Mafic-Ultramafic Rock Studies

GEOLOGY AND PRECIOUS METAL POTENTIAL OF MAFIC-ULTRAMAFIC ROCKS IN BRITISH COLUMBIA: CURRENT PROGRESS*

By G.T. Nixon

KEYWORDS: Economic geology, ophiolite, listwanite, Alaskan-type ultramafic complex, Polaris, Wrede, Johanson, Shulaps, structure, geochemistry, gold, platinum group elements.

INTRODUCTION

The geology, geochemistry and mineral potential of mafic and ultramafic rocks in British Columbia have recently become the objectives of a number of research projects involving principally government and university workers. An evaluation of the mineral potential of ultramafic-mafic rocks in the province by the British Columbia Geological Survey Branch, funded by the Canada/British Columbia Mineral Development Agreement, was initiated in 1987 as part of a 3-year program that ends in March, 1990. This project has focused on the economic potential of Alaskan-type ultramafic complexes for platinum group elements (PGE) and gold. A more recent initiative by the British Columbia Geological Survey Branch in 1989, established a 2-year program to develop a metallogenic model for the lode gold–listwanite (carbonatized ultramafic rock) association in British Columbia. The listwanite model is particularly relevant in ophiolitic terranes. In a recent supporting project partly funded by the British Columbia Geoscience Research Grant program, university workers have also directed their attention toward a further understanding of ophiolite evolution and petrogenesis. The six papers contained in this section, and summarized below, present previously unpublished results of fieldwork conducted in 1988 and 1989 that has focused on ophiolite assemblages and Alaskan-type intrusions. Project locations are shown in Figure 3-1-1.

The ophiolite stratigraphy that represents obducted oceanic crust and uppermost mantle is rarely preserved intact. Dismembered ophiolite assemblages in British Columbia are found in the oceanic terranes of Cache Creek (*e.g.* Nahlin ophiolite), Bridge River (*e.g.* Shulaps ophiolite), and Slide Mountain (Figure 3-1-1). These tectonostratigraphic terranes represent the deformed sequences of Paleozoic to Early Mesozoic ocean basins that closed in the Mesozoic during the accretion of island arcs to the North American craton. Alaskan-type mafic-ultramafic complexes, on the other hand, represent the subvolcanic magma chambers of Late Triassic to Middle Jurassic arc volcanoes situated within these accreted terranes. They formed on continental crust where penetrative deformation during the accretion event was not nearly as severe as that which ocurred within and at the margins of the ocean basins. The subparallel belt of Alaskan-type complexes west of the Coast Mountains in southeastern Alaska is believed to be largely Cretaceous in age (Figure 3-1-1).

OPHIOLITES AND THE LISTWANITE – LODE GOLD ASSOCIATION

In the opening paper in this series, Ash and Arksey (1990a) provide an overview of the listwanite–lode gold association and examine how this model might be more extensively applied in British Columbia. Listwanites are formed where CO_2-rich hydrothermal fluids encounter serpentinized ultramafic rocks and form predominantly iron-magnesium carbonates ± quartz veins that are potentially associated with gold mineralization. Where carbonatization is accompanied by alkali metasomatism, the bright green, chrome-rich mica, mariposite(fuchsite), also occurs. Listwanitic alteration is primarily developed in fault zones that serve as channelways for circulating fluids. These zones are easily recognized in the field by their characteristically bright orange-brown weathering which stands out against a background of dark green to black serpentinite. Alteration halos are common in which talc-carbonate rocks occur in the outer envelope, at some distance from the fault zone, and quartz ± carbonate ± mariposite ± gold ± sulphides occupy the central conduits. Listwanite-generating fluids may also transport PGE leached from ultramafic rocks; the source of the gold is controversial. The development of listwanite appears to favour an ophiolitic or alpine ultramafic tectonic setting where imbrication by thrusting promotes fluid access, and serpentinization is prevalent both before and during obduction of oceanic crust and mantle sequences.

Ash and Arksey (1990b, c) go on to describe the structural controls of listwanitic alteration within the Atlin ultramafic allochthon, an imbricated package of oceanic upper mantle rocks obducted in the Mesozoic. These rocks form part of the Cache Creek Terrane, a subduction complex related to the Late Paleozoic–Early Mesozoic volcanic arcs of Quesnellia and Stikinia. The Atlin area has a long history of placer gold mining; lode gold deposits and listwanitic alteration are spatially related to major zones of southwesterly directed thrusting such as the Monarch Mountain fault (Ash and Arksey, 1990b). Rocks within these thrust packages include depleted mantle harzburgite tectonite, minor podiform dunite, metabasalts and a tectonic mélange assemblage. The listwanites are preferentially developed within serpentinized harzburgite tectonites in the hangingwall of the thrust.

In another investigation of an accreted oceanic terrane, Calon *et al.* (1990) present a preliminary report on the tectonic and petrologic evolution of the Shulaps ophiolite and a discussion of its Mesozoic accretionary history. The Shulaps, situated along the boundary of the Intermontane Superterrane, is one of the largest intact ophiolite fragments in the Cordillera (Figure 3-1-1). These authors recognize a southwest-verging, northeast-dipping imbricate thrust sys-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

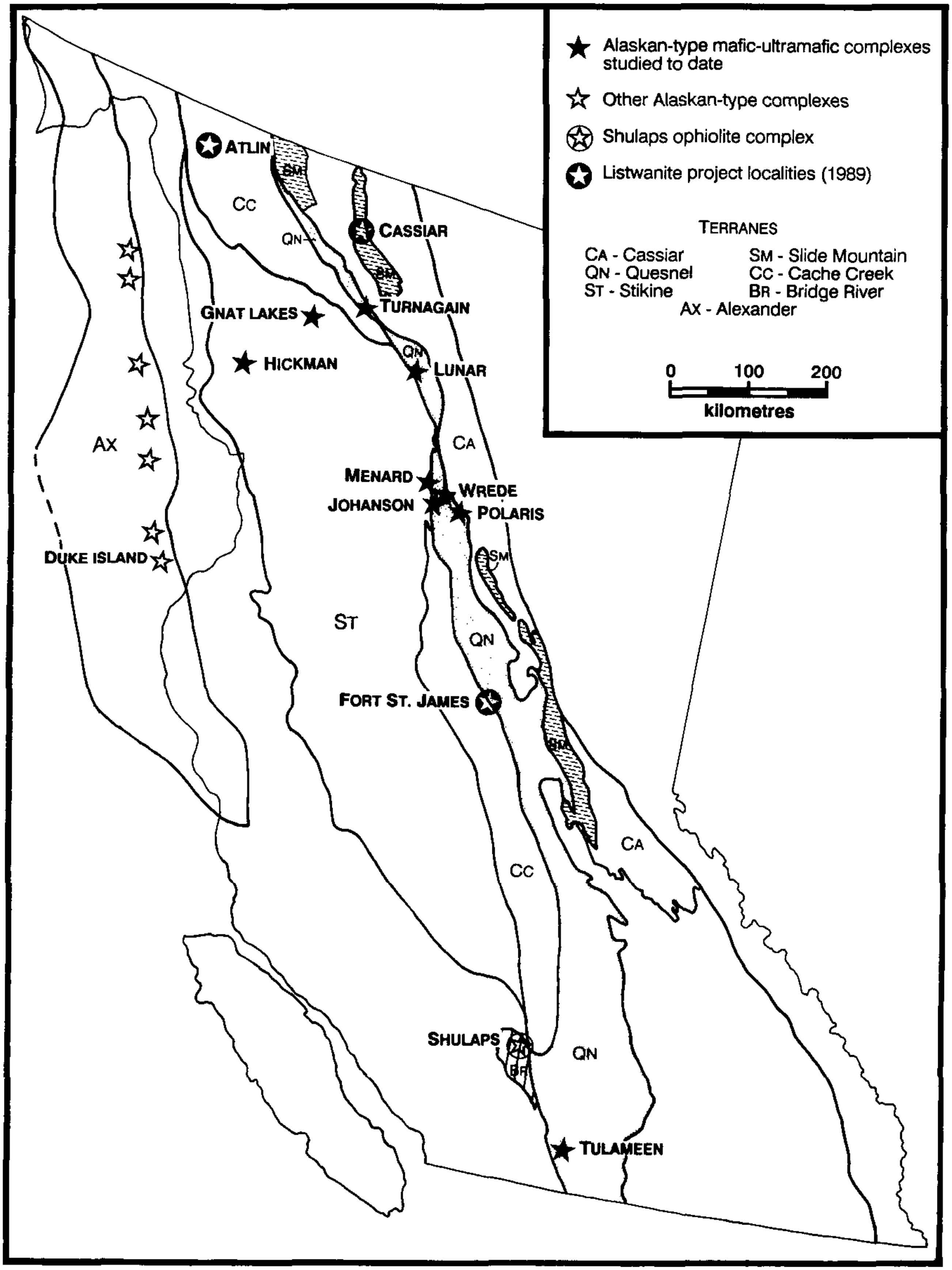

Figure 3-1-1. Map showing location of listwanite project sites, Shulaps ophiolite and most known Alaskan-type complexes in British Columbia in relation to accreted tectonostratigraphic terranes of the Cordillera.

tem comprising four main lithotectonic units. The uppermost unit, the Shulaps peridotite, is composed of depleted mantle harzburgite tectonite and minor podiform dunite, much like the upper mantle lithologies described by Ash and Arksey in the Atlin area. The peridotite unit structurally overlies a serpentinite mélange that contains variably sized, rare blocks of volcanic and sedimentary rocks, as well as more common gabbros and ultramafic cumulates. This, in turn, is thrust upon a suite of mafic plutonic and volcanic rocks. The lowermost unit comprises arc-derived siliciclastic and calcareous sedimentary rocks tentatively assigned to the Late Triassic Cadwallader Group. Fault-controlled listwanitic alteration accompanied by magnesite is known along the Yalakom fault some 12 kilometres to the northeast of the project area, and along the Relay Creek–Marshall Creek fault system 15 kilometres to the northwest, where listwanites have developed in serpentinite and are associated with tungsten and scheelite mineralization, and contain anomalous mercury, silver and gold (Schiarizza *et al.*, 1989).

ALASKAN-TYPE COMPLEXES AND THEIR PGE POTENTIAL

The Alaskan-type mafic-ultramafic complexes studied to date include all of the known major complexes (Tulameen, Polaris, Wrede Creek, Lunar Creek and Turnagain) as well as many minor bodies (Johanson Lake, Menard Creek, Gnat Lakes and Hickman; Figure 3-1-1). All such complexes in British Columbia occur within the Intermontane Superterrane and form part of the accreted volcanic arc terranes of Quesnellia and Stikinia. Only the Menard Creek, Hickman and Gnat Lakes complexes (Nixon *et al.*, 1989b) occur in Stikinia as presently defined (Wheeler and McFeeley, 1987; Wheeler *et al.*, 1988). Aspects of the geology, noble metal geochemistry and platinum mineralogy of the Tulameen, Polaris and Turnagain complexes have been documented previously (Nixon and Rublee, 1988; Nixon, 1988; Nixon *et al.*, 1989a, c, d).

The type localities for Alaskan-type ultramafic complexes are found in southeastern Alaska (Figure 3-1-1) and the Ural Mountains. Taylor (1967) has summarized many of their diagnostic features but Irvine's (1974a) classic memoir on Duke Island (Figure 3-1-1) still remains one of the most complete and detailed accounts of Alaskan-type complexes. Most of these complexes have been interpreted to represent the fractionation products of mantle-derived, crystal-poor magma or remobilized cumulates emplaced high in the crust. Their general structural and petrological characteristics include a crude outward zonation of rock types ranging from dunite in the core through wehrlite and clinopyroxenitic and/or hornblende-rich lithologies towards the periphery of the intrusion. Primary mesoscopic layering, such as that so spectacularly developed at Duke Island, is seldom observed. In many cases the ultramafic complexes are partially or completely enveloped by gabbroic to dioritic rocks, which may be genetically related. Some intrusions have well-developed contact metamorphic and metasomatic aureoles of amphibolite grade; others appear to be completely fault-bounded. Not all of the characteristic rock types are represented in each intrusion, which can make their Alaskan-type affinity difficult to establish, particularly if only the later differentiates are exposed. Early cumulate minerals are typically represented by forsteritic olivine, chromite, diopsidic clinopyroxene and rare phlogopitic mica, whereas hornblende, biotite, magnetite and plagioclase may predominate in the more evolved rock types. Orthopyroxene is characteristically absent, which has been taken to indicate an alkalic affinity.

The classification of ultramafic rocks used to characterize Alaskan-type complexes is essentially that recommended by the IUGG (Streckeisen, 1976; Figure 3-1-2). It was found beneficial in the field to arbitrarily subdivide extensive wehrlitic units into olivine wehrlite (65 to 90 per cent olivine; 10 to 35 per cent clinopyroxene) and wehrlite (40 to 65 per cent olivine; 35 to 60 per cent clinopyroxene). All of the Alaskan-type ultramafic rocks lie along the olivine-clinopyroxene join.

The Alaskan-type complexes in British Columbia are potentially important hosts for commercially exploitable platinum group metals (Rublee, 1986; Evenchick *et al.*, 1986) as well as other commodities (*e.g.* chrome, nickel, cobalt, gold, asbestos, jade). The Tulameen complex in southern British Columbia (Figure 3-1-1) ranks as the foremost producer of placer platinum in the province, reportedly having yielded over 680 000 grams of platinum nuggets between 1885 and 1932 (O'Niell and Gunning, 1934). Recent studies of the Tulameen complex have identified platinum group minerals in lode occurrences where they are associated with concentrations of chromite (St. Louis *et al.*, 1986; Nixon *et al.*, 1989a). In particular, Nixon *et al.* (1989a) were able to trace the source of platinum nuggets to chromitite horizons within the dunite core of the complex by matching the phase chemistry of gangue minerals, notably spinel and olivine, in nugget and lode occurrences. The chromitite-PGE association in Alaskan-type complexes is a promising exploration target that deserves further investigation. For example, highly anomalous PGE have recently been discovered in chromitites within the Wrede Creek complex as described below.

Alaskan-type complexes investigated during the 1989 field season include the Lunar Creek, Polaris, Wrede Creek and Johanson Lake bodies in north-central British Columbia. The former three complexes are the subjects of Open File releases (Nixon *et al.*, 1990b, d; Hammack *et al.*, 1990b) and the latter three are described in this publication (Nixon *et al.*, 1990a, c; Hammack *et al.*, 1990a).

Briefly, the Polaris complex (Nixon *et al.*, 1990c) forms a transgressive sill-like body with a minimum length of 14 kilometres and a maximum width of 4 kilometres. It intrudes Paleozoic metavolcanic and metasedimentary island arc sequences that are believed to form the basement of Quesnellia, and has a metamorphic aureole of lower amphibolite grade. All of the Alaskan-type complexes in the region are considered to be Late Triassic in age, and both coeval and cogenetic with arc-related volcanic rocks of the Takla Group (Irvine, 1974b, 1976). Kinematic indicators suggest that the Polaris complex and its hostrocks are allochthonous, having been uprooted along a westerly dipping reverse fault and transported eastwards toward cratonic North America during terrane accretion in the Mesozoic.

All of the lithologies that characterize Alaskan-type ultramafic complexes are well represented in the Polaris intrusion, although exposures of olivine-rich ultramafic rocks predominate. The complex exhibits a crude upward zonation from dunite through wehrlite and clinopyroxenite to clinopyroxene hornblendite and gabbroic rocks near the roof. The lower margin of the intrusion displays a similar variation but the zoning is much more condensed. Cumulate textures are well preserved and penetrative deformation is lacking. Chromitites are widespread in the dunite, but invariably small in size and have been remobilized shortly after deposition. Lithogeochemical analyses reveal some platiniferous chromitite horizons but they appear too few and far between to be of economic interest. Weak gold anomalies are restricted almost entirely to the contacts with metasedimentary and metavolcanic hostrocks, which suggests an external source for the gold.

The Wrede Creek complex (Hammack *et al.*, 1990a) appears to be a stock-like intrusion hosted by Takla Group volcanic and volcaniclastic rocks. Ultramafic lithologies, particularly dunite, are well represented and vestiges of an amphibolite-grade metamorphic aureole are present. In the past, the Wrede Creek complex was extensively prospected and drilled for porphyry copper-molybdenum mineralization associated with Jurassic granitoid intrusions at its southern margin (Wong *et al.*, 1985). Apparently chromitite horizons in the dunite core were not tested for their PGE potential. However, all of the chromitite samples analyzed during the course of this investigation proved to be anomalous in platinum, and some extremely so (2500 ppb). It is this same PGE-chromitite association that has been linked to the source of platinum placers in the Tulameen district (Nixon *et al.*, 1989a).

The final paper of the series describes the Johanson Lake mafic-ultramafic complex (Nixon *et al.*, 1990a), a gabbroic to pyroxenitic body spatially associated with Takla Group volcanic rocks and Jurassic dioritic plutons. The pegmatitic phases of the complex exhibit well-developed comb layering formed by acicular hornblende crystals that appear to have crystallized *in situ*. Lithogeochemical analyses for PGE do not reveal anomalous lithologies although the background for gold is distinctly higher than has been observed in other Alaskan-type complexes.

OBSERVATIONS AND FUTURE CONSIDERATIONS

The first-order spatial correlation observed between listwanite–lode gold occurrences and ophiolites or alpine serpentinites/peridotites reflects a fundamental tectonic environment. The closure of ocean basins and ensuing collisional events provide a mechanism for the emplacement of variably serpentinized oceanic crust in regions of orogenesis and crustal thickening. Imbrication of mafic-ultramafic ocean-floor stratigraphy, and subsequent high-angle faulting during later isostatic readjustment or migration of previously

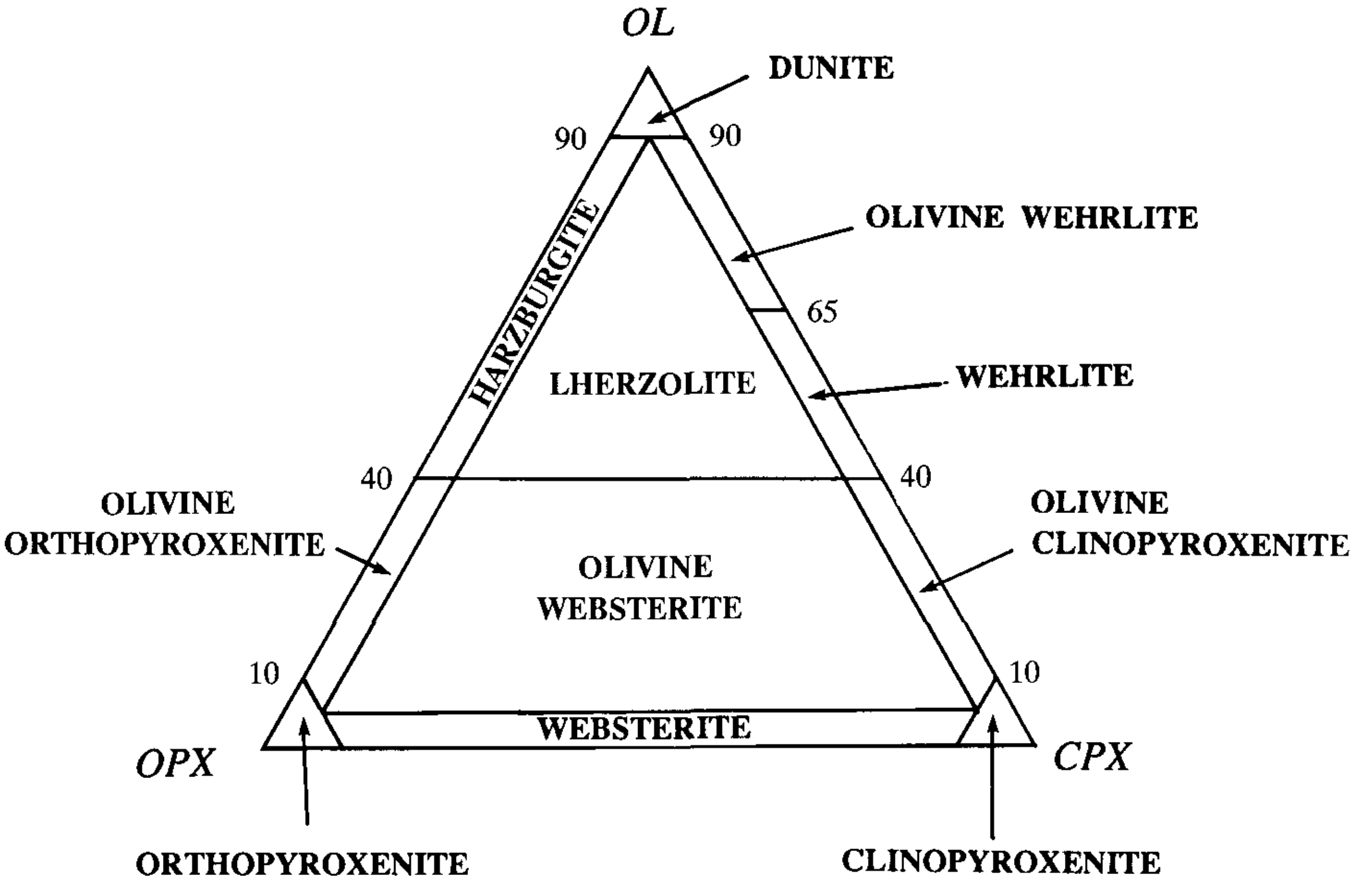

Figure 3-1-2. Classification of ultramafic rocks used to subdivide Alaskan-type ultramafic complexes (modified after Streckeisen, 1976).

accreted terranes provides adequate structural preparation for carbon dioxide rich hydrothermal fluids that promote listwanite development and deposition of precious metals. The fact that listwanite-associated lode gold deposits have been the major source of over 19 million grams of placer gold in the Atlin area, and that these zones have been shown to occur along regional-scale thrusts, should provide a firm focus for future exploration efforts (Ash and Arksey, 1990a).

That the listwanite–lode gold association appears to be *insignificant* in Alaskan-type ultramafic complexes can also be rationalized in terms of the geotectonic setting. In British Columbia, at least, many of the latter complexes have intruded at relatively high-levels in supracrustal rock sequences situated within the accreted terranes. In many cases, these complexes probably represent the subvolcanic magma chambers of Late Triassic to Early Jurassic arc volcanoes. The fact that Alaskan-type complexes have formed within continental crust in an environment relatively protected from collisional deformation, together with their limited amount of olivine-rich ultramafic lithologies and restricted degree of serpentinization, do not make them a propitious target for auriferous listwanite development. Gold-bearing fluids may have been largely spent by the time they reach these sites.

The PGE potential of Alaskan-type ultramafic complexes has not been adequately evaluated and deserves further attention by the exploration community. In northern British Columbia, many of the known intrusions form a northwesterly trending belt stretching from the Polaris complex to at least as far as the Turnagain River. Other Alaskan-type complexes will no doubt be discovered within this belt, particularly when aeromagnetic coverage in this part of the province becomes more complete. In at least two cases, Tulameen and Wrede Creek, the platinoid minerals are closely (genetically?) related to chromitites within the dunite core of these intrusions. This association should, therefore, be considered a prime target for lode occurrences and derived placers.

REFERENCES

Ash, C.H. and Arksey, R.L. (1990a): The Listwanite–Lode Gold Association in British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1989, Paper 1990-1, this volume.

——— (1990b): The Atlin Ultramafic Allochthon: Ophiolitic Basement Within the Cache Creek Terrane; Tectonic and Metallogenic Significance; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1989, Paper 1990-1, this volume.

——— (1990c): Tectonic Setting of Listwanite-related Gold Deposits in Northwestern British Columbia (104N/12); *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1990-22.

Calon, T.J., Malpas, J.G. and McDonald, R. (1990): The Anatomy of the Shulaps Ophiolite; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1989, Paper 1990-1, this volume.

Evenchick, C.A., Monger, J.W.H. and Friday, S.J. (1986) Potential Hosts to Platinum Group Element Concentrations in the Canadian Cordillera; *Geological Survey of Canada,* Open File 1433.

Hammack, J.L., Nixon, G.T., Wong, R.H. and Paterson W.P.E. (1990a): Geology and Noble Metal Geochemistry of the Wrede Creek Ultramafic Complex, North-central British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1989, Paper 1990-1, this volume.

Hammack, J.L., Nixon, G.T., Wong, R.H., Paterson, W.P.E. and Nuttall, C. (1990b): Geology and Noble Metal Geochemistry of the Wrede Creek Ultramafic Complex (94D/9); *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1990-14.

Irvine, T.N. (1974a): Petrology of the Duke Island Ultramafic Complex, Southeastern Alaska; *Geological Society of America,* Memoir 138, 240 pages.

——— (1974b): Ultramafic and Gabbroic Rocks in the Aiken Lake and McConnell Creek Map-areas, British Columbia; *Geological Survey of Canada,* Paper 74-1A pages 149-152.

——— (1976): Alaskan-type Ultramafic-Gabbroic Bodies in the Aiken Lake, McConnell Creek, and Toodoggone Map-areas; *Geological Survey of Canada,* Paper 76-1A, pages 76-81.

Nixon, G.T. (1988): Geology of the Tulameen Ultramafic Complex; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1988-25.

Nixon, G.T. and Rublee, V.J. (1988): Alaskan-type Ultramafic Rocks in British Columbia: New Concepts of the Structure of the Tulameen Complex; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1987, Paper 1988-1, pages 281-294.

Nixon, G.T., Cabri, L.J. and Laflamme, J.H.G. (1989a) Tulameen Placers, 92H/7, 10: Origin of Platinum Nuggets in Tulameen Placers: A Mineral Chemistry Approach with Potential for Exploration; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Exploration in British Columbia 1988, pages B83-B89.

Nixon, G.T., Ash, C.H., Connelly, J.N. and Case, G. (1989b): Alaskan-type Mafic-Ultramafic Rocks in British Columbia: The Gnat Lakes, Hickman, and Menard Creek Complexes; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1988, Paper 1989-1, pages 429-442.

——— (1989c): Preliminary Geology and Noble Metal Geochemistry of the Polaris Mafic-Ultramafic Complex; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1989-17.

——— (1989d): Geology and Noble Metal Geochemistry of the Turnagain Ultramafic Complex, Northern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1989-18.

Nixon, G.T., Hammack, J.L. and Paterson, W.P.E. (1990a) Geology and Noble Metal Geochemistry of the Johanson Lake Mafic-Ultramafic Complex, North-central British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Geological Fieldwork 1989 Paper 1990-1, this volume.

Nixon, G.T., Hammack, J.L., Paterson, W.P.E. and Nuttall, C. (1990b): Geology and Noble Metal Geochemistry of the Lunar Creek Mafic-Ultramafic Complex (94E/13, 14); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1990-12.

Nixon, G.T., Hammack, J.L., Connelly, J.N., Case, G. and Paterson, W.P.E. (1990c): Geology and Noble Metal Geochemistry of the Polaris Ultramafic Complex, North-central British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1989, Paper 1990-1, this volume.

Nixon, G.T., Hammack, J.L., Ash, C.H., Connelly, J.N., Case, G., Paterson, W.P.E. and Nuttall, C. (1990d): Geology of the Polaris Ultramafic Complex (94C/5, 12); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1990-13.

O'Neill, J.J. and Gunning, H.C. (1934): Platinum and Allied Metal Deposits of Canada; *Geological Survey of Canada*, Economic Geology Series 13, 165 pages.

Rublee, V.J. (1986): Occurrence and Distribution of Platinum Group Elements in British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1986-7, 94 pages.

Schiarizza, P., Gaba, R.G., Glover, J.K. and Garver, J.I. (1989): Geology and Mineral Occurrences of the Tyaughton Creek Area (92O/2, 92J/15, 16); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1988, Paper 1989-1, pages 115-130.

St. Louis, R.M., Nesbitt, B.E. and Morton, R.D. (1986): Geochemistry of Platinum Group Elements in the Tulameen Ultramafic Complex, Southern British Columbia; *Economic Geology*, Volume 81, pages 961-973.

Streckeisen, A. (1976): To Each Plutonic Rock its Proper Name; *Earth Science Reviews*, Volume 12, pages 1-33.

Taylor, H.P., Jr. (1967): The Zoned Ultramafic Complexes of Southeastern Alaska, *in* Ultramafic and Related Rocks, P.J. Wyllie, Editor, *John Wiley and Sons Inc.*, New York, pages 97-121.

Wheeler, J.O. and McFeely, P. (1987): Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America; *Geological Survey of Canada*, Open File 1565.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J. W.H., Tipper, H.W. and Woodsworth, G.J. (1988): Terrane Map of the Canadian Cordillera; *Geological Survey of Canada*, Open File 1894.

Wong, R.H., Godwin, C.I. and McTaggart, K.C. (1985): 1977-Geology, K-Ar dates and Associated Sulphide Mineralization of Wrede Creek Zoned Ultramafic Complex (94D/9E); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geology in British Columbia 1977-1981, pages 148-155.