



TOWARDS A DEPOSIT MODEL FOR OPHIOLITE RELATED MESOTHERMAL GOLD IN BRITISH COLUMBIA

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INTRODUCTION

The Listwanite Project was initiated in 1989 to develop a regional metallogenic deposit model for mesothermal gold veins associated with ophiolitic ultramafic rocks in oceanic terranes throughout British Columbia. To date, investigations have been conducted in six lode-gold or related placer camps throughout the province. These include the: Atlin, Stuart-Pinchi Lakes, Bralorne, Cassiar (Erickson), Rossland and Greenwood areas (Figure 2-3-1). Most of the fieldwork has focused on the geology and potential source of gold placers in the Atlin camp (Ash and Arksey, 1990a, c). Results of this work, describing the origin and tectonic setting of the ophiolitic rocks and related gold mineralization will appear separately (Ash, in preparation).

This report summarizes the present understanding of the ophiolite-lode-gold association in British Columbia. It reviews the resource potential of this deposit type, the scientific approach taken and the current stage of development of the evolving deposit model. Detailed results will appear in an upcoming publication (Ash *et al.*, in preparation). An introduction to the listwanite-lode-gold association and a description of the deposit type have been given previously (Ash and Arksey, 1990b).

LISTWANITE - LODE GOLD RELATED DEPOSITS

Listwanite is a term applied to an alteration assemblage generated by carbon dioxide metasomatism of serpentinized ultramafic rocks. This alteration type is not only associated with most of the major mesothermal vein deposits in British Columbia (Figures 2-3-2 and 3), but also with many major mesothermal vein deposits in Phanerozoic and Archean gold camps worldwide. This relationship appears to be due primarily to similarities in tectonic history and involves using ultramafic and related plutonic rocks to delineate major structural breaks which act as a "first order control" for the development of mesothermal gold deposits (Groves, 1990).

The term listwanite has not been formally defined. It is loosely characterized as "a carbonatized ultramafic rock" (Buisson and Leblanc, 1986). The process of listwanitization produces a varying sequence of alteration products caused by differences in the intensity of alteration. A listwanite, therefore, consists of an alteration suite with the individual units of the suite best described in terms of their mineralogy. This suite commonly includes, in order of increasing intensity of alteration: talc-altered serpentinite; talc-carbonate; quartz-talc-carbonate; quartz-carbonate-mariposite and quartz-carbonate-mariposite-sulphides \pm gold.

ECONOMIC SIGNIFICANCE

The economic significance of this deposit type in British Columbia is demonstrated by historic gold production (Schroeter *et al.*, 1989). Of the six gold camps producing more than 1 million ounces of gold (Figure 2-3-2), which together account for approximately 80 per cent of the gold produced in the province, three are mesothermal vein camps with a clear ophiolitic association. Five of the ten largest mesothermal vein deposits (Figure 2-3-3) have a currently defined ophiolitic association. Added economic significance for this deposit type lies in the fact that the majority of placer gold camps in British Columbia are closely associated with accreted oceanic terranes (Hodgson *et al.*, 1982).

APPROACH

Development of a deposit model has followed two main avenues of investigation:

- (1) The lithotectonic setting of lode-gold deposits and associated ophiolitic rocks; and,
- (2) The timing of lode-gold deposition relative to the tectonic and plutonic history of the host terrane.

These topics are addressed by combining regional reconnaissance and detailed geological mapping and, at specific properties, core logging and trench mapping was used to compliment surface data.

The existing geochronological database in areas of interest is being supplemented by additional radiometric dating in order to define the timing of plutonism and mineralization. Combined K-Ar and U-Pb isotopic dating techniques are being used to constrain the age of plutonic episodes thought to be associated with listwanitic alteration and gold mineralization. Where available, mariposite (fuchsite), a green chrome-bearing muscovite (phengite) commonly associated with carbonatized ultramafic rock, is being dated by Ar-Ar or K-Ar methods to obtain apparent mineralization ages.

In listwanites, the existence of a variety of green minerals other than, or in addition to mariposite, necessitates detailed mineralogical studies. Hand-picked concentrates are being studied optically and analyzed by x-ray diffraction for mineral identification and by inductively coupled plasma techniques for major and minor element content.

The potential for platinum group element (PGE) mineralization within this style of deposit is also being crudely assessed. A number of sulphide-rich samples from the various camps studied have, or are being analyzed to test for anomalous PGE concentrations.

REGIONAL GEOLOGICAL SETTING

All six areas investigated (Figure 2-3-1.) are either within accreted oceanic terranes or, as in the case of Rossland,

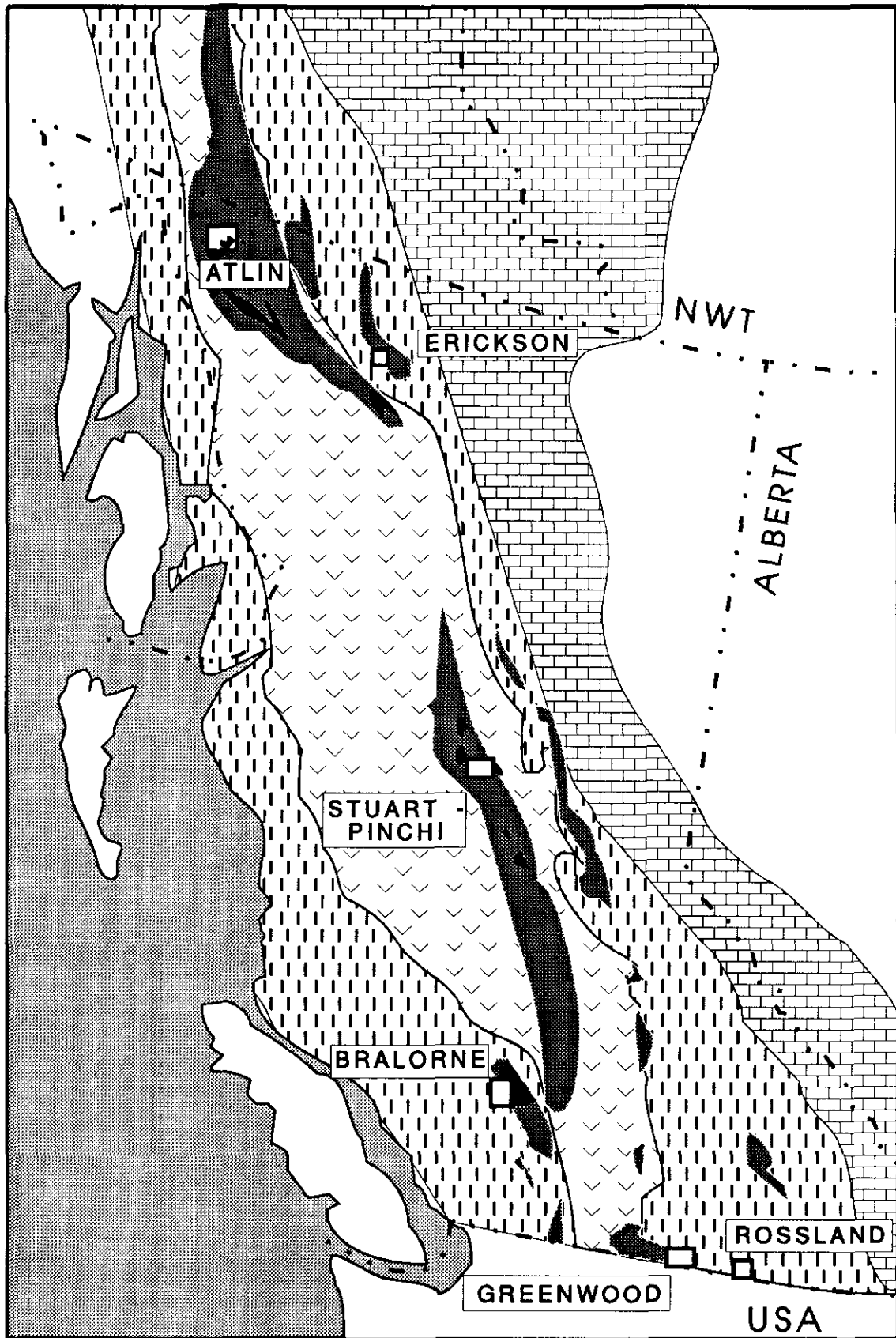


Figure 2-3-1. Study areas of the Listwanite Project in British Columbia.

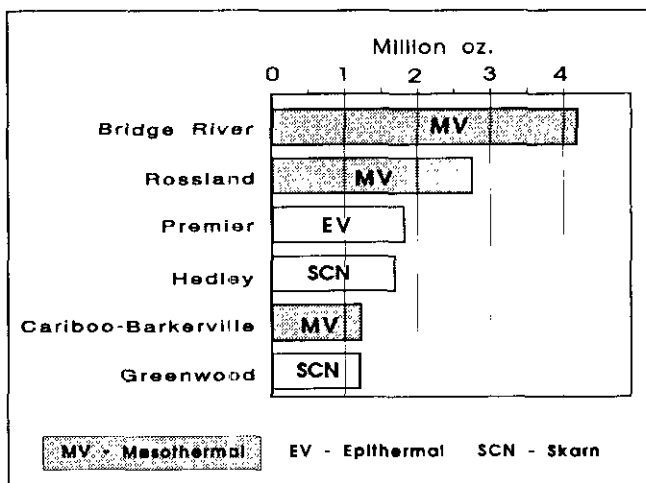


Figure 2-3-2. Top six gold-producing mines in British Columbia (data from Schroeter *et al.*, 1989).

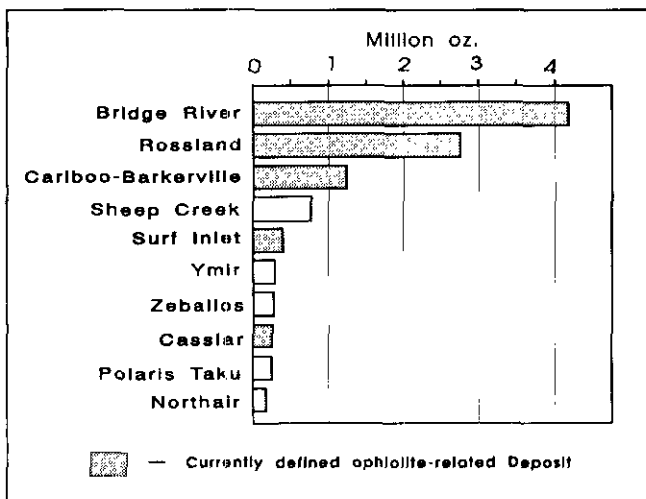


Figure 2-3-3. Top ten past-producing mesothermal gold vein deposits in British Columbia (data from Schroeter *et al.*, 1989).

overlie ophiolitic tectonic slivers along an accretionary structure (Rossland break; Fyles, 1984). Three of the camps are underlain by the Cache Creek Terrane and three by the Slide Mountain Terrane. The Cache Creek Terrane is a composite oceanic terrane which includes two distinctive elements; subduction-related accretionary complexes developed during the destruction of late Paleozoic to early Mesozoic oceanic crust (Monger *et al.*, 1982; Monger, 1984; Coney, 1989; Gabrielse and Yorath, 1989), and dismembered ophiolitic complexes emplaced by obduction of oceanic crust and upper mantle during final closure of the oceanic basin during collision.

Lithologically chaotic and tectonically mixed mélanges (Raymond, 1984) are a third important element of the Cache Creek Terrane and are imbricated with elements of both the accretionary and ophiolitic complexes. Mélanges are mappable on outcrop to regional scales throughout the terrane, and are interpreted as lithotectonic units intrinsic to both

subduction and accretionary processes. In this regard, references to the Cache Creek as "a Tethyan-bearing mélange-like terrane" (Coney, 1989), or an "ophiolitic mélange" (Oldow *et al.*, 1989) truly reflect the large and small-scale lithological and structural complexities of the terrane as a whole.

The Slide Mountain Terrane is made up of a tectonically dismembered, commonly imbricated, Devonian to Permian ophiolitic slices transported across a former continental margin during early Mesozoic time. Lithotectonic relationships common throughout the terrane (Nelson and Bradford, 1989; Klepacki and Wheeler, 1985) indicate classic inverted ophiolite stratigraphies (Gealey, 1980) resulting from the structural stacking of fault-bounded sections of dismembered oceanic crust and upper mantle during obduction. In comparison to the Cache Creek Terrane, the Slide Mountain Terrane has a conspicuous lack of subduction-related accretionary complexes.

DEPOSIT SETTING

Gold deposits investigated in each area are hosted by structures within or marginal to ophiolitic crustal and/or mantle lithologies. Having formed at oceanic crustal depths of 6 to 12 kilometres, the present tectonic setting of these lithologies suggests the presence of deep, through-going crustal structures along which reverse movement must have occurred. These structures, most likely active during collision and ophiolite obduction, are necessary to account for such significant vertical displacements.

All listwanite protoliths investigated are ophiolitic, upper mantle metamorphic harzburgite or crustal plutonic dunite to wehrlitic ultramafic cumulates. These ultramafic rocks are commonly found in fault contact with mafic plutonic and volcanic members of a classic, dismembered ophiolitic suite (Anonymous, 1972; Coleman, 1977). These crustal rocks appear to be significant, as they provide competent lithologies suitable for the development of dilatational fractures during the ore deposition process.

In most of the camps studied there is a spatial and apparent temporal association between minealization and syn- to primarily post-accretionary felsic magmatism. The Erickson camp near Cassiar may be an exception, although a thermal metamorphic halo of appropriate age suggests that such an intrusion may be present at depth (Nelson, 1990). Felsic intrusive rocks are predominantly granodiorite; however, some compositional variability is evident as diorite and monzodiorite are also identified. Intrusions and magma injection are structurally controlled, a feature which is, in general, most evident at the deposit scale. Most appear to immediately postdate the main phase of accretionary deformation and intrude all oceanic lithologies. However, in the Rossland area the intrusion associated with mineralization, the Rossland monzonite, may predate collisional tectonism (Höy *et al.*, 1992, this volume).

In terms of tectonic setting and history, the most comprehensive picture to date has been developed for the Atlin area (Figure 2-3-4). Lode-gold mineralization throughout the camp is hosted by structures either within or marginal to a relatively flat-lying, dismembered and imbricated ophiolite complex. This complex overlies with marked

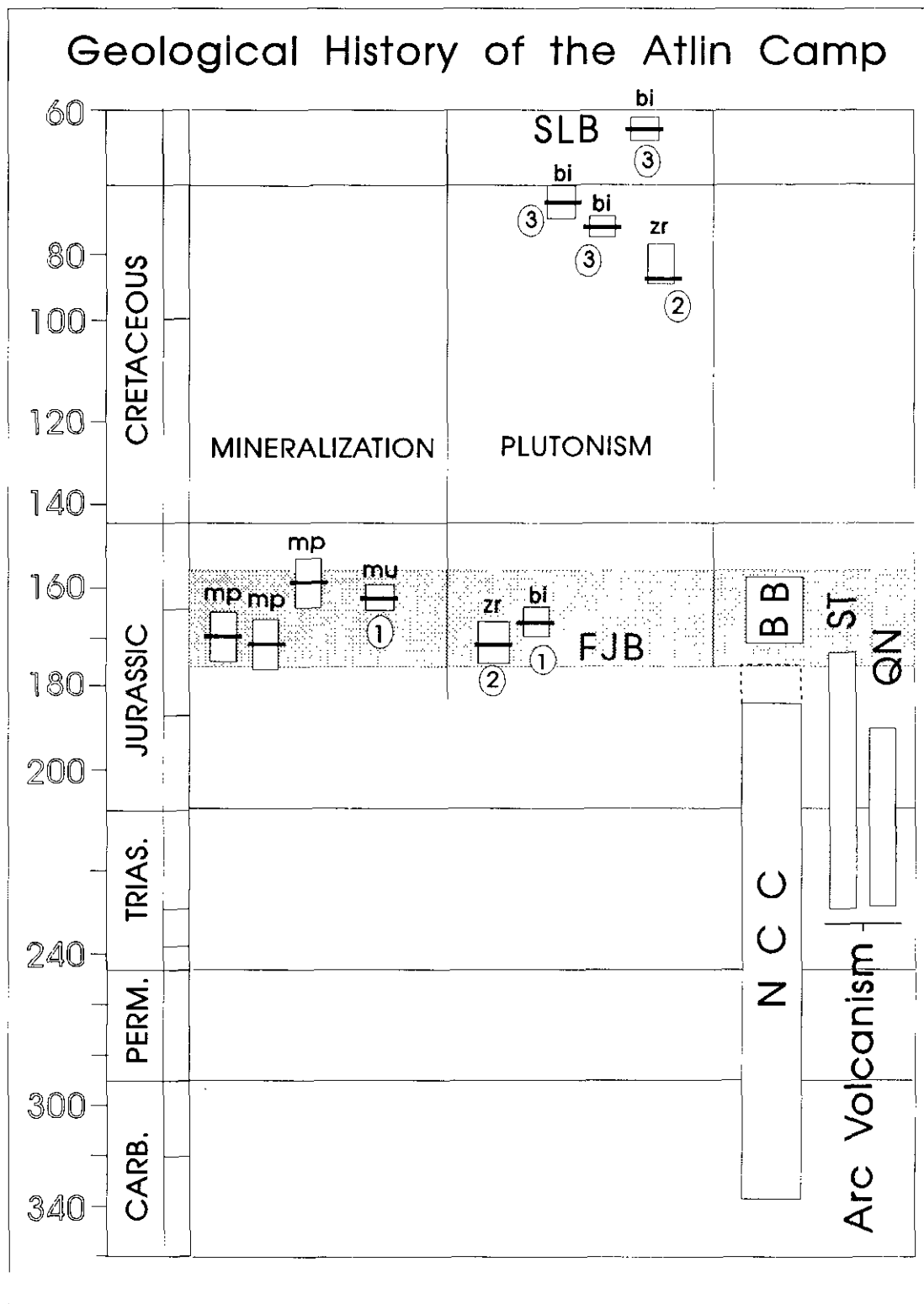


Figure 2-3-4. Geological history of the Atlin area.
 FJB – Fourth of July batholith BB – Bowser Basin mp – mariposite/fuchsite mu – muscovite
 NCC – Northern Cache Creek ST – Stikinia zr – zircon bi – biotite
 SLB – Surprise Lake batholith QN – Quesnellia

References: 1 – Dawson (1988)
 2 – Mihalyuk *et al.* (in preparation)
 3 – Christopher and Pinsent (1979)

structural discordance, a lithologically variable, imbricated package of oceanic metasedimentary and metavolcanic rocks, interpreted to represent a remnant subduction accretionary complex (Ash, in preparation).

In Atlin, the timing of lode-gold mineralization, as inferred from mariposite radiometric ages (Figure 2-3-4), clearly reflects both the timing of oceanic closure and ophiolitic obduction as evidenced by: the ending of both oceanic crustal formation (Monger, 1984; Cordey, 1990) and arc volcanism (Tipper, 1984); and the shedding of oceanic material into the Bowser Basin (Monger, 1984). Felsic magmatism is spatially and temporally related to mineralization and tectonism. Throughout the camp most areas of listwanitic alteration with anomalous gold values are in close proximity or immediately adjacent to a felsic dike or stock.

Limited trace and rare-earth element chemistry from the Fourth of July batholith is consistent with intrusions found in a syn-collisional tectonic environment. Rubidium-strontium isotopic data for this suspected syn-collisional pluton (Mihalynuk *et al.*, in preparation.) indicates a primitive origin and supports partial melting of a stacked and hydrated oceanic crustal package as a possible source.

In both the Bralorne (Leitch, 1990) and Rosland camps (Höy *et al.*, 1992, this volume) gold deposits are spatially related to structurally controlled felsic intrusions which are contemporaneous with mineralization.

PRELIMINARY DEPOSIT MODEL

Lode-gold deposits within or marginal to ophiolitic terranes in British Columbia appear to be generated during and immediately following the period of oceanic accretion. They are hosted by accretionary structures and are spatially associated with both oceanic crust and mantle lithologies. Hostrocks are cut by syn-collisional felsic intrusions generated during the accretionary episodes. This model invokes leaching of gold from a tectonically thickened package of oceanic crustal rocks which is undergoing partial melting at deeper levels, producing the contemporaneous intrusion (Figure 2-3-5).

The structural configuration of the accreted package controls the geometry of the felsic intrusive rocks. Fluids are thermally driven by the heat of intrusion and are possibly supplemented by volatiles released from the intrusions. These fluids leach metals from the thickened oceanic package. Metals are then precipitated as the fluids move away from the magmatic heat source along pre-existing structures bounding and within the accreted ophiolite package.

EXPLORATION GUIDELINES

Systematic surface mapping that focuses on both the tectonic setting and the spatial distribution of the listwanitic alteration suite is extremely useful. The distinctive listwanite alteration assemblage occurs in linear arrays reflecting the structural control on the mineralizing system. Both alteration mineralogy and intensity vary systematically away from the controlling structure. The locus of significant mineralization is typically associated with silicified zones

(veins or stockworks) at the core of the structural zone or in its related splays.

When evaluating the tectonic setting of the deposit type, it is critical to distinguish pre-accretionary, allochthonous, ophiolitic mantle and metamorphic or crustal plutonic rocks from those plutonic rocks which are syn to post-collisional and intrude the accreted oceanic package. Many reports and maps continue to interpret ophiolitic plutonic and metamorphic rocks throughout British Columbia as intrusions rather than fault-bounded tectonic slivers of oceanic crust and mantle. The most significant temporal relationship between the ophiolitic rocks and mineralization is that the tectonic emplacement of ophiolites by obduction generally occurs just prior to the mineralizing event. A classic example is the "Bralorne diorite" or "Bralorne intrusion" which hosted the largest lode-gold deposit in the Canadian Cordillera. This unit is the mafic plutonic portion of an obducted, dismembered ophiolitic assemblage, formed as part of the ocean crust and subsequently tectonically transported to its present position. It was not intruded into its present position as its name implies.

DISCUSSION

These preliminary results are consistent with current models for the development of mesothermal vein deposits in Archean greenstone belts (Barley *et al.*, 1989; Kerrich, 1989; Kerrich and Wyman, 1990) which promote vein development in association with periods of deformation, metamorphism and plutonism during terrane collision.

Current interpretations for the origin of greenstone belts invoke a prograde arc-trench model (Hoffman, 1990) in which:

"greenstone belts are viewed as remnants of fore-arc accretionary complexes, the volcanic/subvolcanic rocks being allochthonous island arcs, seamounts microcontinents, etc., and the overlying sediments being indigenous trench turbidites and allochthonous pelagic and deep sea fan deposits."

The Paleozoic Cordilleran model presented here may be viewed as a well-defined Archean analogue in terms of tectonic history and mesothermal vein development.

CONCLUSION

Mesothermal vein deposits within and adjacent to accreted oceanic terranes are:

- Typically hosted within accretionary or related structures that are consistently defined by allochthonous ophiolitic plutonic or metamorphic lithologies which commonly host or are immediately associated with the vein system.
- Spatially and temporally associated with structurally controlled felsic intrusive rocks which are probably generated by crustal melting during an accretionary or collisional episode.

Accreted ophiolitic crustal or upper mantle lithologies, where intruded by structurally controlled syn-collisional felsic magmas, offer regional-scale targets for mesothermal lode-gold exploration.

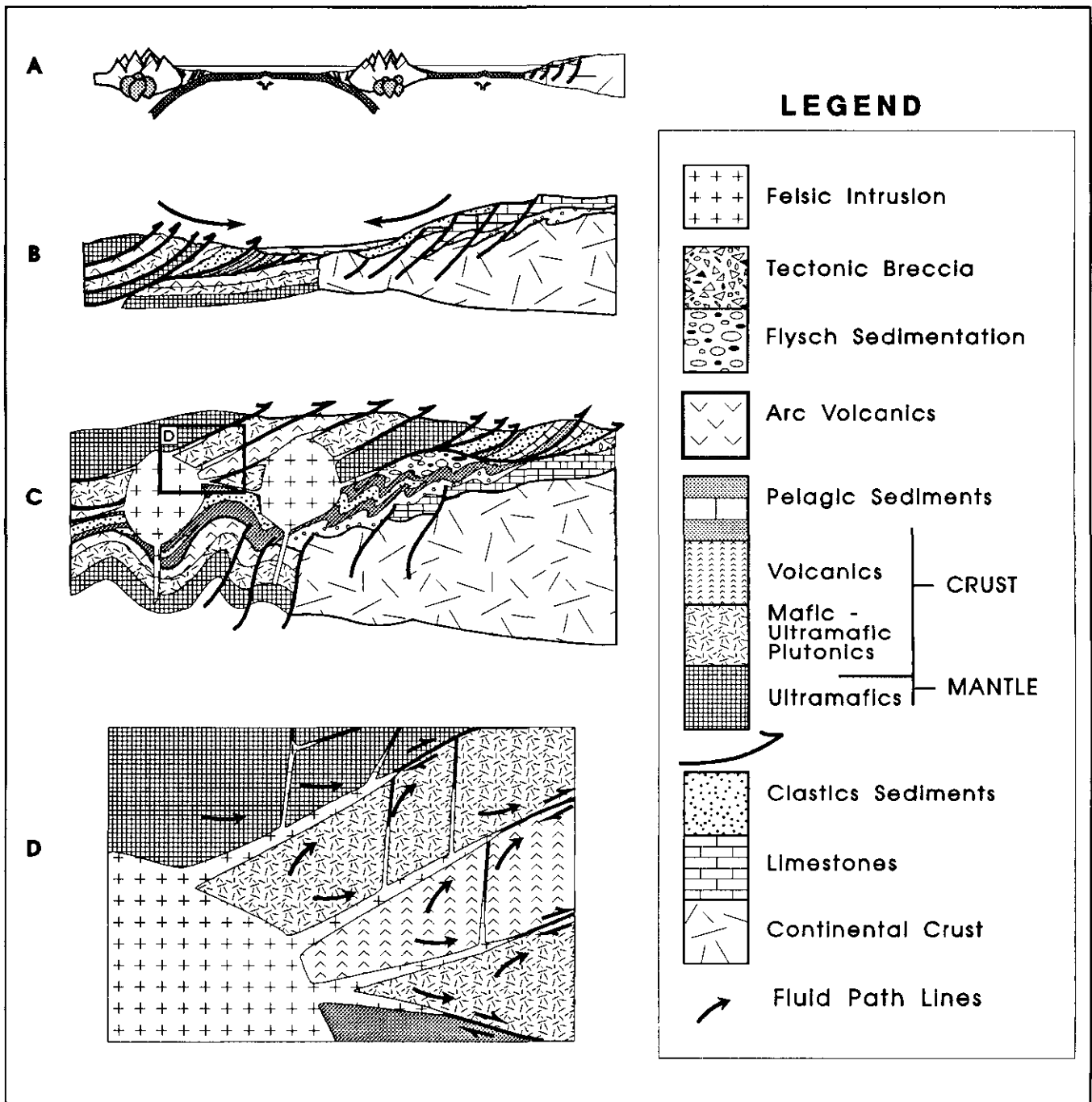


Figure 2-3-5. Schematic model for the development of ophiolite-related mesothermal vein deposits.

- A. Development of oceanic crust and depleted mantle (Alpine-type ultramafics).
- B. Decoupling of oceanic lithosphere and initiation of obduction with development of flysch sediments.
- C. Crustal thickening causes partial melting and metamorphic dehydration of oceanic lithosphere to produce mineralizing fluids.
- D. Fluids are thermally driven along pre-existing structures and deposit metals.

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