulting localized along the carbonaceous horizon (black) within the F_2 fold limb; (3) hydrothermal epigenetic emplacement of sulphide-gold mineralization (stippled) along the fault shatter zone; and (3) late normal faulting (F) causing displacement of the mineralized zone.

Boston Bar and Manning Park areas (Monger, 1970; Coates, 1974) the Hozameen and Ladner Groups are in direct fault contact. The Hozameen Fault marks the eastern boundary of the belt while the fracture along the belt's western margin (Figure 1) is currently unnamed. Near Carolin mine the belt is dominated by two major rock types: massive dark serpentinite of probable peridotite parentage (Cairnes, 1929) and medium to coarse-grained, massive and highly altered hornblende diorite. The basalts, diabases, and multiple sheeted dykes observed by Anderson (1976) were not seen in this portion of the belt.

Serpentinite is the dominant rock type and characterizes the belt, except in the Serpentine Lake vicinity (Figure 1) where diorite is abundant and forms sub-parallel sheets and lenses up to 250 metres in width. The age and genetic relationships between these two rock types are unknown because their rarely observed contacts are highly sheared.

The Hozameen Group in the map-area consists of phyllitic argillites interlayered with both massive and ribbon cherts. They have been subjected to intense deformation and lower greenschist metamorphism, and other than the ribbon layering in the cherts, no sedimentary structures have been positively identified. Some schistose argillites contain highly deformed clasts, but it is uncertain whether these represent sedimentary or tectonic features. Elsewhere, the Hozameen Group includes spillitic basalts (greenstones) and minor limestones interlayered with cherts and pelites (Daly, 1912; Cairnes, 1924; McTaggart and Thompson, 1967; Monger, 1970). Monger (1975) interprets the group as a supracrustal oceanic sequence of possibly Triassic or pre-Triassic age.

The Ladner Group (Cairnes, 1924) consists of a thick sequence of fine-grained, poorly bedded, black slaty argillites and well-bedded, grey-coloured siltstones with minor amounts of coarse clastic sedimentary rocks. Most outcrops show evidence of low grade metamorphism with the imposition of a weak to intense slaty cleavage, but in many instances the original sedimentary structures are clearly preserved. Graded bedding is commonly observed in the siltstones and coarse clastic units, while other, less common, sedimentary structures present include cross-bedding, ripple marking, scouring, flame, load cast, ball and pillow structures, and chaotic slumping. Graded bedding and scour structures indicate that most Ladner Group rocks adjacent to the Serpentine Belt, including those hosting the gold mineralization at Carolin mine, are structurally inverted (Figures 3 and 4).

A broad stratigraphic sequence is recognized in the Ladner Group consisting of a thin, lowermost unit characterized by a heterogeneous assortment of coarse clastic, partly volcanogenic, sedimentary rocks, that pass upwards into a thicker sequence of fine to medium grained well bedded siltstones. These are overlain in turn by a thick unit of very fine-grained, organic, and iron-rich argillites (Figure 5). The lower clastic unit hosts the Carolin gold mineralization; it includes discontinuous wedges of greywacke, lithic wacke, conglomerate, and possible reworked tuffs with intervening units of argillite and finely bedded volcanogenic siltstones. Pebbles of volcanic origin are common with lesser amounts of quartz, jasper, and chert; one extensive conglomerate unit contains fragments of limestone that are derived from an unknown source. Cochrane, et al. (1974) mentions possible welded tuffs and volcanic bombs in the lowermost section, while Anderson (1976) notes the presence of 'serpentine (clasts) recognizably derived from Coquihalla Belt rocks' but these observations were not verified in this study. The overall upward fining of the Ladner Group suggests a progressive temporal change from shallow to deeper water conditions. The initial rapid and chaotic deposition of near-shore clastics was superceded by early siltstones (proximal turbidites) and later argillites (distal turbidites).

The Ladner Group overlies a volcanic greenstone (Figure 5) of unknown age, whose relationship to the other major rock units in the area is controversial (see Discussion). Consequently, the greenstone is provisionally separated from the Ladner Group (Figures 1, 2, and 5). This greenstone unit can be traced discontinuously for 13 kilometres along the eastern side of the Hozameen fault, and now structurally overlies the Ladner Group because of the regional tectonic inversion. Thus, its thickest development, up to 400 metres in outcrop width, occurs on higher ground, while along the bottom of the Ladner Creek valley, south of Carolin mine the unit disappears, and the Ladner Group is in faulted contact with the Coquihalla Serpentine Belt (Figure 1). The greenstone is a highly altered, fine to medium grained rock of probable andesitic composition (Cairnes, 1924). Outcrops vary from massive to very weakly layered and, in places, excellent pillow structures are preserved with some interpillow breccias, which in one instance include chert clasts. Many greenstone outcrops contain numerous dark green angular fragments, in a lighter green matrix which could represent evidence of autobrecciation within the lavas. Some greenstones north of Carolin mine also show evidence of tectonic brecciation and shearing (Shearer, pers. comm.).

In the vicinity of the Emancipation mine, the Ladner Group and the greenstones are separated by a fault whereas further south the contact appears to represent an unconformity. Near the junction of Dewdney Creek and the Coquihalla River, the pillowed greenstones are overlain directly by finely laminated, volcanogenic siltstones of the Ladner Group, but northeast of Serpentine Lake the contact is marked by a coarse conglomerate varying from 1 to 200 metres in outcrop width (Figure 1).

A variety of intrusive rocks cut the Ladner Group. East of Ladner Creek the metasediments are intruded by the Needle Peak Pluton which has been dated at 39 Ma by K-Ar methods (Monger, 1970). The metasediments adjacent to this granodiorite body are characterized by a thermal metamorphic aureole up to 0.75 kilometre wide, which is marked by the growth of biotite and cordierite.

Other intrusive rocks within the Ladner Group are broadly separable into granitic and mafic types. The latter form dykes, sills and sub-rounded masses up to 0.3 kilometre in width that comprise a highly varied suite ranging from leucogabbroic to ultramafic rocks (Figure 1). Granitic intrusive rocks form narrow dykes and sills generally less than 10 metres wide that have been mapped as either quartz or feldspar porphyries; the latter are locally of syenitic composition (Cairnes, 1924). Some dykes contain disseminated pyrite and arsenopyrite and are cut by quartz veining; Cairnes (1924, 1929) considered these bodies to be genetically related to some of the reef-hosted gold in the district.

GEOLOGY AND STRUCTURAL HISTORY OF THE CAROLIN MINE VICINITY

The surface geology around the Carolin mine is shown on Figure 2 and the structural history of the area summarized on Figure 6 and in Table 1. The Hozameen Fault dips steeply northeast, and detailed geological sections across the mine area reveal that most of the stratigraphic sequence, including that hosting the gold-bearing Idaho Zone, is structurally inverted (Figures 3 and 4). After this early F_1 tectonic overturning, the supracrustal rocks were deformed by the F_2 folding and overprinted by a weak to intense slaty cleavage which forms the dominant tectonic foliation in area. Thus, the slaty cleavage was imposed on inverted beds. Several generations of fault movement subsequently occurred, particularly along the F_2 fold axial planes and limbs. An early phase of fault shattering appears to be spatially related to several zones of alteration which are marked by either quartz, calcite, or feldspar veining and pervasive sulphide mineralization (Figure 4). However, most of the fractures shown on Figures 3 and 4 belong to a later phase of generally normal faulting which post-dates and displaces the earlier alteration zones. The Idaho Zone (Figure 4), 150 metres east of the Hozameen fault, forms the largest surface exposure of alteration and is the only one to date in which economic gold mineralization has been found. At a cut-off grade of 0.05 ounce per ton gold it appears to form an irregular, steeply inclined ore body approximately 35 metres wide, 100 metres deep, and over 300 metres in length which is still open down plunge (R. Niels, pers. comm.). The deposit passes upward into unmineralized chloritic schists, and the top of the ore zone plunges gently northward at approximately 25 degrees (W. Clarke, pers. comm.). The predominant mineral assemblage in the zone comprises quartz, plagioclase (An_{4-6}), carbonate, chlorite, pyrrhotite, arsenopyrite, and pyrite; other rarer opaque minerals, in decreasing order of abundance, include magnetite, chalcopyrite, bornite, and gold (Kayira, 1975). In outcrop, the zone is characterized by abundant sulphides, intense hydrothermal alteration which weathers to give a distinctive black or grey-coloured rock, and a multi-stage network of quartz, calcite and albite veining. Many veins are orientated parallel to the slaty cleavage, demonstrating that some alteration in the Idaho Zone post-dates the main F_2 structural event. Mineralization involved the spasmodic introduction of silica, carbonate, Na, Fe, Cu, As, Mo, Sb, and Au, and Table 2 shows the results of some trace element analyses completed on fresh, underground samples collected from mineralized and unmineralized portions of the Idaho Zone. Cochrane (pers. comm.) notes that soils over the surface exposures of the Idaho Zone contain anomalous mercury values, but underground ore samples (Table 2) show no significant enrichment in this element. Thus a vertical zoning of mercury could exist in the deposit.

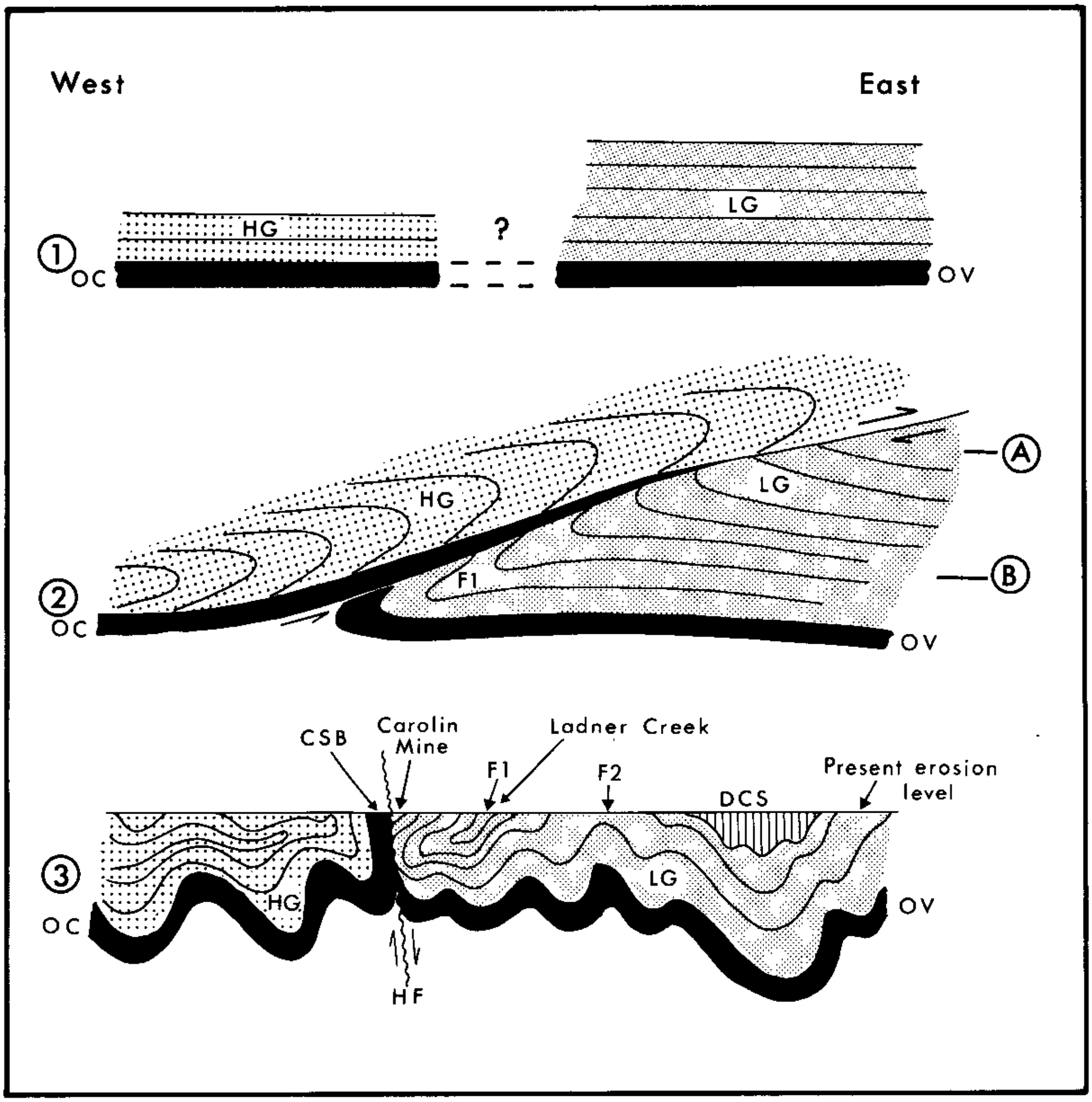

Figure 6. Postulated evolutionary history of the Coquihalla Serpentine Belt:

(1) pre-Triassic to Triassic deposition of the Hozameen Group (HG) oceanic supracrustal rocks (Monger, 1975). Jurassic (Cairnes, 1924; Coates, 1974) deposition of the Ladner Group (LG) arc trench gap sediments onto ocean volcanic rocks (Anderson, 1976). OC = oceanic crust; OV = oceanic volcanic rocks.

(2) eastward overthrusting of the Hozameen Group along a horizon of serpentinized ocean crust causing F_1 structural inversion in the Manning Park area (Coates, 1974); B = present erosion level in the Carolin mine area.

(3) F_2 folding resulting in a steepening of all units including the Coquihalla Serpentine Belt (CSB), with later development of the Hozameen fault (HF). DCS = Dewdney Creek Series (Cairnes, 1924). NOTE: Granitic plutons omitted; length of section 3 approximately 15 kilometres.

TABLE 2. TRACE ELEMENT ANALYSES ON FRESH UNDERGROUND SAMPLES COLLECTED FROM CAROLIN MINE

	Sample No.	Au[1] ppm	Ag[1] ppm	As[2] per cent	Co[2] ppm	Cu[2] ppm	Pb[2] ppm	Sb[2] ppm	Mo[2] ppm	Hg[3] ppb	Sn[4] ppm	Ba[2] ppm
1.	25163M	17.5	<10	6.23	19	89	21	185	75	72	<1	<100
2.	25164M	16.0	<10	0.46	13	81	15	13	20	112	<1	<100
3.	25167M	3.5	<10	1.18	20	161	15	<10	<2	78	<1	155
4.	25169M	17.5	<10	6.27	18	88	20	185	75	82	<1	150
5.	25168M	<1	<10	0.007	12	49	16	<10	<2	76	<1	1184
6.	25165M	<0.3	<10	0.07	3	40	9	<10	5	108	<1	<100
7.	25166M	<0.3	<10	0.005	3	34	27	<10	<2	182	<1	<100

[1]Fire assay; [2]atomic absorption; [3]cold vapour; [4]emission vapour.

1. Idaho Zone material with abundant sulphides and veining; collected from the 900-metre drift.
2. Idaho Zone material with abundant sulphides and veining; collected from the 900-metre slot.
3. Idaho Zone material with abundant sulphides and veining; collected from the 850-metre slot.
4. Idaho Zone material with abundant sulphides and veining; collected from the 900-metre slot crosscut.
5. Unmineralized greywacke adjacent to the Idaho Zone; abundant feldspar and quartz veining but no sulphides; collected from the 835-metre north scram.
6. Sample of 10-centimetre-wide white quartz vein cutting mineralized Idaho Zone; collected from the face of the 900-metre perimeter drift (east).
7. Sample of white calcite veins cutting mineralized Idaho Zone; collected from the end of the 875-metre perimeter drift (west).

Analyses completed at the Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources.

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The exact controls of mineralization are unknown. Clarke (pers. comm.) notes that selective replacement has occurred in the ore zone with preferential enrichment of the more brittle, coarse-grained sediments and a tendency for less mineralization to be present in the finer grained argillites. Detailed surface mapping indicates that the Idaho Zone is located close to the disrupted limb of an F_2 fold (Figure 4) and it is noteworthy that the top of the ore zone and the F_2 fold axes both have very similar plunges. Consequently, the Idaho Zone is believed to represent an epithermal replacement deposit (Kayira, 1975) that was laid down along a high-angle reverse fracture of late F_2 age (Figure 7). The presence of carbonaceous metasediments adjacent to the orebody (Cochrane, et al., 1974; Kayira, 1975) could also be significant. Initially this incompetent horizon may have localized the reverse fault movements and later provided a favorable reducing geochemical environment

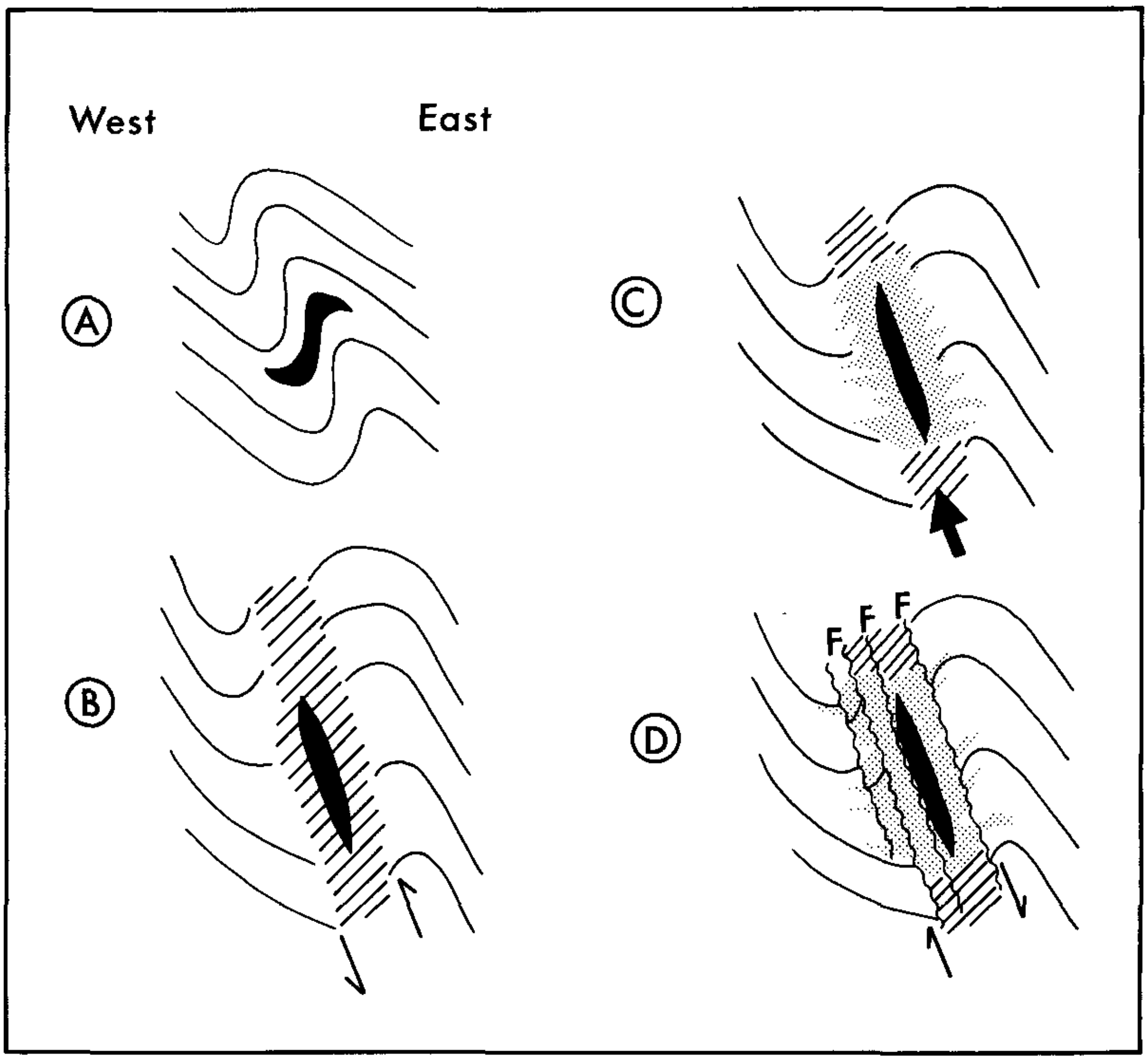

Figure 7. Postulated development of the Idaho Zone, Carolin mine.

for the deposition of sulphides and gold when hydrothermal solutions passed up the fracture (Figure 7). This postulated lithostructural control of the gold mineralization may help outline underground extensions of the Idaho Zone and assist exploration for similar deposits in the region. Subsequent to gold emplacement, late normal faulting rejuvenated the mineralized, pre-existing fracture zone. This intense late faulting cut the orebody (R. Niels, pers. comm.) but apparently played no role in ore genesis (Figure 7).

DISCUSSION

The pillowed volcanic greenstones which separate the Ladner Group from the Hozameen fault in the Carolin mine area are a problematic unit because the following stratigraphic relationships are possible:

(1) They could form part of the oceanic supracrustal Hozameen Group as suggested by Cairnes (1924). However, this seems unlikely because they are separated by the fault-bounded Coquihalla Serpentine Belt, which has probably been the locus of major tectonic movements.

(2) They could belong to the Coquihalla Serpentine Belt, a possible oceanic crustal assemblage, as advocated by Anderson (1976). This interpretation would suggest that relatively minor movements occurred along the Hozameen Fault, and that the Ladner Group unconformably overlies an older oceanic volcanic basement. This possibility is indirectly supported by observations in the Emancipation mine area where the volcanic rocks are intruded by diorite bodies (Cairnes, 1924, 1929) that bear a superficial resemblance to diorites within the Coquihalla Serpentine Belt (Cardinal, pers. comm.), while these intrusives have not been observed cutting the Ladner Group. Furthermore, no proof exists that volcanism occurred during the Ladner Group sedimentation in this area, and the volcanogenic character of the coarsely clastic, lowermost sediments may merely reflect their erosional derivation from an older volcanic terrane.

(3) The greenstones may have no genetic relationship with any rocks west of the Hozameen fault, and instead represent the lowest exposed portion of the Ladner Group, as suggested by Cochrane (pers. comm.). If this is correct, the volcanic-sedimentary unconformity is probably of relatively minor importance.

Detailed structural mapping along the Coquihalla River suggests that the volcano-sedimentary sequence between Ladner Creek and the Hozameen fault occupies the inverted limb of a major F_1 synform which is overturned to the east and whose axial trace probably lies along Ladner Creek (Figure 6). Further southeast, in Manning Park, the Coquihalla Serpentine Belt is absent and the Ladner Group forms an essentially upright sequence even adjacent to the Hozameen fault (Coates, 1974). Thus, the tectonic inversion of the Ladner Group appears to be spatially related to the Coquihalla Serpentine Belt rather than the Hozameen fault. This raises the possibility that the belt and the F_1 recumbent folding share a genetic relationship. One possible explanation is that the Coquihalla Serpentine Belt originated as a thin, sub-horizontal unit of obducted oceanic crust over which the Hozameen Group was thrust in an easterly direction (Figure 6). Serpentinization presumably accompanied this movement with the belt forming the lubricated, sub-horizontal sole below a nappe structure whose easterly transport resulted in the F_1 tectonic inversion of the underlying Ladner Group (Figure 6). This mechanism would explain the absence of a F_1 tectonic foliation in the Ladner Group which was probably unlithified and not deeply buried during this overturning event. Subsequent F_2 deformation caused a refolding of the F_1 synformal structure (Figure 6) and steepened the Coquihalla Serpentine Belt into its present sub-vertical position, as suggested by McTaggart and Thompson (1967) and Anderson (1976). This model implies that major tectonic dislocations occurred along both margins of the Serpentine Belt and that the Hozameen fault is a late, normal and relatively minor fracture lying close to one of the early thrust planes (Figure 6). If this interpretation is correct, other 'Alpine-type' serpentine belts in the region may also represent obducted oceanic material marking early, refolded thrust zones.

CONCLUSIONS

The Carolin mine orebody (Idaho Zone) is hosted in a structurally inverted sequence of Ladner Group sedimentary rocks, close to their faulted contact with the Coquihalla Serpentine Belt.

The Idaho Zone represents hydrothermal replacement mineralization that involved the multistage introduction of silica, carbonate, Na, Fe, As, Mo, Sb, Cu, and Au.

Mineralization was emplaced along an early reverse fault that occupies the disrupted limb of an overturned fold. Incompetent carbonaceous sedimentary rocks lying close to the ore zone may have localized the reverse faulting and geochemically controlled the subsequent gold mineralization.

The widespread tectonic inversion of the Ladner Group appears to be spatially and genetically related to the Coquihalla Serpentine Belt. The Belt could represent oceanic crust that was obducted and serpentinized during easterly directed, subhorizontal thrusting. These movements caused the structural inversion in the Ladner Group and subsequent folding steepened the belt into its present sub-vertical position.

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