

# Controls on the Nickel Mineralization of the Alaskan-Type Turnagain Deposit, North-Central British Columbia (Parts of NTS 104I/07, 10)

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Broda, K.R., Williams-Jones, A.E. and Vasyukova, O.V. (2024): Controls on the nickel mineralization of the Alaskan-type Turnagain deposit, north-central British Columbia (parts of NTS 104I/07, 10); in Geoscience BC Summary of Activities 2023, Geoscience BC, Report 2024-01, p. 23–32.

## Introduction

Alaskan-type complexes constitute a distinct class of ultramafic–mafic igneous rocks formed through the emplacement and fractional crystallization of a hydrous, magnesium-rich basaltic magma derived from partial melting of the mantle wedge at convergent plate margins (Irvine, 1963; Naldrett and Cabri, 1976; Himmelberg and Loney, 1995; Naldrett, 2004). The presence of hydrous minerals (hornblende), absence of orthopyroxene and their plate-tectonic setting distinguish Alaskan-type complexes from other ultramafic–mafic complexes. They are zoned from a core of dunite outward to wehrlite, clinopyroxenite, hornblendite, gabbro and diorite, and are considered to represent cumulates of olivine, clinopyroxene and hornblende (Irvine, 1959, 1963, 1974; Naldrett and Cabri, 1976; Naldrett, 2004; Thakurta et al., 2008; Thakurta, 2018). Because of their relatively oxidized nature and depth of formation, Alaskan-type magmas are undersaturated with respect to sulphide (Mavrogenes and O’Neil, 1999) and, consequently, do not generally host significant sulphide mineralization (Irvine, 1963, 1974; Naldrett and Cabri, 1976; Naldrett, 2004; Thakurta, 2018).

The Turnagain complex in north-central British Columbia (BC) is an unusual example of an Alaskan-type complex that contains a potentially economic body of magmatic nickel-sulphide mineralization. It comprises a core of dunite and wehrlite surrounded by clinopyroxenite and hornblendite (Clark, 1980; Scheel, 2007; Jackson-Brown, 2017). Pentlandite ( $[\text{Ni}, \text{Fe}]_9\text{S}_8$ ) is the principal nickel-ore mineral (25 to 35 wt. % Ni), although a significant proportion of nickel is also present in olivine (mean 1400 ppm), serpentine (mean 800 ppm) and pyrrhotite (mean 400 ppm; Blue Coast Research Ltd., unpublished reports, 2019,

2020). The complex has experienced variable but extensive serpentinization, leading to the replacement of the olivine by serpentine minerals and the remobilization of sulphur. Because of the presence of nickel in both sulphide and silicate minerals, and the intricate interplay between magmatic and hydrothermal processes, the nickel-to-sulphur ratios within the deposit display extreme variability, posing challenges for the metallurgical recovery of the nickel. The Turnagain complex has the highest known endowment of nickel sulphide of any Alaskan-type ultramafic complex (1574 Mt of ore grading 0.21 wt. % Ni; Giga Metals Corporation, 2023) and therefore represents an ideal natural laboratory, in which to investigate the processes that lead to economic concentrations of nickel-sulphide mineralization in such complexes.

A detailed petrographic and geochemical study of a suite of representative samples from the Horsetrail-Northwest zone of the Turnagain complex (Figure 1) has been initiated to unravel the history of nickel-sulphide mineralization in the complex. Preliminary results from that study are presented in this paper.

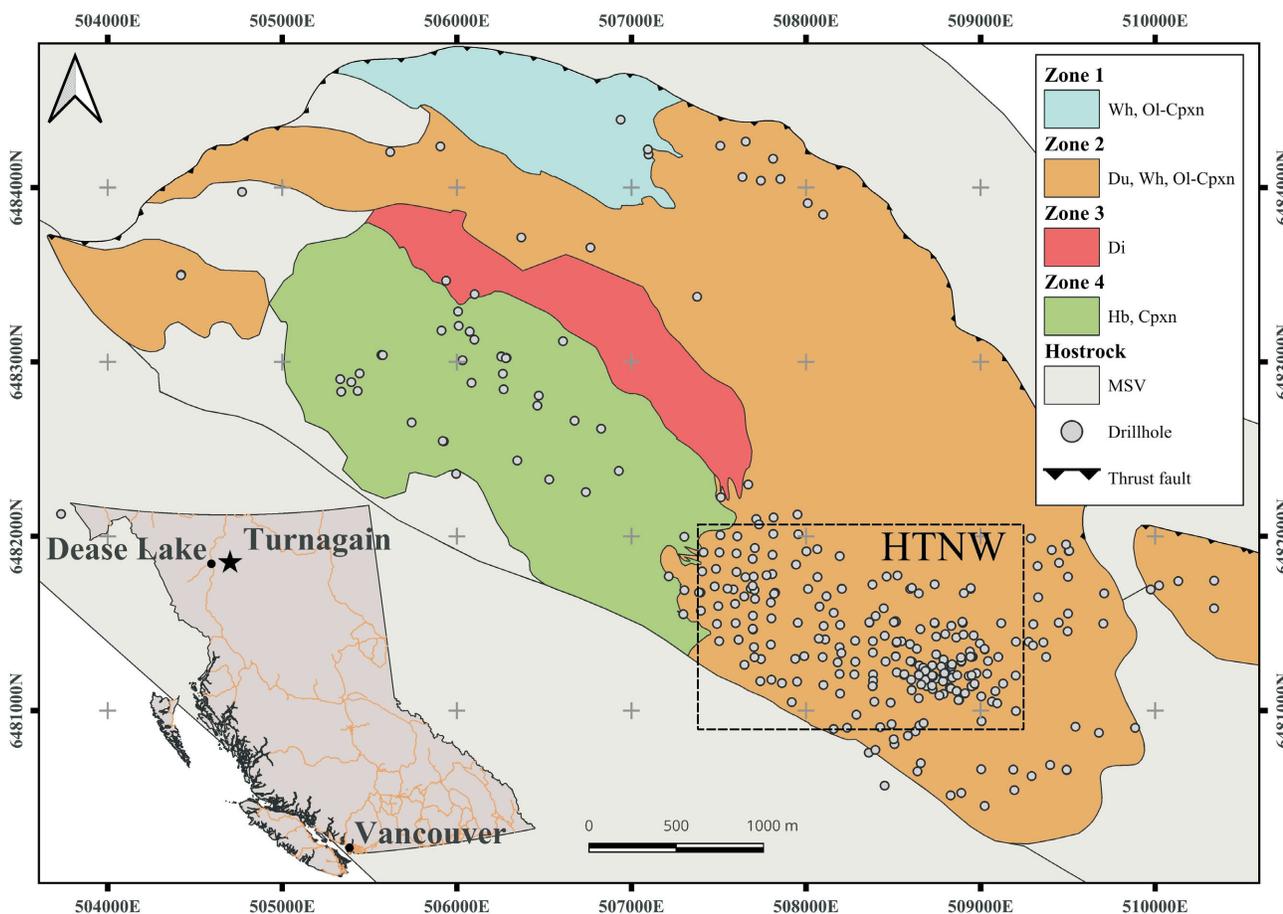
## The Geology of the Turnagain Complex

The Turnagain complex is situated in north-central BC, approximately 65 km east of Dease Lake (Figure 1) and is part of a belt of Alaskan-type intrusions of Early Jurassic age 250 km long located between Turnagain in the north and the Polaris intrusion in the south (Nixon et al., 2020). It is an elliptical body of intrusive mafic to ultramafic rocks approximately 8 km long by 3.5 km wide in plan, with a northwest-trending long axis that roughly parallels the regional structural trend (Scheel, 2007; Jackson-Brown et al., 2017; Nixon et al., 2020). The magma that formed the complex intruded into Middle to Late Paleozoic graphitic phyllite and metasedimentary-volcanic rocks with Yukon-Tanana or Quesnellia terrane affinity between 189 and 185 Ma, during the initial accretion of arc-related terranes onto the ancient North American continental margin (Nixon et al., 2020). The Turnagain complex is fault-bounded and juxta-

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<sup>1</sup>The lead author is a 2023 Geoscience BC Scholarship recipient.

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**Figure 1.** Location (inset) and generalized geology of the Turnagain complex. The study area, the Horsetrail-Northwest resource zone (HTNW), is outlined by the rectangle in the southeastern part of the complex. Zones 1 through 4 represent distinct intrusive bodies composed of different lithological assemblages. Abbreviations: Cpxn, clinopyroxenite; Di, diorite; Du, dunite; Hb, hornblendite; MSV, metasedimentary-volcanic; Ol-Cpxn, olivine-clinopyroxenite; Wh, wehrlite. All co-ordinates are in UTM Zone 9N, NAD 83.

posed against pyrite-bearing graphitic phyllite on its northern and eastern margins, whereas on its southern boundary it is in intrusive contact with metavolcanic and metasedimentary rocks (Scheel, 2007; Jackson-Brown, 2017; Nixon et al., 2020).

The Turnagain complex has been subdivided into four zones, with each zone representing a separate intrusive body defined by sharp intrusive contacts (Figure 1). Zone 1 is a body in the north-northwestern sector of the complex, composed primarily of wehrlite (Wh) and olivine-clinopyroxenite (Ol-Cpxn) and minor dunite (Du). Zone 2, which hosts the deposit, comprises dunite and wehrlite, with minor olivine-clinopyroxenite (Ol-Cpxn). Hornblendite (Hb) occurs as rare crosscutting dikes. Zone 3 is a small diorite (Di) lens that occurs in the centre of the complex and intrudes part of zone 2. Finally, zone 4 comprises a body of clinopyroxenite and hornblendite, with minor wehrlite that intruded zone 3 to the north and zone 2 to the east. All the intrusive rocks have undergone varying degrees of alteration (Nixon et al., 2020). Enclaves of pyrite-

bearing graphitic phyllite and metavolcanic rock occur within zones 1, 2 and 4.

The nickel-sulphide deposit, the Horsetrail-Northwest zone, occurs in the southern part of the zone 2 intrusive body (Figure 1), which, as mentioned above, consists dominantly of dunite and wehrlite. However, a feature that distinguishes the Horsetrail-Northwest zone from other parts of zone 2 is that it contains numerous enclaves of pyrite-rich graphitic phyllite. Moreover, it is evident from examination of drillcore that the sulphide content of the dunite and wehrlite is markedly higher proximal to these enclaves. Alteration, mainly serpentinization of the olivine, varies from incipient to intense. Pyrrhotite ( $Fe_{1-x}S$  [ $x = 0-0.2$ ]) is the main sulphide mineral and has a disseminated-interstitial to net-textured mode of occurrence. It is accompanied by pentlandite ( $[Ni, Fe]_9S_8$ ), trace proportions of chalcopyrite ( $CuFeS_2$ ) and the secondary sulphides, heazlewoodite ( $Ni_3S_2$ ) and millerite ( $NiS$ ). The sulphides typically make up 0.5 to 1 wt. % of the rock, but lenses (<20 cm in length) of net-textured to semi-massive sulphides containing up to 30 wt. % sulphide occur locally.

## Methodology

Drillcore samples ( $n = 140$ ) representative of the altered and unaltered silicate rocks of the Horsetrail-Northwest zone and their sulphide ores were collected for petrographic, mineral, chemical and bulk-rock analyses. A subset of ten samples was selected for preliminary petrographic examination and analysis. The petrographic analysis was conducted at the Earth and Planetary Sciences Department of McGill University on polished thin sections of these samples using an Olympus BX51-P polarizing microscope and a Hitachi High-Tech Canada, Inc. SU5000 field-emission scanning electron microscope, equipped with an X-Max<sup>N</sup> 80 silicon drift detector from Oxford Instruments plc. This ensured reliable identification of the minerals and accurate determination of the textural relationships among them.

A set of 110 samples was analyzed by SGS Minerals Services (Burnaby, BC) and a set of 30 samples was analyzed by Activation Laboratories Ltd. (Ancaster, Ontario) for their bulk-rock chemical composition using lithium borate fusion for the major and trace elements, sodium peroxide fusion for their trace elements (SGS Minerals Services) and infrared combustion for total sulphur. The loss-on-ignition (LOI) was also determined.

As many of the samples had undergone moderate to intense alteration (mainly serpentinization), the whole-rock data were used to help distinguish the primary igneous rock types. The MgO concentration in the silicate fraction (normalized to anhydrous MgO, CaO and SiO<sub>2</sub>, and corrected for Fe in sulphide, assuming that all the sulphide was present as pyrrhotite) was used for this purpose. Samples containing >53 wt. % MgO were classified as dunite, samples containing between 34 and 53 wt. % MgO were classified as wehrlite, and samples containing between 19 and 34 wt. % MgO were classified as olivine-clinopyroxenite. These groupings were calculated assuming end-member compositions of rock types and minerals dunite (100–90 vol. % forsterite and 0–10 vol. % diopside modal abundance), wehrlite (90–40 vol. % forsterite and 10–60 vol. % diopside modal abundance) and olivine-clinopyroxenite (40–10 vol. % forsterite and 60–90 vol. % diopside modal abundance).

## Results

### Primary Silicate Minerals and Their Textures

The Horsetrail-Northwest rocks are composed primarily of olivine and clinopyroxene. The olivine, which displays an obvious cumulate texture, occurs as euhedral to anhedral crystals and is typically equigranular (1–3 mm), although olivine crystals up to 15 mm in diameter may be observed locally. In many samples, the olivine crystals exhibit kink banding that appears as undulatory extinction; these crystals

commonly exhibit two angles of parting (at 90°) that gives the appearance of cleavage. The olivine exhibits two types of fractures, specifically random fractures within crystals and fractures that crosscut several crystals.

The clinopyroxene occurs interstitially to olivine and, locally, as cumulates. In rare cases, the interstitial clinopyroxene is oikocrystic, with numerous inclusions of olivine and chromite (<15 mm). Cumulate clinopyroxene occurs as 1–3 mm subhedral crystals and exhibits a moderate to strong prismatic cleavage. Locally, there are thin (2–5 mm) layers of interlocking clinopyroxene crystals.

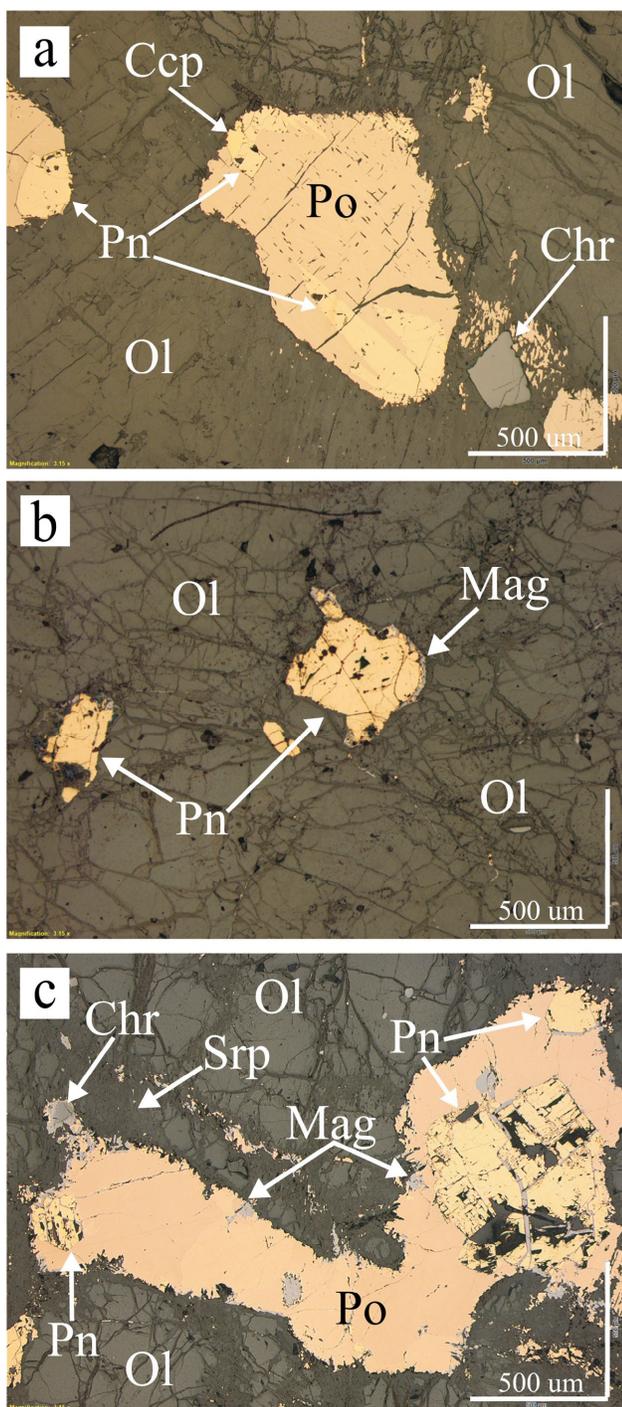
Chromite is an important accessory mineral and occurs as small (<1 mm) subhedral to euhedral crystals that may be isolated or form clusters interstitial to cumulate clinopyroxene. Locally, chromite occurs as inclusions in olivine and clinopyroxene or as thin chromite schlieren (observed in drillcore). The chromite crystals are commonly rimmed by a second chromite phase, distinguished by its lighter colour in reflected light.

### Sulphide Minerals and Their Textures

The sulphide mineralization in the Horsetrail-Northwest zone is generally disseminated or net textured, but locally replaced olivine. The principal sulphide minerals are pyrrhotite and pentlandite, with pentlandite being the main nickel-ore mineral; chalcopyrite is present in trace proportions.

Pyrrhotite occurs as disseminated aggregates of subhedral to euhedral crystals (typically 50 to 500 μm), with or without pentlandite. As the sulphide content and the interconnectivity of sulphides in the interstitial space increase, the pyrrhotite becomes net textured. Locally, pyrrhotite contains exsolution lamellae of pentlandite (Figure 2a) and may occur as inclusions in olivine, clinopyroxene and chromite. These inclusions are commonly composed of a single pyrrhotite crystal ± pentlandite.

Pentlandite occurs in both the disseminated-interstitial and net-textured pyrrhotite aggregates and has two main modes of occurrence, namely as the exsolution lamellae mentioned above and as discrete crystals or clusters of crystals that occur within pyrrhotite aggregates or in isolation (Figure 2a–c). Both the discrete crystals and those in the pentlandite aggregates are euhedral to subhedral and range in diameter from <20 to 150 μm; the pentlandite aggregates range in diameter from <100 to >1500 μm. Locally, pentlandite fills the space at the triple junctions of cumulate olivine crystals (Figure 2b). Where pentlandite occurs in isolation from pyrrhotite, it is the only sulphide mineral present, whereas, if it occurs with pyrrhotite, the ratio of pyrrhotite to pentlandite ranges from approximately 90:10 to approximately 10:90. Locally, pentlandite may occur as



**Figure 2.** Photomicrographs of magmatic sulphide textures of samples from the Turnagain deposit taken under reflected light: **a**) pyrrhotite (Po) with crystallographically controlled exsolved pentlandite (Pn) and local chalcopyrite (Ccp) interstitial to cumulate olivine (Ol) and chromite (Chr), as well as traces of serpentine along the fractures (note the serpentine intergrowths at the edges of the sulphide aggregate, which are suggestive of partial dissolution and mobilization of sulphide and replacement by serpentine); **b**) pentlandite interstitial to olivine, with traces of serpentine along the fractures and the pentlandite showing evidence of minor replacement by magnetite along its edges; **c**) pyrrhotite, blocky pentlandite interstitial to olivine and chromite, with minor serpentinization along fractures and the pyrrhotite showing evidence of minor replacement by magnetite.

both exsolution lamellae and discrete crystals in the same sulphide mass.

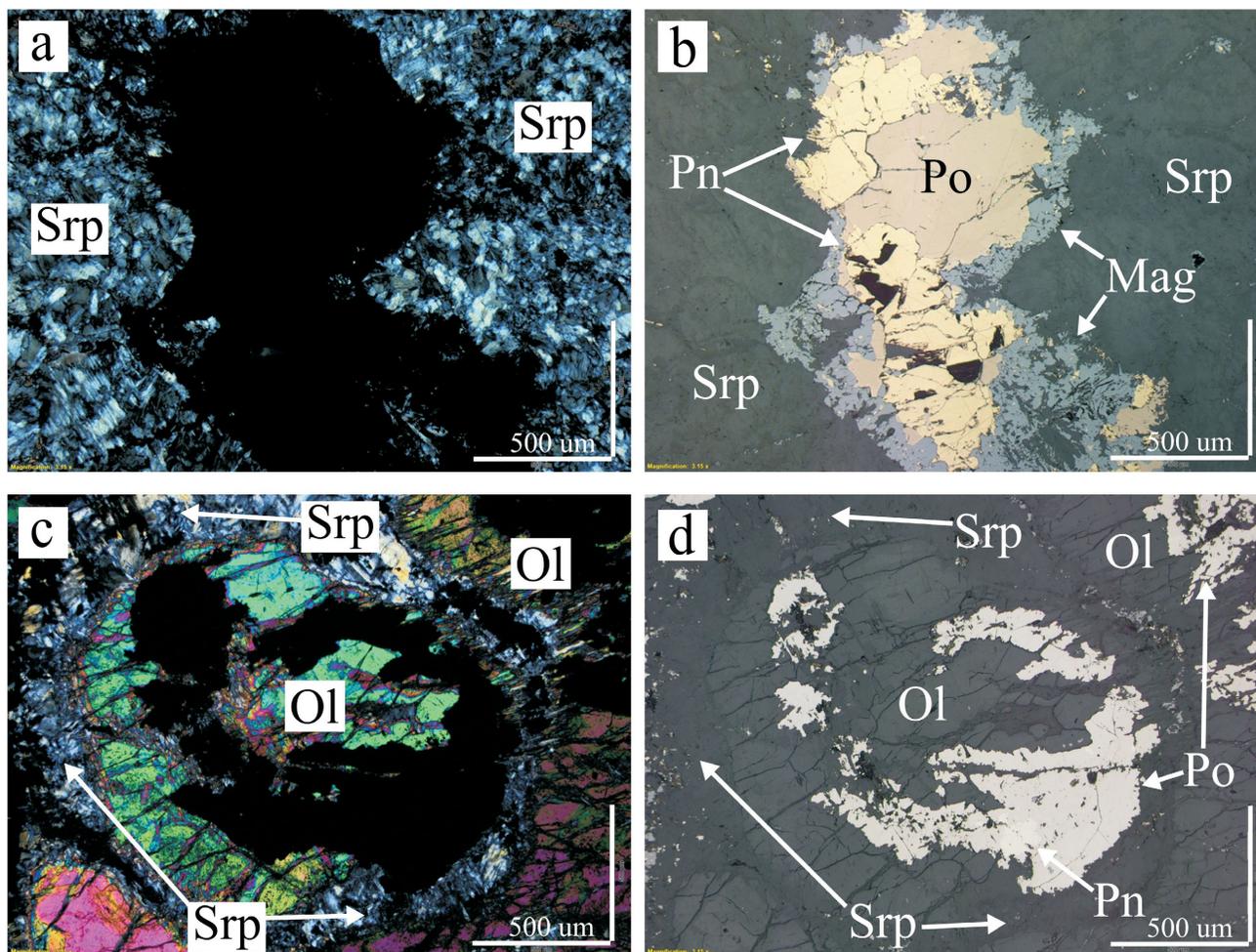
### Alteration

Serpentinization has affected olivine to varying degrees in all parts of the Horsetrail-Northwest zone and, where it was intense, left no relicts of this mineral (Figure 3a). Thus, some dunite samples now consist almost entirely of serpentine. This alteration proceeded primarily along fractures and grain boundaries. In weakly altered rocks, the serpentine typically grew perpendicular to the olivine crystal boundaries, whereas in more strongly serpentinized samples, serpentine forms pseudomorphs of olivine, in some cases outlined by thin mantles of magnetite. Magnetite produced during the serpentinization of olivine also occurs as disseminated anhedral grains. Rarely, alteration of the olivine led to the crystallization of brucite. In contrast to olivine, the clinopyroxene altered to tremolite and locally to serpentine minerals.

The main effect of alteration on the sulphide minerals was the replacement of pyrrhotite by magnetite (Figure 3b). Sulphide alteration is also evident from the occurrence of heazlewoodite and millerite, which are inferred to be breakdown products of pentlandite. In one sample, heazlewoodite was observed to have replaced pentlandite in contact with olivine that had been altered to brucite and serpentine group minerals. Finally, olivine was altered locally to serpentine group minerals and pyrrhotite, with rare pentlandite (Figure 3c, d).

### Bulk-Rock Geochemistry

The bulk-rock geochemistry results for silicate rocks ( $n = 140$ ) in the Horsetrail-Northwest zone are summarized in Table 1. For all rock types, the CaO content increases as MgO decreases, ranging from 0.01 to 1 wt. % in dunites (>53 wt. % MgO;  $n = 61$ ), 0.07 to 12 wt. % in wehrlites (34 and 53 wt. % MgO) and 7 to 22 wt. % in olivine-clinopyroxenites (19–34 wt. % MgO; Figure 4a). Sulphur concentrations show no relationship with MgO content or rock type, ranging from 0.02 to 8 wt. % in dunites, 0.06 to 8 wt. % in wehrlites and 0.15 to 10 wt. % (with one outlier at 24 wt. %) in olivine-clinopyroxenites (Figure 4b). Nickel concentrations, on the other hand, increase with increasing MgO content, and range from 0.02 to 0.3 wt. % (with an outlier at 1.2 wt. %) in olivine-clinopyroxenites, 0.01 to 1.2 wt. % in wehrlites, and 0.1 to 1 wt. % in dunites (Figure 4c). Thus, nickel-to-sulphur ratios are weakly correlated with MgO, displaying ranges from <0.01 to 1.2 ( $R = 0.27$ ) for olivine-clinopyroxenites, 0.04 to 2.5 ( $R = 0.32$ ) for wehrlites and 0.05 to 14.2 ( $R = 0.32$ ) for dunites (Figure 4d). Loss-on-ignition (LOI) appears to be unrelated to rock chemistry, ranging from 2 to 17 wt. % in dunites, 1 to 23 wt. % in wehrlites and 2 to 10 wt. % in olivine-clinopyroxenites (Table 1).

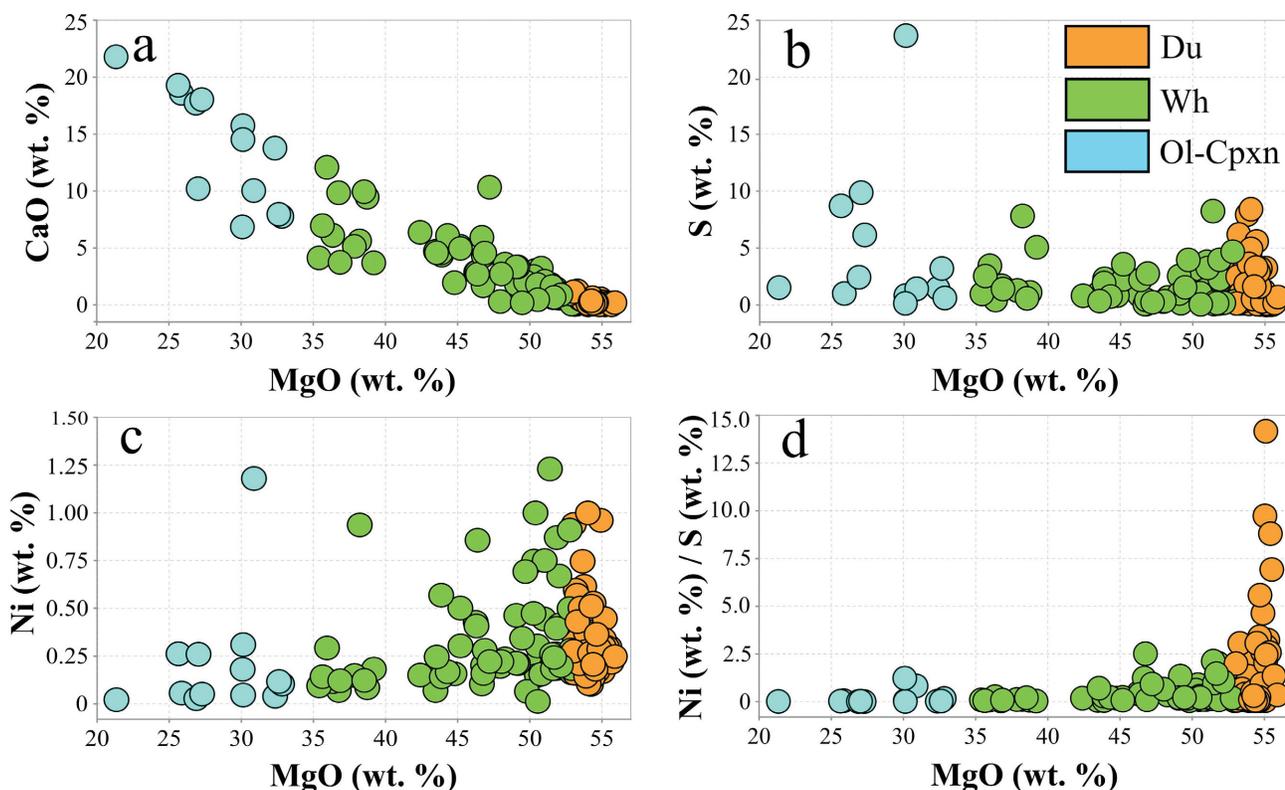


**Figure 3.** Photomicrographs of silicate and sulphide alteration textures of samples from the Turnagain deposit: **a)** image in cross-polarized light of serpentine (Srp) that has completely replaced olivine; **b)** same image as (a) in reflected light showing magnetite (Mag) that has partially replaced an aggregate of pyrrhotite (Po), pentlandite (Pn); **c)** image in cross-polarized light of olivine (Ol) partially pseudomorphed by serpentine; **d)** same image as (c) in reflected light showing olivine partially pseudomorphed by pyrrhotite and pentlandite.

**Table 1.** Summary statistics for bulk-rock geochemical analysis of samples from the Turnagain deposit. Abbreviation: LOI, loss-on-ignition.

	MgO <sup>1</sup> (wt. %)	CaO (wt. %)	S (wt. %)	Ni (wt. %)	Ni vs S	LOI (wt. %)
<b>Dunite (n = 61)</b>						
Minimum	53	0.01	0.02	0.1	0.05	2
Maximum	56	1	8	1	14.2	17
Mean	54.3	0.3	1.6	0.3	1.6	5.4
Median	54.3	0.2	0.6	0.3	0.4	4.9
<b>Wehrlite (n = 66)</b>						
Minimum	35	0.07	0.06	0.01	0.04	1
Maximum	53	12	8	1.2	2.5	23
Mean	47.2	3.2	1.6	0.3	0.5	7.3
Median	49.1	2.3	1.0	0.2	0.2	5.8
<b>Olivine-clinopyroxenite (n = 13)</b>						
Minimum	21	7	0.15	0.02	0.01	2
Maximum	33	22	24	1.2	1.2	10
Mean	28.7	14.0	4.7	0.2	0.2	5.8
Median	30.1	14.5	1.5	0.1	0.03	5.2

<sup>1</sup>Minimum and maximum values do not refer to the limits used in grouping the three rock types (see 'Methodology') but the actual values of the samples analyzed.



**Figure 4.** Binary plots of bulk-rock compositions of samples from the Turnagain deposit coloured according to rock type: **a)** CaO content versus MgO content; **b)** S content versus MgO content; **c)** Ni content versus MgO content; **d)** Ni to S ratio versus MgO content. The values of MgO and CaO are shown normalized to anhydrous values for the silicate fraction corrected for the Fe content of the sulphide fraction.

## Discussion

The Turnagain complex shares similarities with other Alaskan-type complexes with respect to mineralogy and the zonal distribution of the main intrusive rock types. However, the Turnagain complex notably contains a much greater volume of dunite and wehrlite which, coincidentally, host a potentially economic nickel-sulphide orebody.

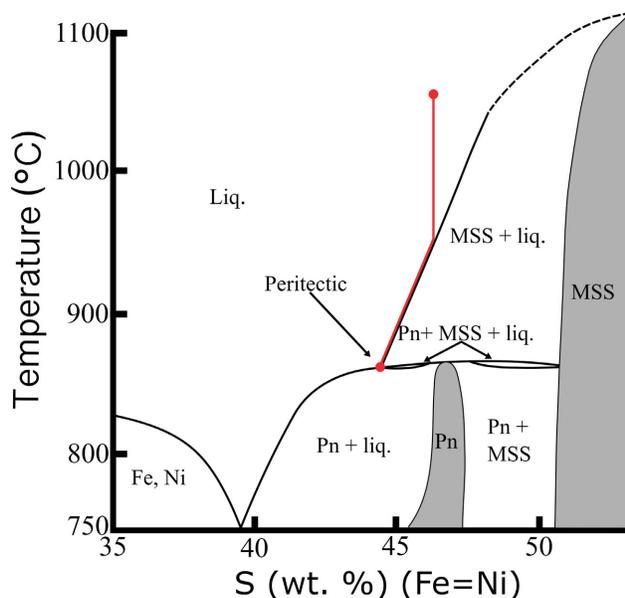
Petrographic observations from this study indicate that the ultramafic rocks in the Horsetrail-Northwest zone consist of cumulate olivine and interstitial clinopyroxene, accompanied by minor cumulate clinopyroxene and cumulate chromite. Varying modal percentages of olivine and clinopyroxene, reflected in variations in MgO and CaO contents, describe a range of rock types from dunite to olivine clinopyroxenite (Figure 4a). The textural relationships indicate that olivine and chromite crystallized first, followed by interstitial clinopyroxene and, finally, cumulate clinopyroxene.

## Magmatic Sulphide

The presence of appreciable proportions of pyrrhotite and pentlandite interstitial to the cumulate olivine is consistent with magmatic sulphide formation. Pyrrhotite is interpreted as a product of the crystallization of sulphide liquid to monosulphide solid solution (MSS). The origin of the

pentlandite is less clear; lamellae of pentlandite in pyrrhotite indicate that at least some of the pentlandite exsolved from MSS (Figure 2a). Based on phase relations in the system Fe-Ni-S, this likely occurred at a temperature of approximately 610 °C (not corrected for pressure; Kullerud, 1963). However, the occurrence of large blocky crystals within pyrrhotite, and particularly the occurrence of isolated crystals of pentlandite, require another explanation (Figure 2b, c). The results of this study lead the authors to propose that, as shown experimentally by Sugaki and Kitakaze (1998) and Kitakaze et al. (2016), this pentlandite was the product of a peritectic reaction, in which the sulphide liquid reacted with earlier formed MSS to crystallize pentlandite (Figure 5). According to Sugaki and Kitakaze (1998) and Kitakaze et al. (2016), this would likely have occurred at a temperature in the range of 865 to 746 °C (not corrected for pressure). The occurrence of much of the pentlandite as inclusions within pyrrhotite aggregates implies that the peritectic reaction did not go to completion and that MSS continued to crystallize, eventually exsolving pentlandite at lower temperature.

In most cases the magmas forming these complexes are undersaturated in sulphide and do not contain significant nickel-sulphide mineralization. This is because sulphide solubility increases with decreasing pressure and because the magmas are oxidized, which further increases this solu-

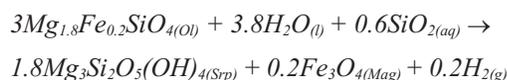


**Figure 5.** A binary diagram showing phase relationships (at Fe = Ni) in the Fe-Ni-S system from 750 to 1100 °C (modified from Kitakaze et al., 2016). The red line shows a possible crystallization path for a sulphide liquid (liq.) that initially crystallized a monosulphide solid solution (MSS) and then evolved to a peritectic point, where it reacted with the MSS to crystallize pentlandite (Pn). This continued until the consumption of the liquid, leaving behind a mixture of MSS and pentlandite.

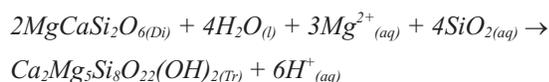
bility (Mavrogenes and O'Neill, 1999; Jugo, 2009). Therefore, an external source of sulphur at or near the site of emplacement of the magmas is required to enable saturation of the magma with sulphide. At the Turnagain deposit, this source could have been the pyrite-bearing graphitic phyllite enclaves within the Horsetrail-Northwest zone. Furthermore, the high oxygen fugacity of the magma may have promoted strong dissolution of the pyrite and the subsequent reduction of the magma by graphite could have led to its supersaturation in sulphide and the exsolution of a sulphide liquid, into which nickel partitioned preferentially (Naldrett, 2004).

### Hydrothermal Alteration

The silicate minerals of the Turnagain complex were variably altered by hydrothermal fluids. Thus, olivine (Ol) was replaced by serpentine group minerals (Srp) and magnetite (Mag) according to the reaction:

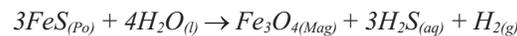


and clinopyroxene (as diopside [Di]) was altered to tremolite (Tr) according to the reaction:

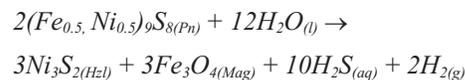


As the olivine contains significant nickel (300 to 2300 ppm), serpentinization would have released much of this nickel making it available to secondary nickel sulphides, such as heazlewoodite and millerite.

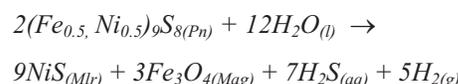
Hydrothermal alteration also affected the sulphide minerals with the replacement of pyrrhotite (Po) by magnetite according to the reaction:



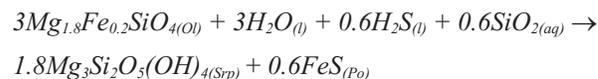
and the alteration of pentlandite (Pn) to heazlewoodite (Hzl) and millerite (Mlr) via the reactions:



and



These reactions both mobilized sulphur as H<sub>2</sub>S, leading to the replacement of the iron component in olivine (containing between 10 to 15 mol. % of fayalite; Scheel, 2007) by pyrrhotite, and the magnesium-silicate component by a serpentine-group mineral according to the reaction:



The occurrence of pentlandite in the pyrrhotite of some samples (Figure 3d) could reflect the reaction of the H<sub>2</sub>S with the nickel component of the olivine (Filippidis, 1982).

### Variability in Ni:S Ratios

A feature of the Horsetrail-Northwest zone is the extreme variability of the Ni:S ratios of the rocks (Figure 4d), which presents a major challenge for the economic recovery of the nickel. In principle, the nickel should be concentrated mainly in pentlandite and pyrrhotite, leading to a strong positive correlation between Ni and S, but because of the relative low proportion of sulphide relative to that of other magmatic sulphide deposits, the effect on the Ni:S ratio of the proportion of nickel hosted by olivine is considerable. Further complicating the issue is the fact that variable degrees of serpentinization led to variable proportions of this nickel being released to form secondary nickel-sulphide minerals. Finally, whereas in most nickel deposits the pentlandite exsolved from MSS, thus ensuring a close correlation between the proportion of pyrrhotite and the proportion of nickel, at the Turnagain deposit much of the pentlandite appears to have crystallized as a peritectic mineral, independently of pyrrhotite, leading to highly variable proportions of the two minerals. The relative importance of these processes and their effects on the Ni:S ratios are the subject of ongoing investigation.

## Future Work

Future research to understand these processes will include analyses of the major- and trace-element contents of rock-forming minerals using an electron microprobe and laser-ablation inductively coupled–mass spectrometry. The data collected will be used to evaluate the spatial and temporal variation in the compositions of the different minerals and, in the case of pentlandite, to determine whether there was a peritectic incorporation of palladium and other trace elements (Mansur et al., 2019). Sulphur isotope compositions will be analyzed using laser-ablation multiple-collector inductively coupled–mass spectrometry to evaluate the sulphur source and determine physicochemical parameters such as oxygen fugacity. Ultraviolet femtosecond laser-ablation multiple-collector inductively coupled–mass spectrometry will be used to analyze the in situ iron and nickel isotope compositions of the rock-forming minerals to evaluate the source of iron and nickel, and the isotopic fractionation of these metals between different minerals during the magmatic and hydrothermal processes (e.g., serpentinization). The resulting data will also be used to determine the temperature and redox conditions during magmatism and serpentinization (Rouxel et al., 2003; Scott et al., 2017).

## Conclusions

Magmatic pyrrhotite and pentlandite mineralization in the Horsetrail-Northwest zone of the Turnagain ultramafic complex occurs as disseminated-interstitial to net-textured sulphide in olivine-rich ultramafic rocks that formed through the assimilation of pyrite-bearing graphitic phyllite enclaves and the subsequent supersaturation of the melt with respect to sulphide. Pentlandite is the main nickel-ore mineral in the deposit and is present largely as a blocky variety that is either enclosed in pyrrhotite or forms isolated crystals. Some pentlandite occurs as lamellae in pyrrhotite. The blocky variety is interpreted as the product of a peritectic reaction between MSS and a sulphide liquid, whereas the lamellae are thought to have exsolved from MSS.

Hydrothermal alteration affected the distribution of nickel significantly by releasing it from olivine during serpentinization to form secondary minerals such as heazlewoodite and millerite, and altering pentlandite to these minerals. This alteration also led to the replacement of pyrrhotite by magnetite, which likely released additional nickel to secondary minerals.

The combination of magmatic processes and the mobilization of nickel and sulphur during hydrothermal alteration were likely responsible for the variable and unpredictable Ni:S ratios. A better understanding of these processes will help considerably in developing a comprehensive genetic model for the mineralization.

## Acknowledgments

Major funding for this project is being provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) and Giga Metals Corporation. The lead author is grateful to Geoscience BC for its financial support through the Geoscience BC Scholarship program. Technical and logistical support provided by Giga Metals Corporation are gratefully acknowledged. The authors would also like to thank K. Rempel for insightful and constructive comments and suggestions during the review process.

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