New Observations on the Geology of the Turnagain Alaskan-Type Ultramafic Intrusive Suite and Associated Ni-Cu-PGE Mineralization, British Columbia

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INTRODUCTION

The Turnagain Alaskan-type ultramafic intrusive suite – a type originally recognized in Duke Island, Alaska (Irvine, 1962, 1967b) – lies 65 km east of Dease Lake, north-central British Columbia. It is a fault bounded, 3.5 by 8 km ultramafic intrusion located on the margin of Ancestral North America and is part of the Mesozoic accreted island-arc terrane of Quesnellia. Alaskan-type intrusions have been recognized in the Alaskan Panhandle, in the accreted terranes of the British Columbian Cordillera (Fig. 1), and in the Ural Mountains in Russia. The term Alaskan-type is synonymous with Uralian-type, zoned, or concentrically zoned, the latter being descriptive of the geometrical arrangement of rock units present in various Alaskan-type intrusive suites. These bodies are exploration targets for chromite and associated platinum-group-element (PGE) mineralization (*e.g.*, Nixon *et al*., 1991, 1993). The Turnagain intrusion is unique, however, in that it contains appreciable contents of magmatic sulphides.

Alaskan-type intrusions are typically composed of cumulate dunite, wehrlite, olivine clinopyroxenite, clinopyroxenite, hornblende clinopyroxenite, hornblendite and diorite, and minor leucocratic feldspar-rich rocks such as granodiorite and syenite. The complete range of rock units is rarely present (Nixon, pers comm, 2004). The Turnagain Alaskan-type ultramafic intrusive suite has been explored for economic Ni-Cu-PGE mineralization since its initial discovery in 1956 (Nixon, 1997). Falconbridge Limited conducted extensive exploration on the ultramafic body in the late 1960s and early 1970s. Currently, the property is owned and operated by Hard Creek Nickel Corporation (formerly Canadian Metals Exploration/Bren-Mar Resources Limited). Recent mapping and sampling by the principal author was undertaken during the summer of 2004 to help better understand the petrogenesis of the Turnagain intrusive suite and the physiochemical processes responsible for its associated Ni-Cu-PGE mineralization.

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REGIONAL GEOLOGY

Many Alaskan-type ultramafic intrusions in the Canadian Cordillera occur in Quesnellia, an Upper Paleozoic to Early Mesozoic arc terrane accreted to the margin of Ancestral North America during the Early Jurassic. The Quesnellia Terrane forms a part of the Omineca Belt in British Columbia and extends south into Washington State and north into the Yukon Territory. The regional geology of the Cry Lake and Dease Lake map areas (Fig. 2), including the Turnagain intrusion, has been mapped by Gabrielse (1998).

The Turnagain intrusion lies to the north of the Mesozoic Kutcho fault and Hottah-Thibert fault system. Although the dextral strike-slip Kutcho fault separates Quesnellia from Ancestral North America in northern BC (Gabrielse, 1998), the amount of displacement is uncertain. The Kutcho fault is not exposed near the Turnagain intrusion (Clark, 1975; Nixon, 1997) but is marked by two large valleys on either side of the Turnagain River. It is part of a major regional fault system that extends southward towards Washington State and northwards towards the Yukon (Gabrielse, 1998).

There are numerous clastic sedimentary rocks, ranging from Cambrian to Mississippian in age, which are proximal to the Turnagain ultramafic suite (Fig. 3). The lower Ordovician Road River Formation and the Mississippian Earn Group are two such examples. Both of these units are juxtaposed against the western, northern and eastern margins of the Turnagain intrusion and comprise the bulk of the regional geology north of the Kutcho fault. These units are dominantly composed of graphitic phyllite with intercalated calc-silicate and quartz-rich tuff layers (Photo 1), and are fairly recessive units that crop out mainly along the Turnagain River and in the alpine areas east of the intrusion. Both stratigraphic packages are commonly pyritic and unfossiliferous near the Turnagain intrusion and have graphite contents reaching up to 80% of the rock. Numerous quartz veins cut through the phyllite. They are commonly only a few millimetres in thickness, and rarely reach up to a metre

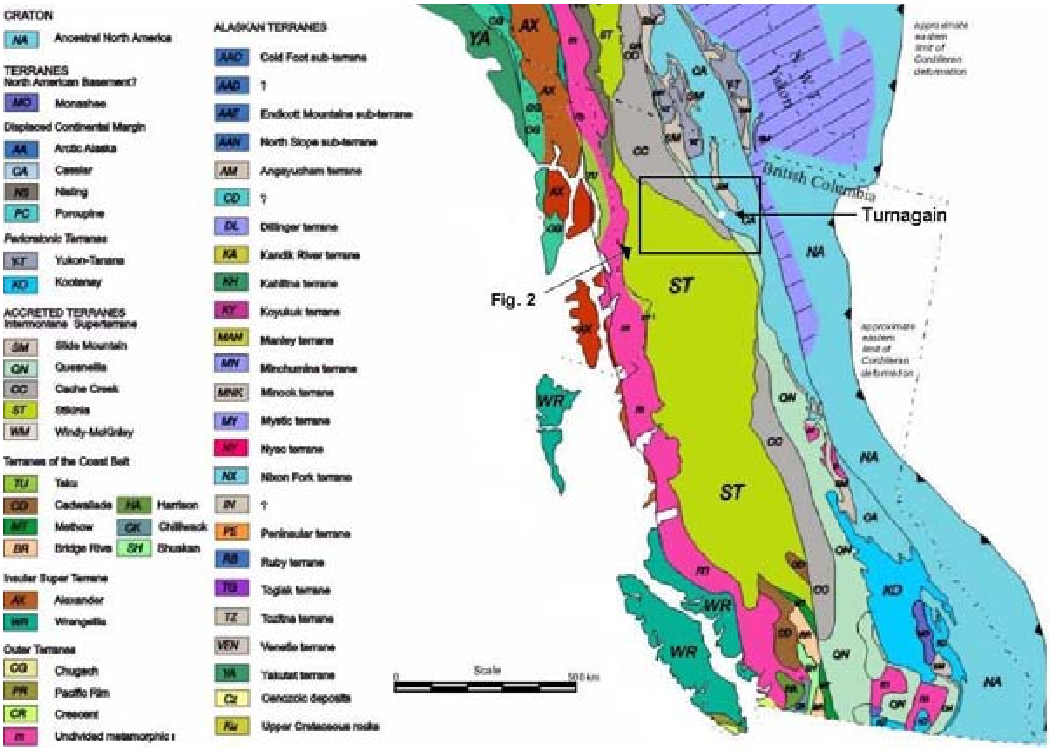

Figure 1. Terrane map of British Columbia and southern Alaska showing the location of the Turnagain ultramafic intrusive suite (white dot). Modified from Wheeler *et al.* (1991).

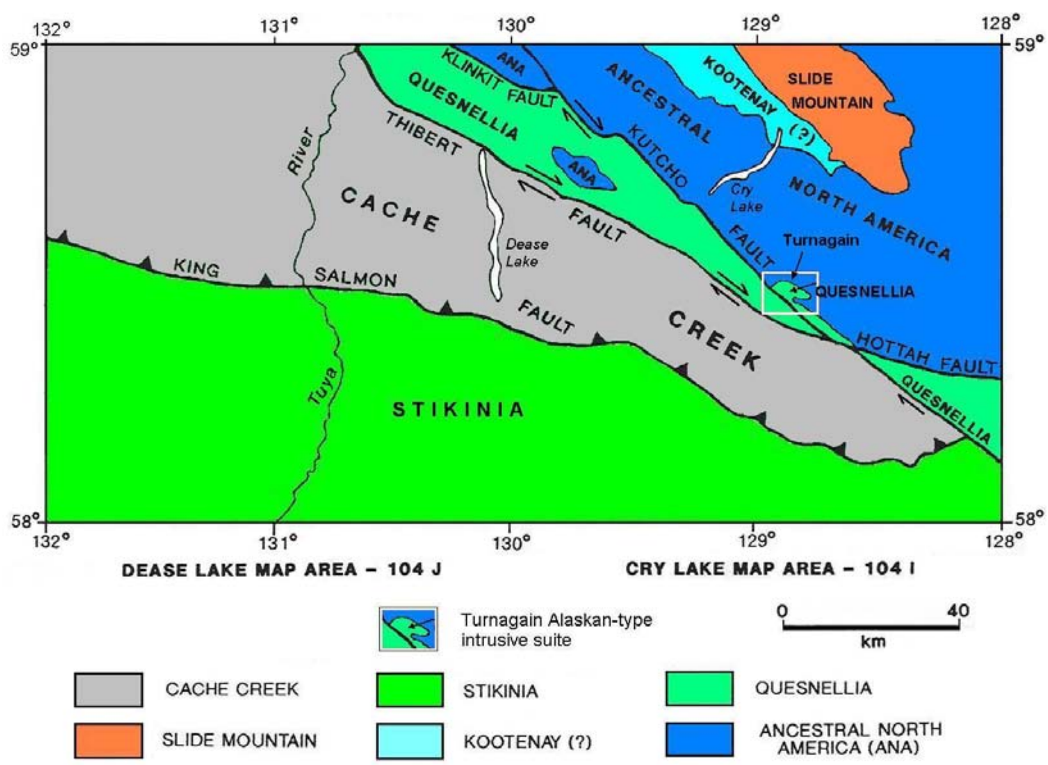

Figure 2. Simplified map of the Dease Lake and Cry Lake map areas, modified from Gabrielse (1998). The area of the Turnagain ultramafic intrusive suite is outlined.

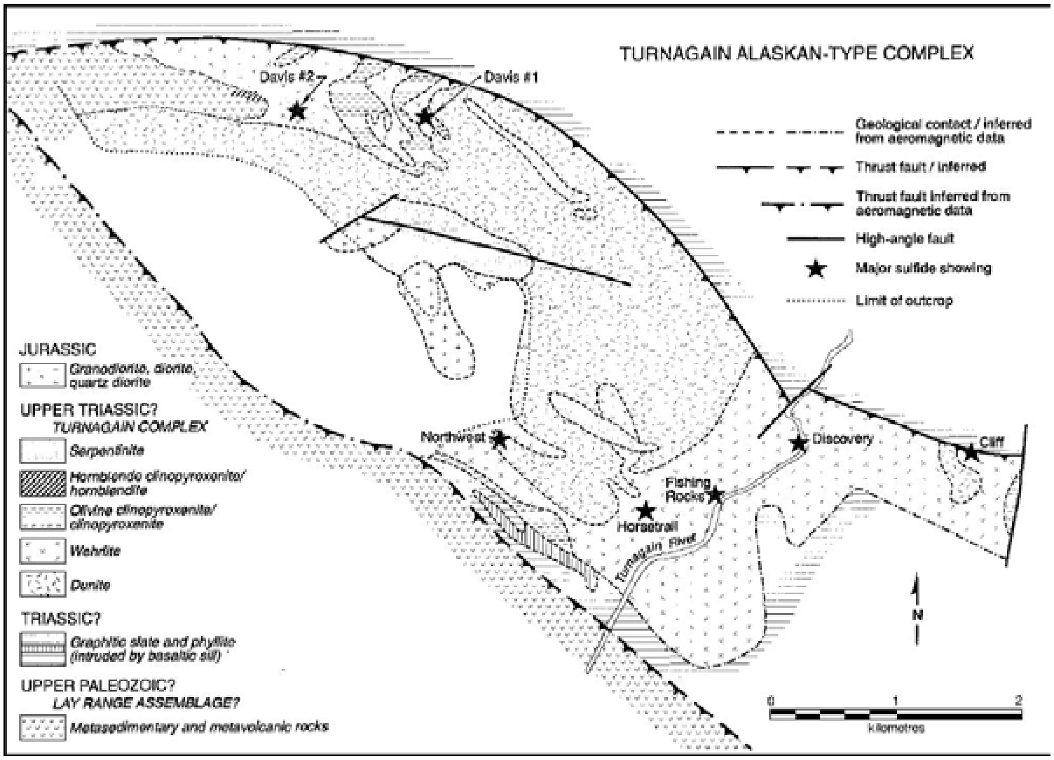

Figure 3. Simplified geological map of the Turnagain intrusion. Modified from Nixon (1997).

Photo 1. Quartz-rich tuff interbedded with graphitic phyllite, east of the Turnagain intrusion. Note the poor cleavage in the bed. Hammer is approximately 30 cm in length. UTM NAD 87, Zone 9 – Easting 513132 Northing 6479300.

thick. These veins do not show any evidence of propagation into the ultramafic cumulate rocks of the Turnagain body. Locally the phyllite is complexly folded (Photo 2), which is attributed to its position within a regional fold axis verging west-northwest.

The phyllite shows no hornfelsing or other contact metamorphism adjacent to the nothern and eastern contacts of the Turnagain intrusion. Its texture and grade are primarily due to the regional greenschist-facies metamorphism that affected the area during the middle Cretaceous (Gabrielse, 1998). The northern faulted contact of the Turnagain intrusion with the phyllite of the Road River Formation and Earn Group is not exposed, but proximal to the contact the rocks are highly altered to talc, serpentine and carbonate (Photo 3).

To the north of the Road River Formation and the Earn Group lies the Upper Cambrian Kechika Formation which is described by Gabrielse (1998) as comprising a "highly cleaved, soft, light to dark grey phyllite" that is conformable with the overlying Road River Formation (Fig. 3). Although it is rarely exposed, a small outcrop of this formation was found near the Turnagain River to the north of the ultramafic rocks. It appeared no different from the graphitic phyllite of the Road River Formation or the Earn Group despite the fact it was mapped by Gabrielse (1998) as the Kechika Formation.

An unnamed group of rocks lies to the southeast of the Turnagain ultramafic suite. The rock units comprise sedimentary rocks of unknown origin, possibly volcaniclastic, with variable amounts of interbedded carbonate (Fig. 3). The group is undated, and assumed to be late Triassic in age (Gabrielse, 1998). Exposures of these rocks are minimal as much of the unit is apparently buried by eolian and glaciofluvial sediments deposited at the confluence of three valleys. The volcaniclastic rocks are thought to be part of the Quesnellia Terrane (Fig. 2), and are probably the remnants of a small Mesozoic fore-arc basin (Gabrielse, 1998). A large hornfelsed raft, presumably a piece of this unit (1 by 0.5 km) is located in the northwestern part of the Turnagain ultramafic suite and will be discussed in detail in the section to follow.

The Eaglehead Pluton dominates much of the geology south of the Kutcho fault. It is generally dioritic to granodioritic in composition and contains phenocrysts of hornblende and rare potassium feldspar. The Eaglehead Pluton is considered to be early Jurassic in age (Gabrielse, 1998). It hosts a marginal porphyry copper deposit and related gold placers (Gabrielse, 1998) and represents the bulk of the rock units southwest of the Turnagain intrusion. Numerous ophiolitic complexes have been thrust on top of this unit.

GEOLOGY OF THE TURNAGAIN

The geology of the Turnagain ultramafic rocks has been previously described by Clark (1975) and Nixon (1989, 1997), but new additions and modifications were made during field mapping in the summer of 2004. The Turnagain intrusion is broadly composed of a central dunite core in the north with peripheral units of wehrlite, olivine clinopyroxenite, clinopyroxenite, and rare hornblende clinopyroxenite and hornblendite (Fig. 3). Feldspathic varieties of the latter are extremely rare and both hornblende clinopyroxenite and magmatic hornblendite are poorly exposed. Representative samples of these rock units were recovered in recent drillcore (Aug-Sept 2004) from the southwestern part of the intrusion. Based on the southward dipping nature of the mineralized zones and the megascopic distribution of the ultramafic rock units present in the Turnagain, these more evolved rocks are believed to be located at the roof of the intrusion.

Orthopyroxene is not present in the Turnagain cumulate rocks, a characteristic feature of all Alaskan-type intrusions and conventionally explained by the silica-undersaturated nature of the parental magma (*e.g.*, Irvine, 1967; Garuti *et al*., 2001). The dunite and wehrlite host disseminated chromite grains, but only the dunite contains discontinuous layers, pods and schleiren of chromitite (Photo 4). Chromitites are typically small, about 30 cm long by a few centimetres thick, and have an erratic distribution. They are commonly complexly folded and discontinuous and appear to be the result of cumulate remobilization after slumping or gravity flow events.

The dunite is mainly composed of cumulus olivine, minor amounts of chromite, intercumulus olivine, and pyroxene, and trace amounts of primary phlogopite. One exposure contains secondary euhedral uvarovite that is spatially associated with multiple parallel black serpentine veinlets (Photo 5) over a thickness of roughly 50 cm. Serpentinization is highly variable in the Turnagain rock units but commonly represents no more than about 10 vol % of the rock. Dunite is distinguished from wehrlite by its dun-coloured weathered surface and its lack of pyroxene cleavages on fresh surfaces. Some dunite from drillcore has olivine with a green colour almost comparable to olivine grains found in mantle xenoliths. Olivine grains in the larger mass of fresh dunite, located in the northern part of the intrusion (Fig. 3), commonly have a very well developed parting.

Dunite commonly hosts grains of poikilitic green diopside, either as discrete, centimetre-scale crystals or elongate aggregations. The latter are interpreted to be small dikes resulting from the escape of trapped liquid but the origin of discrete diopside is still debatable. Such crystals may result from the *in situ* crystallization of trapped melt or later stage injection along zones of weakness or pre-existing fractures. Larger dikes of grey-green clinopyroxenite, commonly pegmatitic, intrude much of the dunite and wehrlite. Such dikes are considered to be injections of evolved magma into the relatively cool olivine cumulates during a syn-crystallization deformational event.

Some dunite that is proximal to massive sulphide mineralization is commonly altered to grey tremolite.

Photo 2. Complex folding, which is especially apparent in quartzite layers, within graphitic phyllite east of the Turnagain intrusion. Pencil end is approximately 4 cm long. E 513605 N 6478887.

Photo 3. Heterogeneous talc-serpentine-carbonate alteration of ultramafic rock from the northern contact of the Turnagain ultramafic intrusive suite. Distribution of the most altered rocks lies within the black lines. Hammer is approximately 30 cm long. E 506151 N 6484799.

Photo 4. Multiple discontinous chromitite pods and schleiren in dunite. Hammer is approximately 40 cm long. E 507767 N 6483550.

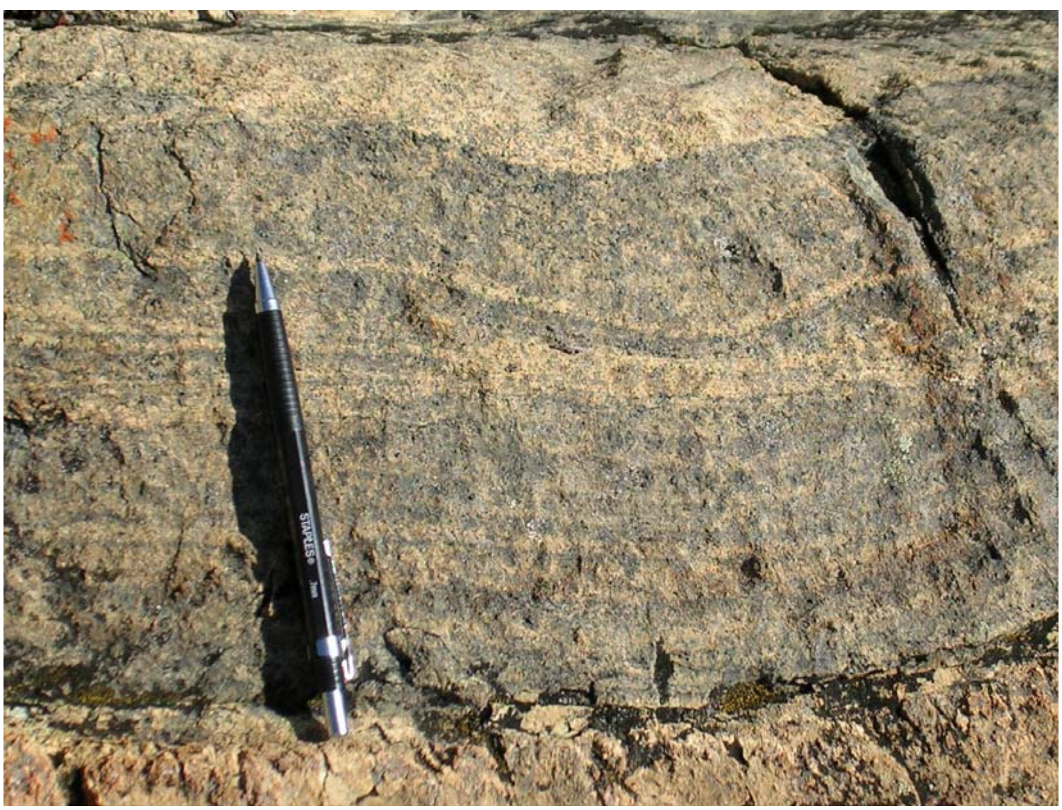

Photo 5. Pervasive magnetite-serpentine alteration of dunite, and spatially associated secondary uvarovite crystals. Pencil is approximately 12 cm long. E 507824 N 6483614.

Individual crystals pseudomorph olivine, are very fine-grained and are indistinguishable in hand sample. Under crossed-polarized light, however, tremolite is optically continuous and is presumed to be in the same optical orientation as the original olivine grains which it replaces. Larger tremolite needles commonly grow in crystallographically controlled fractures or partings within olivine. These tremolite-altered dunites are characterized by the same dun-brown weathering colour, but differ in the fresh surface. The rock appears matte-black on fresh surface with no distinguishable grains. Tremolite-altered dunite is also much harder than fresh dunite, and may be part of the reason for the outcroppings of such material in the Horsetrail Zone (Fig. 3). This zone has been identified as the main area of Ni-sulphide mineralization, although its deformational and magmatic history have yet to be resolved. Dunite-hosted sulphide mineralization is rare, comprising no more than 2 vol % of the rock. Pyrrhotite, possibly troilite, pentlandite, and trace chalcopyrite are commonly found as disseminated grains in the dunite. Rare net-textured aggregations of sulphides occur locally, including examples at the Discovery showing (Fig. 3).

Wehrlite, the second most abundant rock type in the intrusion, can be generally expressed by two distinct textural subtypes. On the west side of the Turnagain River, where the bulk of the intrusion resides, it is mainly composed of cumulus olivine with a sizable proportion of intercumulus clinopyroxene and minor amounts of cumulus pyroxene. This type of wehrlite is the most common and appears to be associated with Fe-Ni sulphide mineralization throughout the intrusion. On the east side of the river, and in the far northwest of the intrusion, cumulus clinopyroxene reaches approximately 40 vol %. Wehrlite with cumulus pyroxene is commonly mineralized with disseminated grains of Ni-poor pyrrhotite. Wehrlite containing only intercumulus pyroxene, such as that found in the Horsetrail showing, tends to contain extensive pentlandite mineralization.

Contacts between wehrlite and dunite are sharp to gradational over short distances, represented by a slight change in the size and modal abundance of pyroxene, and appear to reflect magmatic layering (Photos 6 and 7). As stated above, chromite grains are found only as disseminations in this unit. Large amounts of secondary magnetite are found where serpentinization is pervasive. Clinopyroxenite dikes also intrude the wehrlitic units in the Turnagain intrusive suite.

Olivine clinopyroxenite and clinopyroxenite are two rock units that are of relatively minor abundance in the Turnagain intrusion. They mainly occur in the northwestern part of the intrusion and commonly comprise around 85 vol % cumulus pyroxene and small amounts of cumulus olivine. In this area, these units appear to be differentiates of the original Turnagain magma as opposed to brecciated and intrusive clinopyroxenite found elsewhere. Further east, however, where large amounts of coarse to pegmatitic pyroxenites are found, the clinopyroxenites appear intrusive. This type of pyroxenite is commonly found in all Alaskan-type intrusions (Nixon, pers comm, 2004). Olivine clino-pyroxenite also exhibits rare magmatic layering where it is intercalated with wehrlitic rock units.

Pegmatitic variants of clinopyroxenite, both intrusive and *in situ*, have large crystals that rarely reach up to 20 cm in length. Pegmatitic dikes are commonly found adjacent to the cumulate clinopyroxenite. *In situ* pegmatitic variants within the cumulate pyroxenite are uncommon and confined to the northwestern part of the intrusion (Fig. 3). Clinopyroxenite from the northwest, which is juxtaposed against cumulate dunite, is commonly intruded by multiple thin dikes of fine-grained dunite (Photo 8). These dikes are randomly oriented and are no wider than 20 cm. The forsterite component of olivine within these dikes, based on optical observations, is relatively high. The origin of such Mg-rich olivine in late-stage dikes is problematic and currently unresolved. These dikes may have similar geneses to the pothole structures and dunite pipes observed in the Merensky reef in the Bushveld Complex (*e.g.*, Scoon and Mitchell, 2004).

Hornblende clinopyroxenite and clinopyroxenite are very poorly exposed and their relationships to other units in the Turnagain intrusion are not well constrained. Their occurrence coincides with a Cu-Pt-Pd soil anomaly near the southwestern margin of the intrusion. Mineralization within these hornblende-rich rocks appears to be due to the segregation of magmatic sulphides during the co-crystallization of hornblende and magnetite.

Magmatic hornblendite and hornblende clinopyroxenite found in the southwestern area of the intrusion have amphibole crystals that typically range from less than 1 cm to up to 3 cm in length. These crystals appear to be cumulus, but in some cases they replace pyroxene. Most hornblende-bearing ultramafic rocks in the Turnagain intrusion are associated with large amounts of cumulus(?) magnetite, such that these units can be identified using aeromagnetic surveys. However, the many faults that are associated with complete serpentinization of nearby ultramafic rock units are also associated with large amounts of secondary magnetite. The faults, however, do not pose significant problems for the interpretation of airborne magnetic surveys since they form distinctly linear features.

Float samples collected near the southwestern margin (Fig. 3) of the intrusion are composed almost entirely of hornblende and magnetite with large amounts of secondary pyrite. Preliminary study of drillcore from this area, the only known occurrence of these *in situ* magmatic hornblende-bearing rocks, has revealed pervasive brecciation and erratic chalcopyrite mineralization. Investigations into the nature of the Cu-Pt-Pd mineralization are underway, and preliminary results show that high PGE values do not correlate with sulphide content. Although it is possible the PGE are not present in the sulphides, it is more likely that their distribution in sulphide minerals is highly erratic.

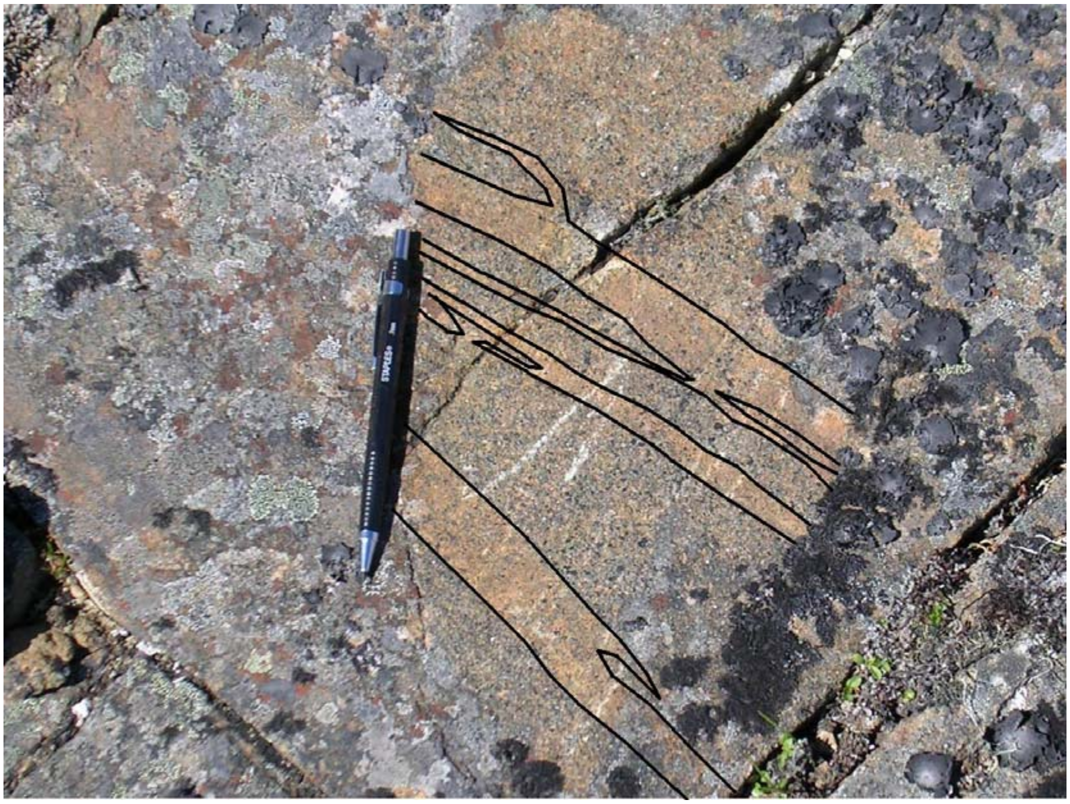

Photo 6. Magmatic layering, defined by distribution and size of cumulus diopside, in wehrlite. Pencil is approximately 12 cm long. E 507127 N 6484162.

Photo 7. Magmatic layering, defined by alternating layers of dunite and wehrlite. Dunitic layers are outlined in black. Hammer is approximately 30 cm in length. E 506777 N 6484487.

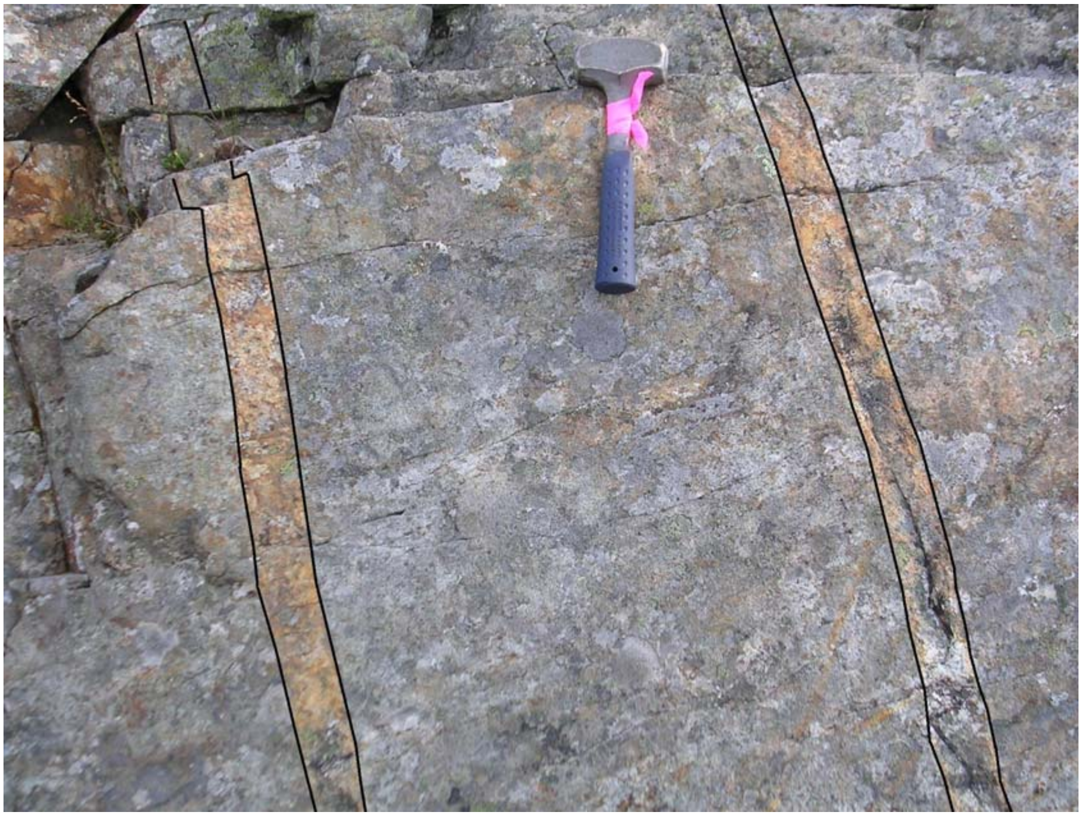

Photo 8. Dunite dikes intruding cumulate clinopyroxenite. Hammer is approximately 30 cm long. E 506830 N 6483988.

One previously unrecognized unit of hornblendite was found during the past field season and appears to be metasomatic in origin. This unit is characterized by a rusty weathered surface and increased strength compared to the metavolcanics that host it. Crystals of fine-grained hornblende are intergrown within the metavolcanic raft (Fig. 3) and are observed at the northeastern contact with cumulate wehrlite in the northwestern corner of the intrusion. Distal veins, which are found several tens of metres away from the contact and are considered to be genetically associated with the hornblendite, show fine-grained quartz margins and coarse-grained hornblende crystals in the centre.

The main hornblendite zone is characterized by planar hornblende altered areas. Hot magmatic fluids that flowed through the metavolcanic raft are considered to be responsible for its alteration. Other areas appear completely bleached and contain quartz and sericite. Clark (1975) mapped a hornblendite unit in the same vicinity, approximately 100 m to the northwest, but no exposures of this unit were found in 2004. This hornblendite appears to be completely covered by talus. It is possible that the hornblendite present here is either greisenous in origin, *i.e.*, it formed by the reaction of the *in situ* Turnagain magma(s) with fluids released from the raft, or it is a magmatic cumulate. Fluids released from the cumulate hornblendite may be responsible for the metasomatic hornblendite, thus the two lithological styles may be cogenetic.

A large 1.5 by 0.5 km metavolcaniclastic raft, which may be part of the unnamed formation to the southeast of the Turnagain ultramafic intrusion, is found in the northwestern part of the intrusion (Fig. 3). It is in intrusive contact with wehrlite at its northern margin, and dunite at its eastern and southern margins. The western margin is not exposed, although it appears to extend to the western bounding fault of the Turnagain. The raft is largely composed of plagioclase and quartz with minor hornblende and biotite. Tightly folded layers are observed in the raft and it has been hornfelsed to a significant degree. This unit, like the phyllite surrounding the Turnagain intrusion, is pervasively crosscut by numerous white quartz veins. These veins are commonly only 10 cm wide but may decrease down to millimetre scale. Present within the volcaniclastic unit are small, 5 cm-wide pods of granitic material, which can connect to centimetre-scale granitic dikes. These pods and dikes are characterized by pink potassium feldspar, cream-coloured plagioclase, white quartz, brown hornblende, brown-black biotite and clear muscovite. Many dikes and pods are randomly oriented, but the bulk of them are preferentially oriented parallel to bedding. The contacts between dikes/pods and the host metavolcaniclastic appear intrusive, but show partial assimilation of the host rock at their margins. This material appears to have formed by partial melting of the raft as it was heated up to magmatic temperatures by the Turnagain parental magma. Middle Cretaceous greenschist-facies metamorphism and deformation occurred after the intrusion was (partially) solidified.

CURRENT AND FUTURE RESEARCH

The Turnagain Alaskan-type ultramafic intrusive suite is the subject of current research for an MSc thesis by the principal author at the University of British Columbia. The goal of this study is to help better constrain the petrogenesis of the Turnagain intrusion and to gain a greater understanding of the physiochemical processes involved in the formation of its Ni-Cu-PGE mineralization.

During the summer of 2004, 172 samples were collected and 150 of these were cut into thin sections, mostly polished sections. Both transmitted and reflected light petrographic investigations of all 150 samples are currently underway. These observations will aid in constraining the crystallization and evolutionary history of the Turnagain intrusion. They will also reveal cryptic and subtle details regarding comagmatic and later-stage alteration, microstructural styles, and the nature of Ni-Cu sulphide mineralization.

Chromite chemistry, as well as associated olivine and pyroxene chemistry, can be used as a petrological indicator in mafic-ultramafic rocks (*e.g.*, Irvine, 1965; Irvine, 1967a; Roeder and Reynolds, 1991; Sack and Ghiorso, 1991; Barnes and Roeder, 2001). In late 2004, the principal author began using the electron microprobe to investigate the spinel chemistry of various representative samples taken from the Turnagain ultramafic intrusive suite. Microprobe analyses of olivine and pyroxene will follow in 2005. Sulphur isotopic analyses of sulphides from the Turnagain Alaskan-type ultramafic intrusive suite and its wallrocks will help to constrain the origin of sulphide. Geochronological studies (U-Pb zircon/baddeleyite, Ar-Ar hornblende/biotite) of four samples collected this past summer will help to constrain the age of the Turnagain intrusion and its associated Ni-Cu-PGE mineralization. Finally, Nd isotopic studies across a transect of the Turnagain intrusion will constrain the amount of crustal input in each lithology to better develop a petrogenetic model for the origin and evolution of the Turnagain ultramafic intrusive suite.

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