GEOLOGY AND NOBLE-METAL GEOCHEMISTRY OF THE LUNAR CREEK ALASKAN-TYPE COMPLEX, NORTH-CENTRAL BRITISH COLUMBIA*

(94E/13, 14)

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INTRODUCTION

Alaskan-type complexes in British Columbia are potentially important hosts for economic concentrations of platinum-group elements (PGEs; Rublee, 1986; Evenchick *et al.*, 1986) as well as other commodities such as chrome, nickel, cobalt, gold, jade and asbestos. To date, only the platinum-rich placers of the Tulameen complex have been exploited economically, yielding some 680 000 grams of impure platinum nuggets between the years 1885 and 1932 (O'Neil and Gunning, 1934). The source of the placer nuggets has been traced to chromitite horizons within the dunite core of the Tulameen complex (Nixon *et al.*, 1990a), and the chromitite-PGE association appears to be one of the most favourable exploration targets for lode occurrences of PGEs in British Columbia (Nixon and Hammack, 1990).

The Lunar Creek complex is part of the "Polaris suite" of Alaskan-type intrusions, a series of mafic-ultramafic complexes concentrated in northern British Columbia along an arcuate zone around the northern and eastern margin of the Bowser basin (Figure 2-8-1). All lie within the allochthonous Quesnel and Stikine terranes which were amalgamated prior to accretion with the North American craton in the Mesozoic (Wheeler and McFeeley, 1987) and form part of the Intermontane Superterrane. These intrusions are typically spatially associated, and believed to be coeval, with augite-phyric volcanic rocks of the Upper Triassic Takla and Stuhini groups (Irvine, 1976). The size of individual intrusive bodies ranges from less than 1 square kilometre to 60 square kilometres, and outcrop patterns vary from round or elliptical to markedly elongate. Elongate intrusions have a northwesterly orientation, parallel to the tectonic grain of the region. These intrusions generally exhibit a crude concentric zonation such that ultramafic lithologies in the centre grade outward into gabbroic lithologies at the margins. In all, nine Alaskan-type intrusions have been examined over the course of this project: the Polaris (Nixon *et al.*, 1990d, e), Wrede (Hammack *et al.*, 1990a, b), Johanson (Nixon *et al.*, 1990b), Turnagain (Nixon *et al.*, 1989a), Menard, Gnat Lakes, Hickman (Nixon *et al.*, 1989b) in northern British Columbia, and the Tulameen complex (Nixon and Rublee, 1988; Nixon, 1988; Nixon *et al.*, 1989c, 1990a) in south-central British Columbia. Although similar in many respects, each has its own unique characteristics.

Ultramafic lithologies characteristic of Alaskan-type intrusions lie along the join between olivine and clinopyroxene in Figure 2-8-2. This diagram essentially illustrates the IUGS classification scheme (LeMaitre, 1989) with modifications to include the olivine wehrlite field (65 to 90 per cent olivine and 10 to 35 per cent clinopyroxene) that was found to be useful for mapping purposes.

Fieldwork at Lunar Creek was conducted during the summer of 1989, and this report summarizes the geology of the previously published Open File map (Nixon *et al.*, 1990c). The project area is covered at a scale of 1:250 000 by the Finlay River map sheet (94E) and 1:50 000 topography maps (94E/13 and 14). Aeromagnetic maps are not currently available.

LOCATION AND ACCESS

The Lunar Creek ultramafic complex (57°55'N, 127°28'W) lies within the Stikine Ranges of the Omineca Mountains, approximately 1 kilometre northwest of the headwaters of Lunar Creek (Figure 2-8-3). Lunar Creek drains southward into the Chuckachida River, a tributary of the Stikine River. Access to the complex was by helicopter from Sturdee airstrip in the Toodoggone River area, which is serviced by scheduled flights from Smithers, or by vehicle along a well-maintained dirt road stretching from Fort St. James to the Cheni mine. Access to the northern part of the road is restricted and requires permission from mine management. The complex lies completely above treeline and is best exposed along ridge crests and high on valley walls. Glacial till and talus aprons cover lower valley walls and floors.

GEOLOGIC SETTING AND GEOCHRONOMETRY

The Lunar Creek ultramafic complex was first recognized in 1973 during regional geologic mapping by the Geological Survey of Canada (Gabrielse and Dodds, 1974). Later, more detailed mapping was completed by Irvine (1976) as part of a study of Alaskan-type ultramafic bodies in the Finlay River map area (Irvine, 1974a, 1976).

The complex lies within Quesnellia, at the boundary between the Stikine and the Quesnel tectonostratigraphic terranes. In the study area, this boundary is defined by the Kutcho fault which marks the western margin of the ultramafite (Figure 2-8-4). Zircon from diorite within the Lunar

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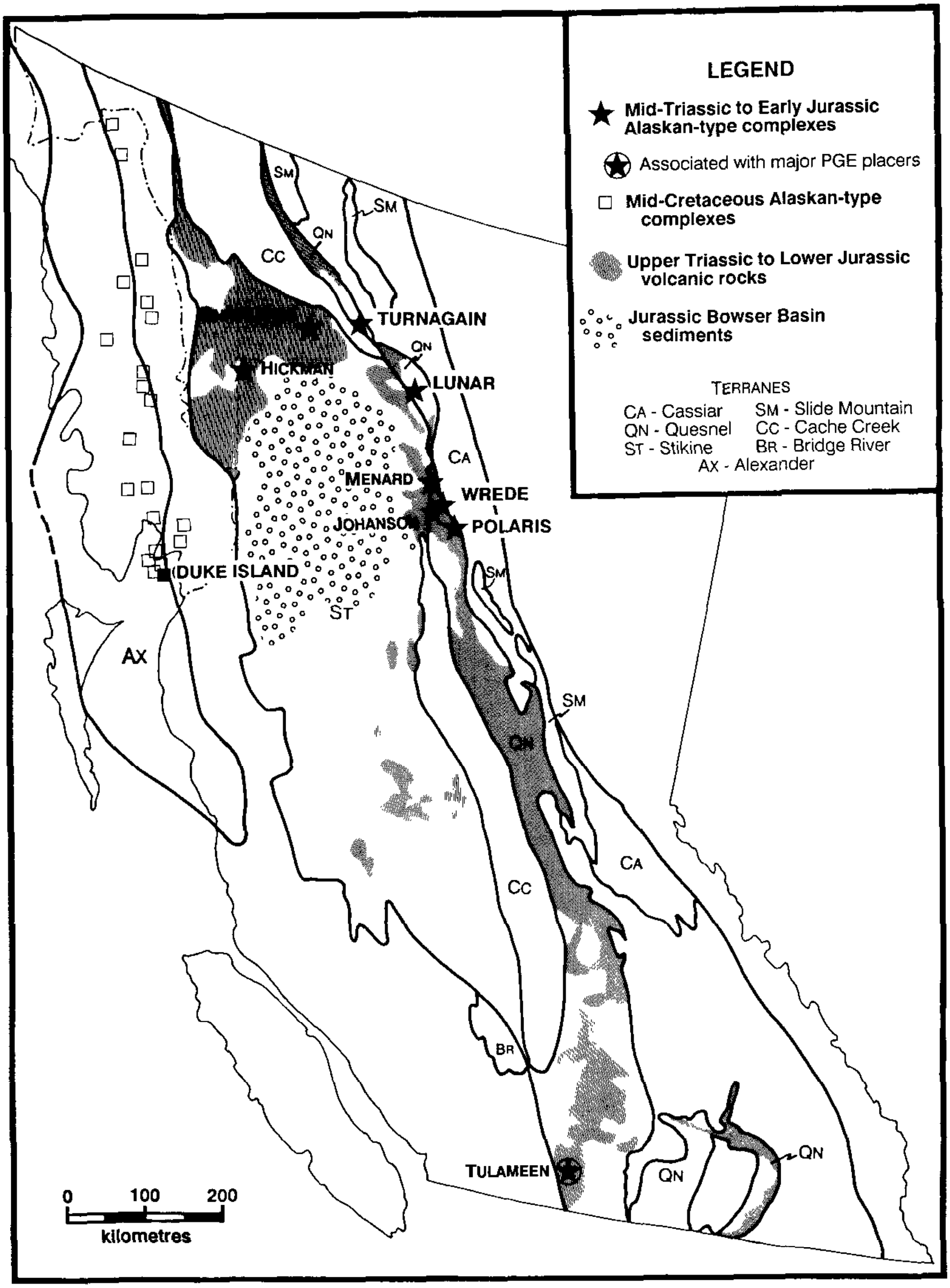

Figure 2-8-1. Distribution of major Alaskan-type ultramafic-mafic complexes in British Columbia and southeastern Alaska and coeval volcanic rocks in relation to tectonostratigraphic terranes of the Cordillera.

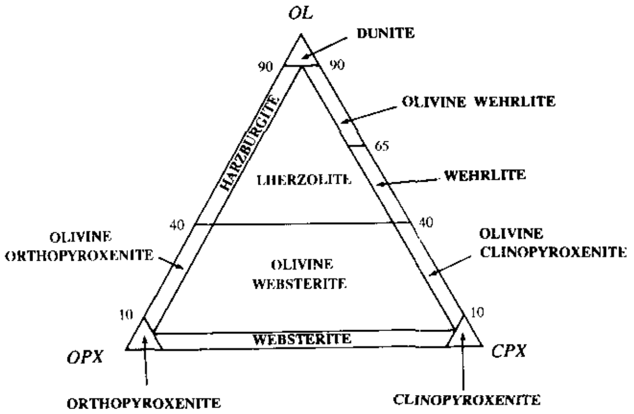

Figure 2-8-2. Classification of ultramafic rocks (modified after Le Maitre, 1989). Lithologies encountered in Alaskan-type complexes in British Columbia lie along the olivine-clinopyroxenite join; other common rock types include hornblende clinopyroxenite (<50 per cent hornblende), clinopyroxene hornblendite (>50 per cent hornblende) and hornblendite.

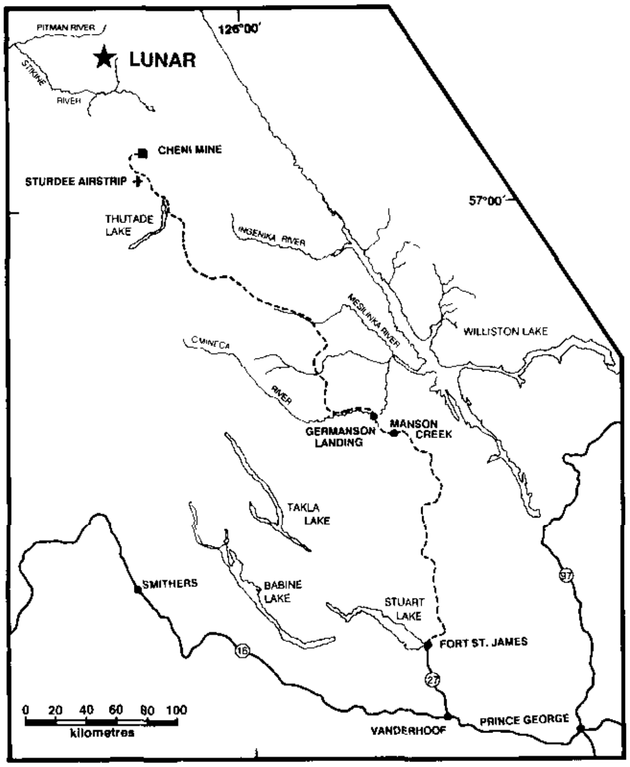

Figure 2-8-3. Location of the Lunar Creek mafic-ultramafic complex.

Creek complex has yielded a U-Pb age of Middle Triassic (237±2 Ma; L. Heaman, personal communication, 1990). Along its eastern margin, the ultramafite lies in contact with, and may intrude, foliated augite-phyric volcanic rocks which, on the basis of lithology, are assigned to the Upper Triassic Takla Group. Granitoids of the Early Jurassic Pitman batholith, part of the Guichon suite of intrusions (Woodsworth *et al.*, in press), intrude these volcanic rocks as well as ultramafic rocks of the complex. Potassium-argon ages, determined on hornblende from this batholith, are 182±13 (2 σ) Ma (Gabrielse *et al.*, 1980) and 190±8 Ma (Wanless *et al.*, 1979; Gabrielse *et al.*, 1980).

The Kutcho fault separates the southwest margin of the ultramafic complex, which lies in Quesnellia, from Paleozoic and younger rocks within Stikinia. Paleozoic rocks in the area are believed to range in age from Devonian to Permian (Thorstad, 1980; H.Gabrielse, personal communication, 1990). Rocks of the Upper Triassic Stuhini Group are also represented west and south of the study area. These arc-derived volcanic and clastic rocks have been intruded by granitoids of the Late Triassic to Early Jurassic Stikine batholith [222±10 (2 σ) Ma, K-Ar date on hornblende: Dodds *in* Wanless *et al.*, 1979; Anderson, 1984] as well as granitoids of the previously mentioned Early Jurassic Guichon suite. Biotite from granite of the Mount Albert Dease pluton, which is part of the Three Sisters suite of intrusions found south of the ultramafic complex, has yielded a K-Ar age of 167±6 (2 σ) Ma (Dodds *in* Wanless *et al.*, 1979; Woodsworth *et al.*, in press). The Three Sisters suite is spatially and temporally associated with volcanic and clastic rocks of the Lower to Middle Jurassic Hazelton Group.

STRATIFIED ROCKS

Stratified rocks within the study area include both metavolcanic and metasedimentary rocks of the Takla Group, which crop out north and east of the complex and lie within Quesnellia, and an unnamed package of metavolcanic and metasedimentary rocks of Paleozoic age, which lies southwest of the Kutcho fault, within Stikinia.

TAKLA GROUP

Rocks tentatively assigned to the Upper Triassic Takla Group crop out north and east of the complex (Figures 2-8-4 and 2-8-5). To the north, augite-plagioclase porphyry, volcanic wackes and siltstones have been metamorphosed to lower amphibolite grade. To the east, the country rock is strongly sheared and metamorphosed, and varies from a medium-grained biotite schist to well-foliated amphibolite.

The contact between rocks of the Takla Group and the Lunar Creek complex is a ductile fault zone. Along it, both lithologies have been mylonitized. Mylonitized metavolcanic rocks of the Takla Group (near Localities 3 and 4; Figure 2-8-6) are medium to dark grey to green-grey augite, augite-plagioclase and plagioclase-porphyritic actinolite schists. Augite augen, up to 0.7 centimetre in diameter, have been partially to completely altered to pale green actinolite. Actinolite, seen in thin section, is the most common constituent of the matrix, forming laths parallel to the foliation. The remainder of the matrix consists of albite, epidote and clay minerals. Northeast of Locality 2, away from the mylonitic zone, the most common lithology is dark grey augite porphyry that is metamorphosed to lower amphibolite grade.

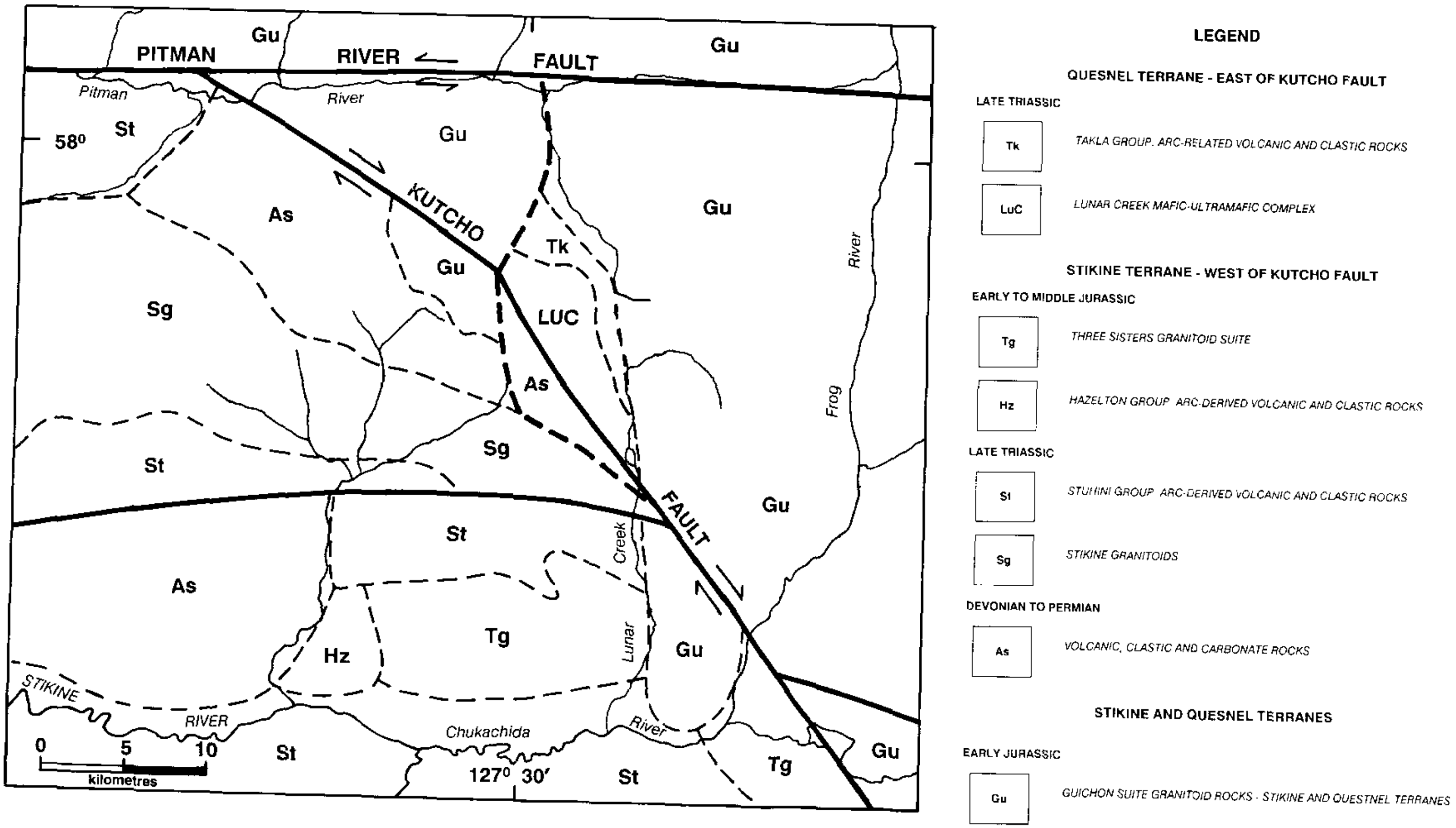

Figure 2-8-4. Regional geological setting of the Lunar Creek mafic-ultramafic complex (LuC).

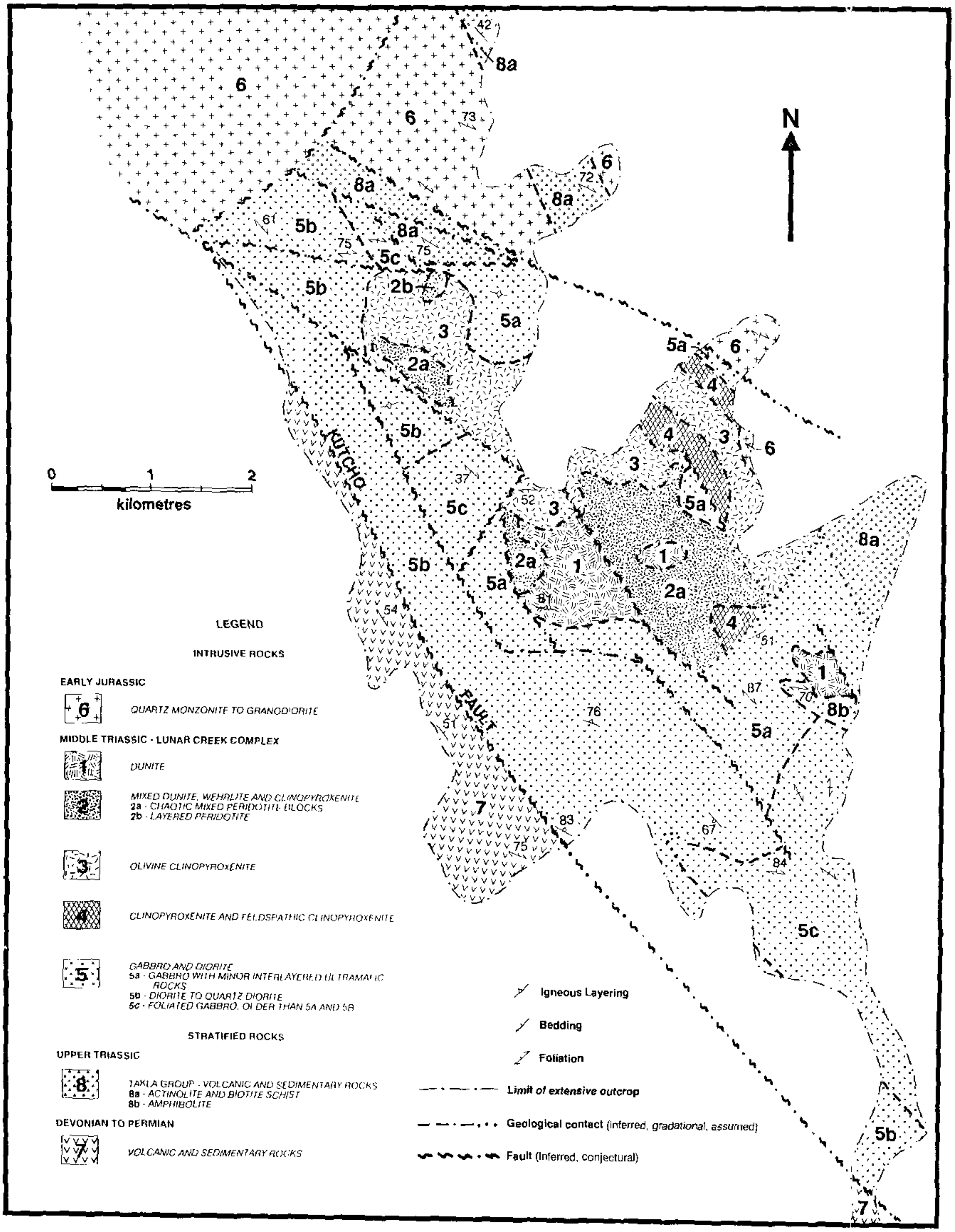

Figure 2-8-5. Generalized geology of the Lunar Creek mafic-ultramafic complex (modified after Nixon *et al.*, 1990).

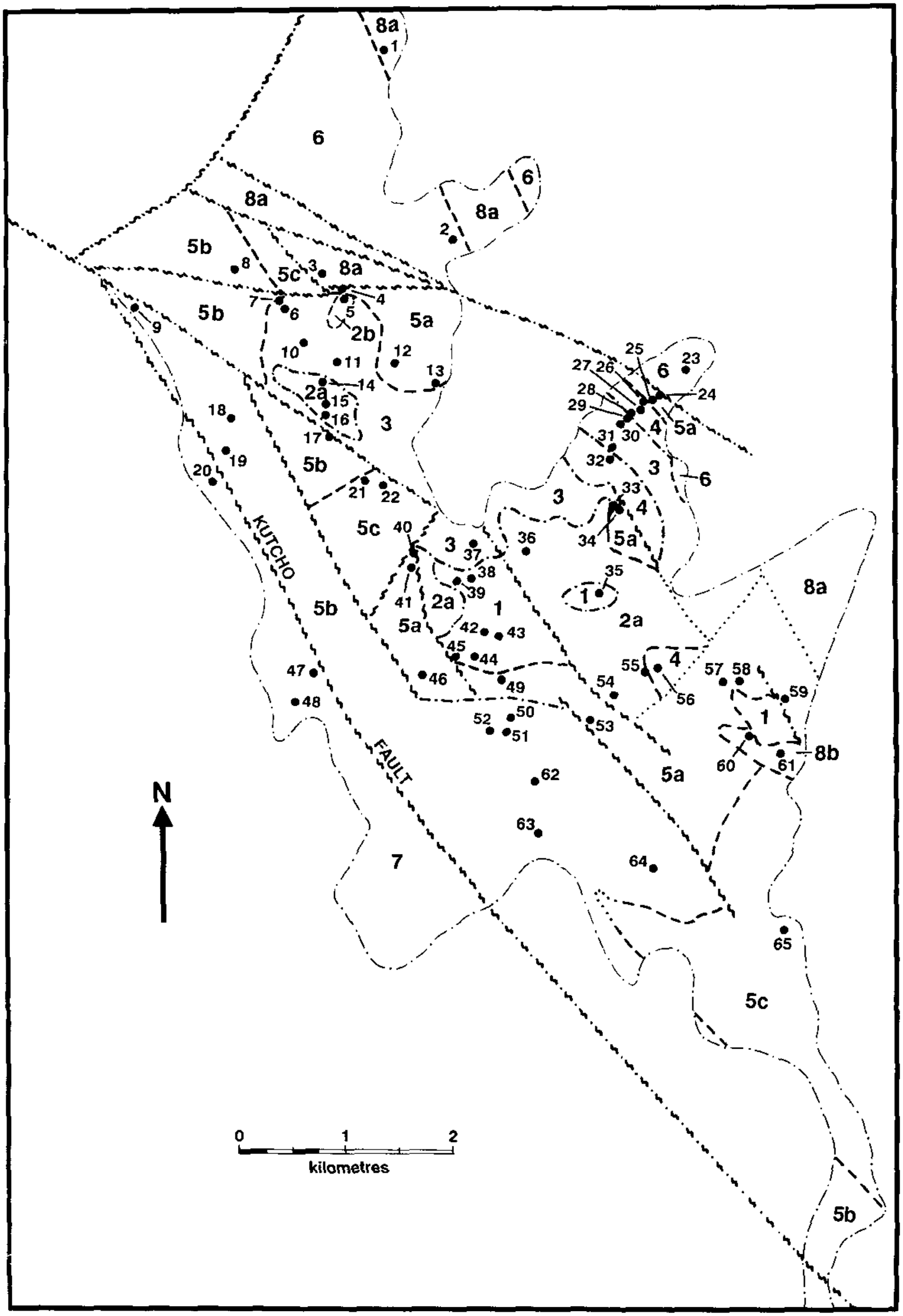

Figure 2-8-6. Location of lithogeochemical sample sites, numbered sequentially from north to south (*c.f.* Table 2-8-1). Units and symbols as in Figure 2-8-5.

Medium grey weathering, medium to dark grey siltstones and fine-grained volcanic wackes at Locality 1 have been metamorphosed to lower amphibolite grade. These rocks are well bedded, dip moderately toward the northeast and have a weak bedding-parallel foliation. Common constituent minerals are plagioclase, potassium feldspar, green pleochroic hornblende and abundant idioblastic biotite that is oriented within the foliation.

UNNAMED PALEOZOIC ROCKS OF STIKINIA

Paleozoic rocks west of the Kutcho fault have not been assigned to a defined stratigraphic unit. Conodont analysis has shown that some of them are Mississippian in age (Thorstad, 1980), and may range from Devonian through Permian (H. Gabrielse, personal communication, 1990). Regionally, lithologies include chlorite schist, sericite schist, phyllite, rhyolite flows and tuffs, chert, sandstone and carbonate (Thorstad, 1980). In the study area, these Paleozoic rocks crop out adjacent to the southwestern margin of the ultramafic complex, west of the Kutcho fault. They have been metamorphosed to upper greenschist grade and include medium grey-green to dark grey quartz-potassium feldspar-actinolite schist, medium green-grey siliceous siltstone and medium grey, gritty micritic limestone with thin chert beds.

LUNAR CREEK MAFIC-ULTRAMAFIC COMPLEX

The Lunar Creek ultramafic complex is an elongate body which measures more than 11 kilometres in length and 4 kilometres in width at its widest point. The northwesterly trending long axis of the body parallels the structural grain of the region. The southwestern margin lies adjacent to the Kutcho fault, a major structure that juxtaposes the Quesnel and Stikine terranes.

Several attributes set the Lunar Creek complex apart from other Alaskan-type complexes:

- Two gabbroic phases are present, one of which is ductily deformed and older than the main part of the complex.
- Cumulate layering is locally very well developed in the ultramafic rocks, a rare feature in the Alaskan-type intrusions of British Columbia.
- Quartz-rich pegmatitic segregations are common in the gabbroic to dioritic phases, which also appears to be relatively uncommon in Alaskan-type intrusions.

ULTRAMAFIC ROCKS

All ultramafic lithologies which typify Alaskan-type ultramafic intrusions are represented in the Lunar Creek complex. Dunite, chromitiferous dunite, wehrlite, olivine wehrlite, olivine clinopyroxenite, clinopyroxenite and gabbroic rocks are found. Of interest is the relatively low abundance of massive wehrlitic lithologies relative to, for example, the Polaris complex (Nixon *et al.*, 1990d, e), and the presence instead of chaotically mixed wehrlite and clinopyroxenite units. These chaotic domains often occur in gradational contact with adjacent ultramafic rocks and are most common at the transition between massive dunite and olivine clinopyroxenite (Figure 2-8-5).

DUNITE AND CHROMITITE

Massive dunite crops out in three areas (near Localities 35, 42 and 59; Figure 2-8-6), underlying a total area of approximately 1.5 square kilometres. Dunite also occurs as irregular blocks within chaotic mixed zones, interlayered with wehrlite, and as dikes within massive dunite, wehrlite and olivine clinopyroxenite (Localities 5 and 14; Figure 2-8-6).

Commonly dunite is medium grained and weathers pale orange-brown. Outcrops are characteristically smooth and rounded. Contacts with clinopyroxene-rich lithologies (wehrlite and clinopyroxenite) are gradational and marked by a gradual increase in clinopyroxene crystals. Serpentinization is pervasive near faults and near contacts with gabbroic units and country rock. Away from these areas the rock is comparatively fresh and composed mainly of glassy, dark olive-green olivine.

Although the contact between dunite and country rock was not observed, relationships suggest that it may be intrusive in at least one location (Locality 60; Figure 2-8-6). In this area, dunite adjacent to the contact is weakly serpentinized but shows no evidence of shearing, implying that the contact here is not faulted. Further, amphibolite-grade metamorphism of adjacent country rock may represent a contact metamorphic aureole.

Disseminated chromite is ubiquitous in dunite, typically forming 1 to 2 per cent of the rock. Chromitite schlieren occur locally, generally in clusters of two or more (Plate 2-8-1). Individual schlieren range in thickness from 1 to

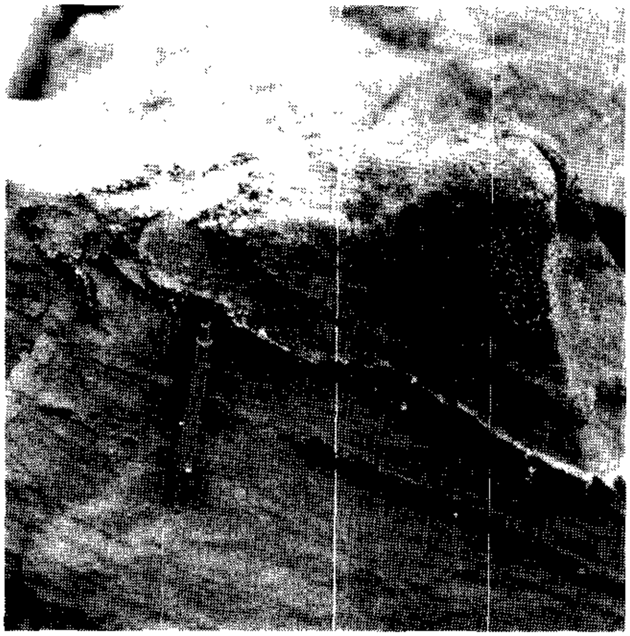

Plate 2-8-1. Deformed chromitite schlieren in dunite at Locality 44, Figure 2-8-6.

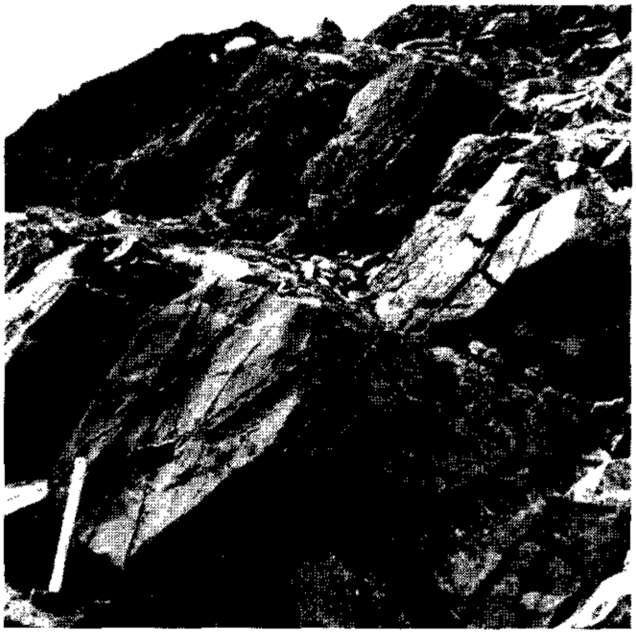

Plate 2-8-2. Olivine clinopyroxenite to clinopyroxenite dikes in dunite.

4 centimetres and in length from 20 to 30 centimetres. Locally, these schlieren are very strongly magnetic, suggesting that some of the chromite has been altered to magnetite.

Chromitite schlieren are known to host platinum group element mineralization within the Tulameen complex (Nixon *et al.*, 1990a) and the Wrede complex (Hammack *et al.*, 1990a, b). The Lunar Creek complex is no exception to this trend. However, the amount of chromitite observed is small, which minimizes the economic potential for platinum group elements.

Dunite bodies are commonly cut by swarms of anastomosing wehrlite, olivine clinopyroxenite, clinopyroxenite and rare dunite dikes (Plate 2-8-2). These dikes range in width from 1 to 20 centimetres and are most common near gradational contacts with clinopyroxene-rich lithologies.

OLIVINE CLINOPYROXENITE AND CLINOPYROXENITE

Olivine clinopyroxenite is the most extensive of the ultramafic lithologies exposed at the Lunar Creek complex (greater than 5 square kilometres). It is characterized by dark green to rusty brown, knobby-weathering outcrops. Fresh surfaces are dark green-grey and the rock is weakly magnetic. Clinopyroxene crystals vary from 2 millimetres to 3 centimetres in diameter, with a modal grain size of approximately 0.5 centimetre. Olivine grain size is fairly constant at 1 to 2 millimetres. Locally, both minerals show cumulate textures. In some cases, clinopyroxene is intercumulus and poikilitically encloses olivine. Phlogopite exists locally as an accessory phase.

Contacts between olivine clinopyroxenite and other ultramafic lithologies are gradational, marked by an increasing or decreasing olivine component. A gradational relationship is also seen between clinopyroxenite and feldspathic clinopyroxenite, marked by the appearance of plagioclase as an intercumulus phase. Rare layering, showing compositional and/or size grading, was observed in all of these lithologies (Plate 2-8-3).

Plate 2-8-3. Layering of coarse-grained clinopyroxenite-olivine wehrlite offset by small syndepositional fault, mixed layered unit 2b, south of Locality 5, Figure 2-8-6.

Pods of dunite and wehrlite, up to 8 metres in diameter, are fairly common within the olivine clinopyroxenite unit, and are most common near gradational contacts with the chaotic mixed units described below. These pods may represent fragments of crystalline material that broke away from the walls or roof of the magma chamber, or they might be disrupted ultramafic dikes. Locally, pods have been flattened and stretched into schlieren which reach 1 metre in width and several metres in length. Locally these schlieren have a well-developed foliation parallel to their margins.

Hornblende clinopyroxenite is a rare rock type within this complex. Microscopic examination has shown that much of the hornblende observed in hand samples of clinopyroxenite is secondary, after clinopyroxene. Primary hornblende in clinopyroxenite was observed only at the narrow, gradational contacts between clinopyroxenite and hornblende-clinopyroxene gabbro.

MIXED ULTRAMAFIC ROCK UNITS

Mixed units comprise a variety of distinct ultramafic lithologies that are not mappable at 1:16 000 scale. Three varieties of mixed ultramafic rocks are observed: layered units which are sequences of interlayered clinopyroxenite,

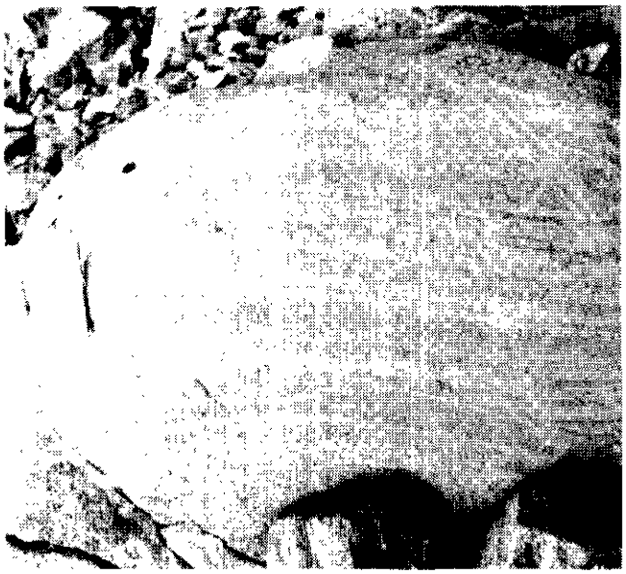

Plate 2-8-4. Fine modal layering of olivine and clinopyroxene in mixed layered unit 2b near Locality 5, Figure 2-8-6.

olivine clinopyroxenite, wehrlite and dunite; chaotic units which consist of blocks of one ultramafic lithology mixed into another; and replacement zones which are sites where dunite has partially replaced clinopyroxenite.

LAYERED MIXED UNITS

Layering is locally well developed in peridotites of the Lunar Creek complex. Near Locality 5 (Figure 2-8-6), dunite, wehrlite, olivine clinopyroxenite and clinopyroxenite exhibit layering produced by modal and/or grain size variations. Most layering in this area is discontinuous; layers vary from less than 1 metre to several metres in thickness. Centimetre-scale layering and rhythmic layering are observed locally (Plate 2-8-4). Interlayered wehrlite, clinopyroxenite and rare dunite are seen farther south at Locality 14 (Figure 2-8-6). Here, dunite layers up to 2 metres thick, with rare chromite accumulations, grade into wehrlite. The dunite layers have sharp, nongradational contacts with adjacent olivine clinopyroxenite.

Soft-sediment deformation-like features are well exposed at Locality 5 (Figure 2-8-6). Locally, large blocks, possibly derived from the walls and roof of the magma chamber, fell onto layered material resulting in compressed and distorted layering. Further crystallization within the chamber led to deposition of more layers, which drape over both the block and the distorted material. Angular unconformities caused by the truncation of layers were observed in several outcrops. These features bear many similarities to sedimentary crossbedding and undoubtedly reflect similar processes (*i.e.* the deposition of cumulate crystals by magmatic currents).

Overall, there is no consistency in layer orientation between outcrops. Facing direction, determined by the truncation of layering and deformed layering below slumped boulders, is also variable. This suggests that significant rotation has occurred since deposition, possibly as a result of slumping within the magma chamber prior to complete solidification.

CHAOTIC MIXED ZONES

Chaotic mixed zones are more widespread than layered zones. They consist of blocks of massive olivine clinopyroxenite to clinopyroxenite, up to 5 metres in diameter, set in a matrix of wehrlite to dunite; or blocks of olivine wehrlite/dunite/wehrlite in a clinopyroxenite matrix. Blocks are typically angular to subrounded (infrequently rounded) and commonly exhibit sharp contacts with their hosts. Contacts between mixed zones and massive peridotite are gradational and expressed by the appearance of scattered, irregular blocks in the massive hostrock. The mixed zones can be subdivided into wehrlite-dominated and clinopyroxenite-dominated domains.

The chaotic mixed zones may represent density flows resulting from the spalling of crystalline material from the walls and roof of the magma chamber; in some cases, they may have formed by dike intrusion into consolidated cumulate rocks that subsequently were deformed plastically. Clinopyroxenite to wehrlite dikes are very common in chaotic zones and add to the chaotic nature of the rock by further subdividing large blocks. It is likely that some diking resulted from overpressuring of the underlying crystal mush, causing expulsion and upward migration of residual pore fluid through the cumulate pile. In fact, diking may have been promoted in chaotic zones, where slumping of large blocks from the chamber walls and roof would result in rapid loading.

REPLACEMENT DUNITE

Locally, in clinopyroxene-rich lithologies, clinopyroxene crystals have been partially to completely replaced by olivine. This process resulted in the development of irregular bodies of dunite and wehrlite within clinopyroxenites and olivine clinopyroxenites. A similar replacement phenomenon has been observed at the Duke Island complex in southeastern Alaska (Irvine, 1974b, 1986). Replacement dunite appears to have resulted from the migration of an olivine-rich magma through a porous, clinopyroxene-rich, crystal mush. The resulting disequilibrium between olivine-rich magma within the pore spaces and the adjacent clinopyroxene crystals likely led to replacement of clinopyroxene by olivine.

At Lunar Creek, replacement dunite is most common in olivine clinopyroxenite, particularly in the layered and chaotic mixed units. The effect is most spectacular in layered olivine clinopyroxenite that grades from fine to coarse grained (Locality 5, Figure 2-8-6). Here, irregular bodies of replacement dunite are up to a metre wide and cut layering at a high angle. Coarse-grained layers show pervasive replacement, whereas finer grained layers are virtually unaffected. This strongly supports the hypothesis that porosity plays an important role in the development of replacement dunite. The lower porosity of fine-grained layers restricted the amount of olivine-rich fluid in the pore spaces and thus limited the degree of replacement in these layers.

Passive infiltration through pore spaces is one mechanism for magma migration through the cumulate pile. Where cumulates were consolidated, and pore spaces were closed, magma movement was accomplished by diking. Ultramafic dikes are fairly common in all of the ultramafic lithologies observed at Lunar Creek, as well as in most other Alaskan-type complexes within the Polaris suite of intrusions.

Dynamic processes within the magma chamber (slumping, infiltration, diking, convection, *etc.*) might explain the lack of layering in most of the ultramafic rocks of this complex, and the scarcity of layering in the ultramafic rocks of the Polaris suite as a whole.

GABBROIC ROCKS

Two suites of gabbroic rocks are found at the Lunar Creek complex. The oldest is a strongly foliated hornblende-clinopyroxene gabbro/diorite. Foliation in this unit predates the intrusion of the main body of the ultramafite and the emplacement of the younger suite of gabbroic rocks. The latter consists of massive equigranular gabbro and diorite which are virtually undeformed and appear to be the youngest rocks associated with the complex.

FOLIATED GABBRO/DIORITE

Weakly to strongly foliated hornblende-clinopyroxene gabbro/diorite is similar in mineralogy to the younger unfoliated gabbros at Lunar Creek. However, crosscutting relationships demonstrate that this foliation predates crystallization of the massive gabbro. The age of deformation of the foliated gabbroic rocks is unknown, but it is possible that they belong to an early phase of the ultramafic complex which was ductily deformed prior to emplacement of the remainder of the complex.

Foliated rock consists of alternating mafic and feldspathic foliae, typically less than 1 centimetre in width (Plate 2-8-5). Mafic layers are composed of black hornblende or dark green clinopyroxene or both. Feldspathic layers are composed of white plagioclase with rare quartz. Clinopyroxenes are subhedral to euhedral and commonly rimmed by hornblende. In many cases, euhedral clinopyroxene crystals have grown across foliation.

Where original igneous layering is preserved it is parallel to foliation; it is commonly boudinaged. Fabric orientation is variable throughout the complex. However, layering and foliation are crudely parallel to contacts with ultramafic components. This feature is well exposed southeast of Locality 58 (Figures 2-8-5 and 2-8-6) where the fabric appears to arch over a large body of dunite.

GABBRO/DIORITE

Gabbro, diorite and quartz diorite underlie a total area of approximately 16 square kilometres (Figure 2-8-5). Of this, diorite to quartz diorite, exposed along the western margin of the complex, make up the majority of outcrop. Gabbro/diorite forms a large body on the southeast end of the complex, and a narrow band along its eastern margin. It is also found as thick units within layered, clinopyroxenite and gabbro sequences (*e.g.* 500 metres north of Locality 12; Figure 2-8-6).

Gabbro/diorite forms massive, resistant, medium grey outcrops. Fresh rock varies in colour from medium grey to black, mafic minerals vary from 50 to 90 per cent. It is typically equigranular and medium to coarse grained, but fine-grained and pegmatitic varieties are also found. Subhedral to euhedral, cumulate hornblende and clinopyroxene

Plate 2-8-5. Mylonitic fabrics in older, foliated gabbro/diorite unit 5c.

Plate 2-8-6. Fine modal layering of poikilitic hornblende and plagioclase in leucocratic layer within the gabbro/diorite unit 5a.

are the common mafic components, anhedral plagioclase occurs as an intercumulus phase. Minor net-textured sulphides were observed locally. Hornblende is typically more abundant than clinopyroxene, except near gradational contacts with ultramafic rocks. Igneous layering, in the form of alternating mafic and feldspathic layers, is fairly common (Plate 2-8-6). Locally layers are leucocratic, with as little as 20 per cent mafic minerals. This leucogabbro/leucodiorite also occurs as thick dikes which crosscut both gabbroic and ultramafic rocks.

Gabbro/diorite has a narrow gradational contact with ultramafic lithologies along the northeastern edge of the complex. In this area, gabbroic rocks form a thin wedge along the margin and lie in fault contact with Takla Group rocks to the northeast. Massive gabbro is also found in gradational contact with zones of interlayered olivine clinopyroxenite, clinopyroxenite, feldspathic clinopyroxenite, hornblende clinopyroxenite and gabbro. In addition, gabbro occurs as dikes which crosscut the foliated gabbro unit described above (Locality 22; Figure 2-8-5).

Rocks of diorite to quartz diorite composition form medium to light grey weathering, blocky outcrops. Fresh surfaces are medium grey in colour. Grain size varies from medium to coarse; the rock is locally pegmatitic. Hornblende±biotite, composes 30 to 50 per cent of the rock. Variably altered plagioclase, together with quartz, constitute the felsic component. Quartz varies in abundance from 1 to 25 per cent and forms an interstitial phase.

Diorite/quartz diorite intrudes ultramafic rocks as well as rocks of the foliated gabbro unit. Contacts with massive gabbro/diorite appear to be gradational. It is therefore believed to be the youngest and most highly differentiated component of the Lunar Creek complex. Zircon from this diorite has yielded a U-Pb age of Middle Triassic (237±2 Ma; L. Heaman, personal communication, 1990) which therefore represents a minimum age for the complex.

Plate 2-8-7. *Zoned quartz-feldspar pegmatite vein cutting* coarse-grained hornblende gabbro/diorite (upper left) and tapering into feldspathic groundmass (lower right) where it is continuous with its host (unit 5b). Note concentration of quartz (pale grey) in centre of vein.

QUARTZ-PLAGIOCLASE VEINS

Quartz-plagioclase veins occur exclusively in ultramafic and mafic rocks of the complex. At one location they were observed to pinch out into, and become continuous with, pegmatitic hornblende-bearing quartz diorite (Plate 2-8-7). They are therefore believed to represent late-stage, silica-rich differentiates.

Veins range from 2 to 20 centimetres in width; most are approximately 4 centimetres. Typically, vein margins are lined with white plagioclase crystals up to 2 centimetres in diameter. Light grey quartz forms vein cores. Graphic feldspar-quartz intergrowths are common in the marginal zones.

PITMAN BATHOLITH GRANITOIDS

Granitoids north and east of the complex are associated with the Early Jurassic Pitman batholith, part of the Guichon suite of intrusions (Gabrielse *et al.*, 1980). Granodiorite dikes emanating from this batholith intrude ultramafic and mafic rocks of the complex as well as Takla Group rocks to the north. Outcrops are commonly lichen covered and form resistant, dark grey cliffs; where not covered by lichen, they are light grey. Fresh surfaces are light to medium grey and the rock is medium grained and equigranular. Composition of the granitoid varies from quartz monzonite to granodiorite. Mafic minerals, chloritized biotite and hornblende, comprise approximately 20 per cent of the rock and quartz varies from 10 to 25 per cent.

PLAGIOCLASE PORPHYRY DIKES

Plagioclase porphyry dikes intrude ultramafic and mafic rocks in the study area, and are intruded by hornblende microdiorite dikes described following. Euhedral to subhedral plagioclase phenocrysts up to 2 centimetres in diameter lie in a dark grey, fine-grained to aphanitic groundmass, which locally has hornblende microphenocrysts. In some dikes, plagioclase crystals are aligned and flattened parallel to the dike walls. These plagioclase porphyry dikes are believed to be derived from granitoids of the Early Jurassic Pitman batholith.

QUARTZ VEINS

Quartz veins cut mafic and ultramafic rocks of the complex, as well as rocks of the Takla Group to the northeast. They average 20 to 40 centimetres in width and consist of massive white quartz with less than 1 per cent pyrite. These veins commonly follow pre-existing foliation planes and often are sheared and folded, illustrating the complex history of deformation.

The veins may represent fluids emanating from Pitman batholith granitoids or they might be metamorphic dewatering features. Geochemical analysis of grab samples shows no evidence of precious metals (Table 2-8-1).

TABLE 2-8-1
ABUNDANCES OF NOBLE METALS IN THE LUNAR CREEK COMPLEX AND ASSOCIATED ROCKS

Locality	Sample Number	UTM Grid Zone 9V		Pt	Pd	Rh	Au
		Northing	Easting		(ppb)		
Dunite (Units 1 and 2)							
14	GN-89-9077A	6421870N	589260E	41	6	<2	10
14	GN-89-9077B	6421870N	589260E	62	7	<2	11
14	GN-89-9077F	6421870N	589260E	343	10	<2	<1
35	GN-89-8096	6419960N	591800E	173	3	12	3
39	GN-89-9060	6420010N	590450E	41	4	<2	4
42	GN-89-7116B*	6419520N	590430E	1017	26	<2	<1
43	GN-89-9100B	6429480N	590850E	14	4	<2	<1
44	GN-89-9101	6419280N	590660E	18	3	<2	<1
Olivine Wehrlite and Wehrlite (Units 2, 3 and dike in Unit 1)							
5	GN-89-9075B	6422695N	584275E	9	3	<2	9
14	GN-89-9077E	6421870N	589260E	15	<2	<2	4
14	GN-89-9077D	6421870N	589260E	60	12	<2	11
15	GN-89-9070B	6421620N	589300E	135	4	4	2
31	GN-89-9065	6421330N	591860E	85	3	<2	<1
36	GN-89-9080A	6420340N	591090E	29	3	<2	4
45	GN-89-7073A	6419250N	590440E	9	24	<2	47
Olivine Clinopyroxenite and Clinopyroxenite (mainly Units 3 and 4)							
10	GN-89-6077	6422240N	589900E	13	<2	<2	5
11	GN-89-9076	6422060N	598225E	136	8	4	<1
15	GN-89-8070B	6421620N	589300E	57	9	<2	12
15	GN-89-9070A	6421620N	589300E	21	<2	<2	111
25	GN-89-9087	6421800N	592170E	41	4	<2	3
28	GN-89-9085	6421670N	592040E	40	6	<2	3
29	GN-89-9084	6421620N	592000E	28	5	<2	<1
30	GN-89-9066D	6421570N	591950E	26	4	<2	<1
33	GN-89-8082	6420760N	591890E	31	11	<2	3
37	GN-89-9064	6420385N	590590E	111	12	7	6
46	GN-89-7076A	6419085N	590150E	3	<2	<2	4
55	GN-89-8117B	6421310N	592290E	12	8	<2	3
59	GN-89-9113A	6418990N	593600E	55	3	<2	175
Hornblende Clinopyroxenite and Feldspathic Hornblende Clinopyroxenite (Units 4, 5a and 5b)							
13	GN-89-7092	6421890N	590180E	27	3	<2	94
27	GN-89-9068	6421710N	592120E	10	6	<2	12
52	GN-89-7099B	6418600N	590810E	7	12	<2	123
56	GN-89-8118	6419240N	592400E	15	16	<2	5
62	GN-89-7111	6418110N	591270E	34	63	<2	8
Clinopyroxene Hornblendite and Hornblendite (Unit 5a)							
40	GN-89-9056	6420290N	590010E	13	18	<2	4
41	GN-89-9058	6420150N	590010E	11	13	<2	3
Gabbro/Diorite (Unit 5a)							
24	GN-89-9090	6421850N	592300E	17	89	<2	8
49	GN-89-7097	6419070N	590880E	3	<2	<2	216
54	GN-89-8103	6418990N	591990E	8	16	<2	9
57	GN-89-9107	6419130N	593020E	<1	2	2	8
58	GN-89-9119	6419250N	593020E	15	8	<2	2
58	GN-89-9119	6419250N	593020E	10	8	<2	81
Diorite/Quartz Diorite (Unit 5b)							
8	GN-89-6110	6422890N	588240E	8	17	<2	64
9	GN-89-8080	6422510N	587290E	6	9	<2	4
17	GN-89-8043	6421340N	589330E	3	<2	<2	64
19	GN-89-8075	6421180N	588210E	2	<2	<2	18
51	GN-89-7107	6418590N	590990E	3	<2	<2	12
52	GN-89-7099A	6418600N	590810E	<1	<2	<2	2
64	GN-89-7120	6417320N	592400E	5	<2	<2	4
Leucogabbro/Leucodiorite (Units 5a and 5b)							
7	GN-89-6107	6422600N	588670E	13	5	<2	373
34	GN-89-8084	6427600N	591940E	13	53	<2	10
51	GN-89-9106	6418590N	590990E	2	<2	<2	<1

* Chromite-rich dunite. Detection limits: Pt and Au 1 ppb; Pd and Rh 2 ppb.

TABLE 2-8-1
ABUNDANCES OF NOBLE METALS IN THE LUNAR CREEK COMPLEX AND ASSOCIATED ROCKS — *Continued*

Locality	Sample Number	UTM Grid Zone 9V Northing	Easting	Pt	Pd	Rh	Au
					(ppb)		
Foliated Gabbro/Diorite (Unit 5c)							
4	GN-89-9073C	6422780N	584240E	12	3	<2	10
12	GN-89-9074B	6422060N	589950E	8	6	<2	2
21	GN-89-9049A	6420930N	589680E	8	7	<2	2
65	GN-89-6149	6416780N	593670E	9	9	<2	9
Leucogabbro/Leucodiorite Dikes							
6	GN-89-6078	6422530N	588725E	2	<2	<2	3
21	GN-89-9049	6420930N	589680E	<1	<2	<2	442
22	GN-89-8046	6420890N	589840E	31	4	<2	17
Quartz Monzonite to Granodiorite (Unit 6)							
2	GN-89-6094B	6423280N	590290E	<1	<2	<2	3
26	GN-89-9069	6421780N	592160E	3	<2	<2	11
Granodiorite Dikes							
26	GN-89-9069B	6421780N	592160E	<1	3	<2	14
30	GN-89-9066C	6421570N	591950E	<1	<2	<2	8
Plagioclase Porphyry Dikes							
30	GN-89-9066A	6421570N	591950E	<1	<2	<2	31
36	GN-89-9080B	6420340N	591090E	<1	<2	<2	<1
53	GN-89-6112B	6418700N	591730E	4	17	<2	21
55	GN-89-8117A	6421310N	592290E	4	6	<2	4
Hornblende Microgabbro/Microdiorite Dikes							
18	GN-89-8077	6421490N	588250E	<1	<2	<2	55
38	GN-89-9063	6420030N	590550E	6	<2	<2	142
50	GN-89-9105	6418720N	591010E	<1	<2	<2	43
53	GN-89-6112A	6418700N	591730E	<1	<2	<2	5
Devonian-Permian Metavolcanic and Metasedimentary Rocks (Unit 7)							
20	GN-89-8073	6420000N	588100E	<1	3	<2	20
47	GN-89-7085	6419060N	589115E	<1	<2	<2	133
48	GN-89-6124	6418790N	589080E	<1	<2	<2	15
Takla Group Metavolcanic and Metasedimentary Rocks (Units 8a and 8b)							
1	GN-89-6090	6425050N	590550E	<1	<2	<2	4
23	GN-89-9094C	6422090N	592550E	<1	4	<2	5
23	GN-89-9094B	6422090N	592550E	9	8	<2	89
60	GN-89-9121	6418460N	593300E	10	5	<2	35
61	GN-89-9115	6418610N	593590E	4	<2	<2	37
Quartz Veins							
3	GN-89-6099	6422900N	589075E	2	<2	<2	17
16	GN-89-8069A	6421550N	589290E	3	<2	<2	3
16	GN-89-8069B	6421550N	589290E	2	<2	<2	<1
21	GN-89-8045B	6420930N	589680E	3	<2	<2	5
32	GN-89-8055A	6421250N	591860E	2	<2	<2	11
51	GN-89-9106C	6418590N	590990E	2	<2	<2	3
63	GN-89-7112	6417630N	591310E	2	3	<2	8

* *Chromite-rich dunite. Detection limits: Pt and Au 1 ppb; Pd and Rh 2 ppb.*

HORNBLENDE MICRODIORITE DIKES OF DUBIOUS AFFINITY

Medium to dark grey hornblende microdiorite dikes intrude Pitman batholith granitoids, plagioclase porphyry dikes (described above), Takla Group volcanic rocks and ultramafic and mafic rocks of the Lunar Creek complex, (Plate 2-8-8). These dikes were not observed southwest of the Kutcho fault, but this area was not mapped in detail.

Dikes weather dark grey to pale brown and have an average width of approximately 50 centimetres. They are fine grained to aphanitic with microphenocrysts of euhedral hornblende and rare euhedral to subhedral white plagioclase. Dike margins are commonly foliated, implying at least some postemplacement deformation.

STRUCTURE

The Lunar Creek ultramafite is bounded on the west by the Kutcho fault, a major structure that forms the boundary between the Quesnel and Stikine terranes. Transcurrent movement on this fault may have been initiated as early as the Middle Jurassic and may have continued through to Eocene time, resulting in an estimated 100 kilometres of

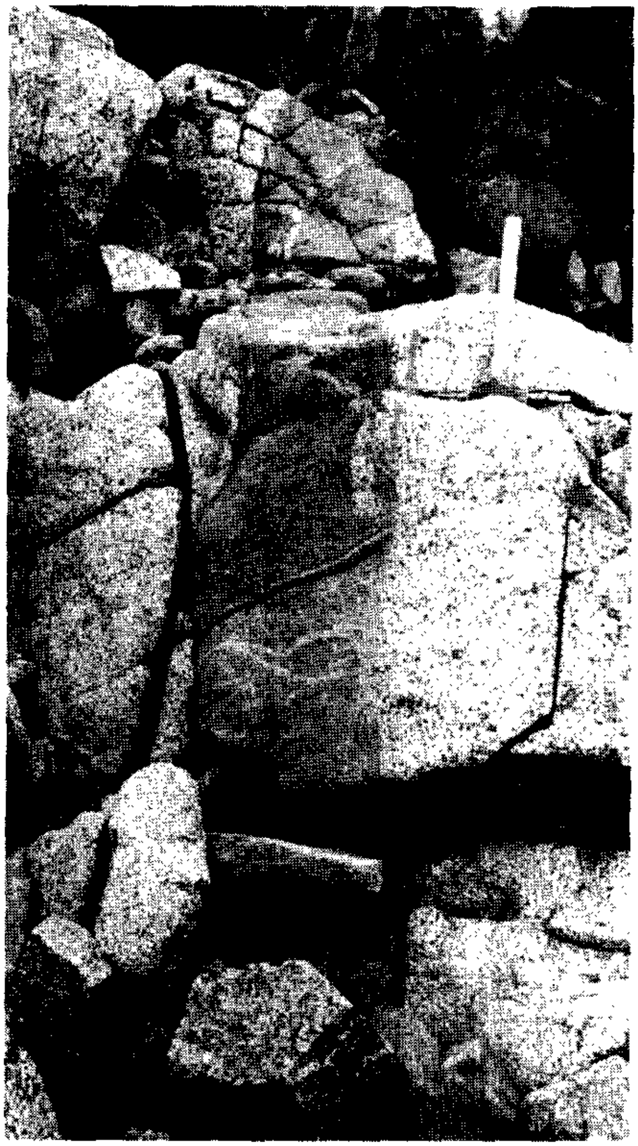

Plate 2-8-8. Hornblende microdiorite dike cutting leucocratic gabbro/diorite unit 5a and enclosing xenoliths of its host.

dextral displacement (Gabrielse, 1985). It is therefore believed to be one of the more important structures in the northern Canadian Cordillera.

Northwest-trending, steeply dipping faults, subparallel to the Kutcho fault, are the dominant structures in the study area. Less abundant, steeply dipping northeast and east-trending faults are also found. Intense faulting has resulted in an outcrop pattern which is a mosaic of disrupted, disconnected blocks. This, coupled with the lack of any marker horizon within the complex, has made the detailed structure irresolvable at the scale of mapping.

At the north and east margin of the complex, Takla Group volcanic rocks and Pitman batholith granitoids, lie in fault contact with gabbroic rocks. All three lithologies are mylonitized along this fault. North of this contact, both the granitoid and volcanic rocks have a steeply dipping, northwest-trending penetrative foliation. Bedding in Takla Group rocks dips moderately to the northeast.

Rocks immediately adjacent to the Kutcho fault are not exposed. Approximately 250 metres southwest of the fault (near Locality 47, Figure 2-8-6), stratified rocks have a steeply dipping, northwest-trending, penetrative foliation, (subparallel to the fault). Bedding within these rocks dips moderately to the northeast. Diorite and quartz diorite, approximately 100 metres north of the Kutcho fault are extensively altered but are not foliated.

An older episode of deformation is preserved in the foliated gabbro unit (Unit 5c, Figure 2-8-5). Crosscutting relationships show that ductile deformation in this unit predates intrusion of the main body of the complex, that is, prior to the collision of the Stikine Terrane with Quesnellia. In other words, this fabric predates regional deformation events proposed for this area.

The outcrop distribution of the foliated gabbro unit is commonly controlled by faults. The orientation of the foliation appears to be fairly consistent within individual fault blocks, but varies between blocks. Outcrops near the north and south margins of the complex tend to have a steeply dipping, east-trending foliation, whereas most other outcrops have a steeply dipping, northwest-trending orientation. The origin and timing of ductile deformation of this unit remains a mystery.

MINERALIZATION AND LITHOGEOCHEMISTRY

Analytical results for platinum, palladium, rhodium and gold in 84 representative rock samples from the Lunar Creek complex, its country rocks, and various dikes and quartz veins in the map area are presented in Table 2-8-1. Sample localities are shown on Figure 2-8-6. The noble metals were preconcentrated by fire assay using 30-gram splits of approximately 200 grams of rock powder (-200 mesh) and analyzed by inductively coupled plasma emission spectroscopy by Acme Analytical Laboratories, Vancouver. Accuracy was checked by international and in-house standards, and analytical precision (and any nugget effect) monitored by hidden duplicates.

Platinum abundances are generally low except in dunites (up to 343 ppb) and a chromite-rich dunite (1017 ppb). Palladium abundances are low overall, and reach their highest values in gabbroic rocks (<90 ppb). With the exception of one weakly anomalous dunite (12 ppb), rhodium is at or near the limit of detection. Gold abundances attain their highest levels in gabbroic rocks (216 to 442 ppb) but show no correlation with platinum-group elements. Quartz veins are uniformly low in gold.

Anomalous abundances of platinum in chromitite and chromitiferous dunite have been documented in many other Alaskan-type intrusions including some in British Columbia such as Tulameen (St. Louis *et al.*, 1986; Nixon and Hammack, 1990) and Wrede Creek (Hammack *et al.*, 1990a). In the Tulameen complex, platinum in the chromitites occurs as discrete platinum-iron alloys enclosed within chromite (Nixon *et al.*, 1990a). The high Pt:Pd ratio (39) in chromite-rich dunite (Sample 7116B, Table 2-8-1) suggests a similar mineralogical association. Unfortunately, chromite is scarce and dunite is not abundant, which suggests that the Lunar Creek complex is not a prime target for further prospecting for platinum-group elements.

Potential for industrial minerals, such as asbestos and chromite, also appears to be low. Asbestiform serpentine occurs as narrow veins within dunite, and near contacts and fault zones. Overall, however serpentine is not abundant.

Other mineralization has been described near the eastern margin of the complex. A copper showing, hosted in skarn and porphyry-style alteration at the West property, was explored in the early 1970s and has been described in assessment reports (Jones, 1970; Ryback-Hardy, 1972). These claims covered minor garnet-epidote skarn that is locally enriched in copper (chalcopyrite, malachite and covellite; Jones, 1970). Malachite staining was also observed along fractures and foliation planes in biotite schists (Ryback-Hardy, 1972). Silt, soil and rock sample geochemistry outlined several zones with modestly anomalous copper values. Skarn samples were also analysed for gold but were found to be barren (Jones, 1970). This mineralization is probably unrelated to the ultramafic complex and is more likely associated with granitoids of the Pitman batholith to the east.

SUMMARY AND CONCLUSIONS

Economic potential for platinum-group elements and economic concentrations of chromite appear to be low at the Lunar Creek complex. Lithogeochemical analyses were completed on 84 samples from the study area (Table 2-8-1). Samples included ultramafic and mafic rocks, dikes and quartz veins which crosscut the complex, and stratified and granitoid rocks at the periphery of the complex. Anomalous platinum was found in some samples of all of the ultramafic rocks, dunite was particularly enriched. One sample of chromitiferous dunite contained 1017 ppb platinum, suggesting that platinum is hosted within the chromitite. This association of platinum-group elements with chromitite has been documented at other Alaskan-type intrusions in British Columbia (Nixon and Hammack, 1990). Unfortunately, chromitite horizons are rare at this complex, and economic platinum concentrations are unlikely.

The Lunar Creek complex is set in a unique structural environment, at the juncture between the Quesnel and the Stikine tectonostratigraphic terranes. Movement on the Kutcho fault, which lies at the southwestern margin, is believed to have been responsible for as much as 100 kilometres of right-lateral displacement. Due to its close proximity to this major structure, the complex is intensely faulted, and interpretation of the internal stratigraphy is impossible at the scale of mapping done.

A wide range of ultramafic and mafic lithologies are represented in the Lunar Creek complex. Dunite outcrop is limited, and with only minor chromitite concentrations. Massive olivine clinopyroxenite is the most extensive ultramafic lithology exposed. Hornblende clinopyroxenite is present along narrow gradational contacts between clinopyroxenite and gabbro, but appears to be absent elsewhere. Zones where blocks of one ultramafic lithology have been mixed into another, are common. Much of the mixing of these rocks appears to have resulted from density flows within the magma chamber. Magmatic layering is locally very well preserved in the ultramafic rocks. Comparable layering has been reported at the Duke Island complex in southeastern Alaska, but is rare in the Alaskan-type complexes in British Columbia.

Gabbroic rocks formed during two phases. The oldest phase has a well-developed foliation which predates intrusion of the ultramafic rocks. The younger phase is massive and includes rocks which range in lithology from gabbro to quartz diorite. This latter phase includes the youngest rocks of the complex. Silica oversaturation, rare in Alaskan-type complexes, is common in the massive dioritic rocks at Lunar Creek. Characteristics indicative of oversaturation are quartz-rich segregations and veins, as well as the presence of interstitial quartz within gabbro/diorite phases.

Alaskan-type complexes are believed to be coeval with widespread Upper Triassic to Lower Jurassic arc volcanics of Stikinia and Quesnellia. The somewhat older Middle Triassic age (L. Heaman, personal communication, 1990) determined for the Lunar Creek complex, confirms that arc volcanism was ongoing within Quesnellia in Middle Triassic time.

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