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Cu-PGE Sulphide Mineralization in the Tulameen Alaskan-type Intrusion: Analogue for Cu-PGE Reefs in Layered Intrusions?

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INTRODUCTION

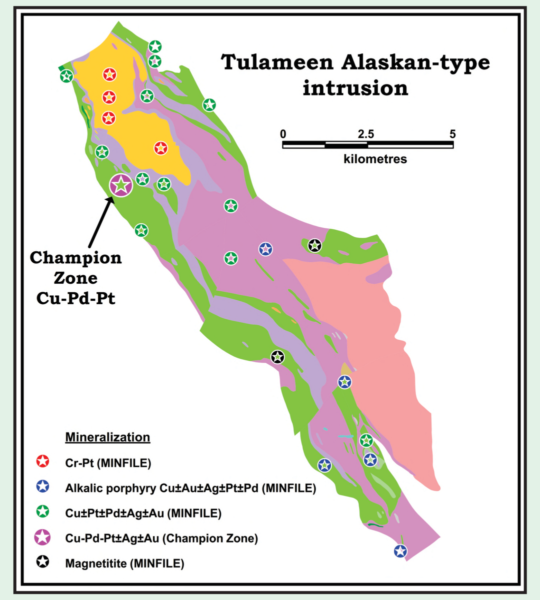
The Tulameen Alaskan-type intrusion (Late Triassic) belongs to a global class of ultramafic-mafic bodies emplaced in convergent margin or supra-subduction zone environments. This class of intrusion is gaining prominence as an exploration target for magmatic Ni-Cu-platinum group element (PGE) mineralization (e.g., Turnagain, Nixon et al., 2015, 2017; Giant Mascot, Manor et al., 2016, 2017). The subclass of Alaskan-type intrusions is well known for economic concentrations of Pt in placer deposits derived from chromitites in the dunite core (e.g., Tulameen, Nixon et al., 1990). However, Ni-depleted Cu mineralization spatially associated with such intrusions has not been adequately investigated.

Here we present preliminary petrographic, mineralogical and geochemical data pertinent to the development of a new mineral deposit model for orthomagmatic Cu-PGE(-Au-Ag) sulphide mineralization in Alaskan-type intrusions in convergent margin settings. We focus on a well-exposed zone of chalcopyrite-bornite mineralization, the Champion Zone, containing low modal proportions of magmatic sulphides and highly anomalous PGE abundances. The nature of the mineralization resembles aspects of stratiform Cu-PGE reefs in layered intrusions which host most of the world's Ni and PGE resources.

CHAMPION ZONE Cu-PGE

The Champion Zone lies near the western margin of the Tulameen intrusion. A 700m-long zone of intermittent Cu mineralization is exposed along a spur road overlooking Champion Creek (see Tulameen geology map). Weak malachite staining betrays the presence of trace amounts of Cu-Fe sulphides hosted by magnetite-bearing biotite-hornblende clinopyroxenite and hornblendite. The principal sulphides are chalcopyrite and bornite accompanied by minor pyrite and rare pyrrhotite. Despite relatively low abundances of Cu, grab samples from this zone contain up to 1.9 g/t Pd+Pt.

Cu mineralization as shown by MINFILE occurrences within the Tulameen intrusion is widespread (see map below). Most occurrences are hosted by the marginal pyroxenite and are likely similar to mineralization in the Champion Zone and orthomagmatic in origin. Note that Cu occurrences associated with gabbroic rocks are classed as alkalic porphyry Cu-Au mineralization in MINFILE. These feldspathic rocks, however, are heavily saussuritized and original magmatic Cu sulphides may have been remobilized.

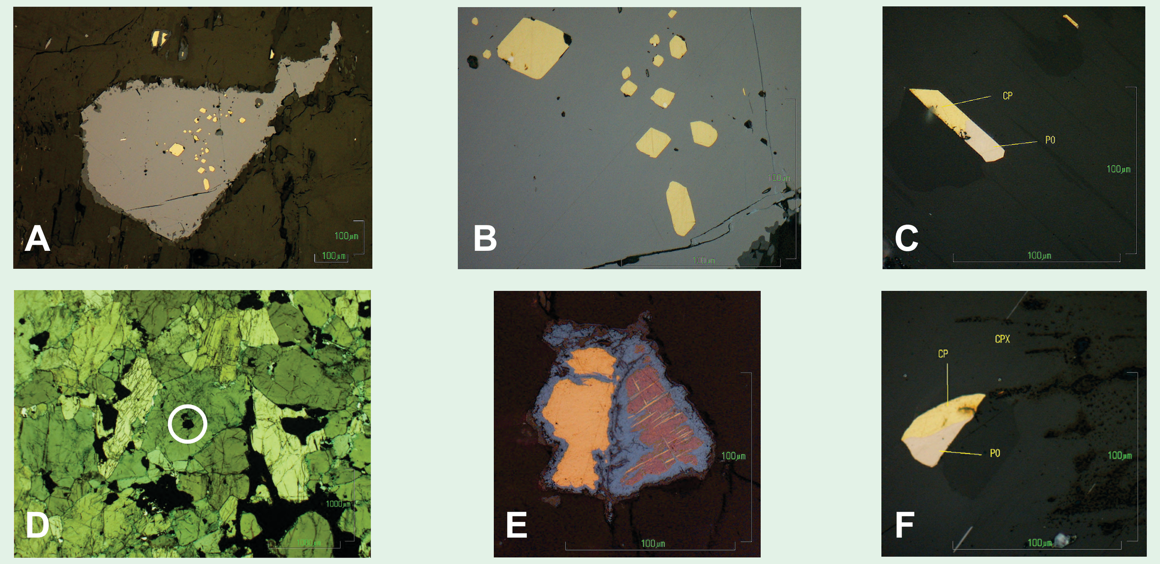


SULPHIDE TEXTURES

Sulphides occur in multiple textural settings within ultramafic cumulates of the Champion Zone. Four distinct sulphide textural associations are recognized:

1) Inclusions

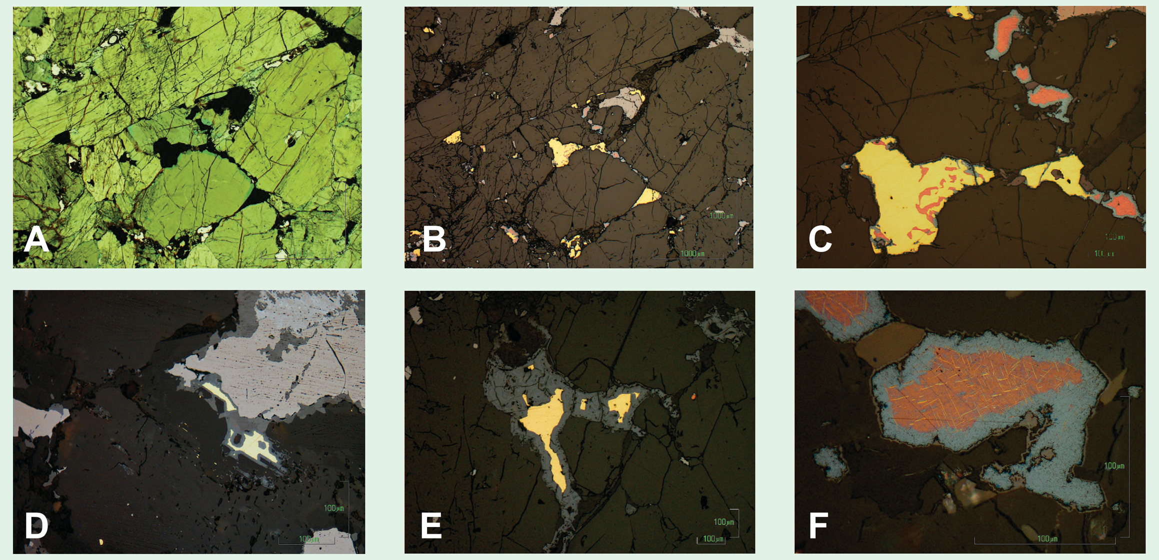
Chalcopyrite, bornite, minor pyrite and rare pyrrhotite are the principal sulphides in primary inclusions within oxides and silicates. Chalcopyrite commonly forms inclusions in hornblende, clinopyroxene and magnetite; bornite occurs in hornblende and magnetite; whereas pyrrhotite is restricted to clinopyroxene, and does not coexist with bornite.



A) Swarm of chalcopyrite inclusions in intercumulus magnetite (magnetite-hornblende clinopyroxenite); B) Note negative crystal morphology; C) Faceted inclusion of chalcopyrite-pyrrhotite in clinopyroxene (hornblende-magnetite clinopyroxenite); D) Magnetite hornblendite (plane- polarized light); E) Composite inclusion of chalcopyrite and bornite in hornblende (circle in D) showing chalcopyrite exsolution lamellae and rim of covellite ; F) Composite inclusion of chalcopyrite-pyrrhotite in clinopyroxene (hornblende-magnetite clinopyroxenite).

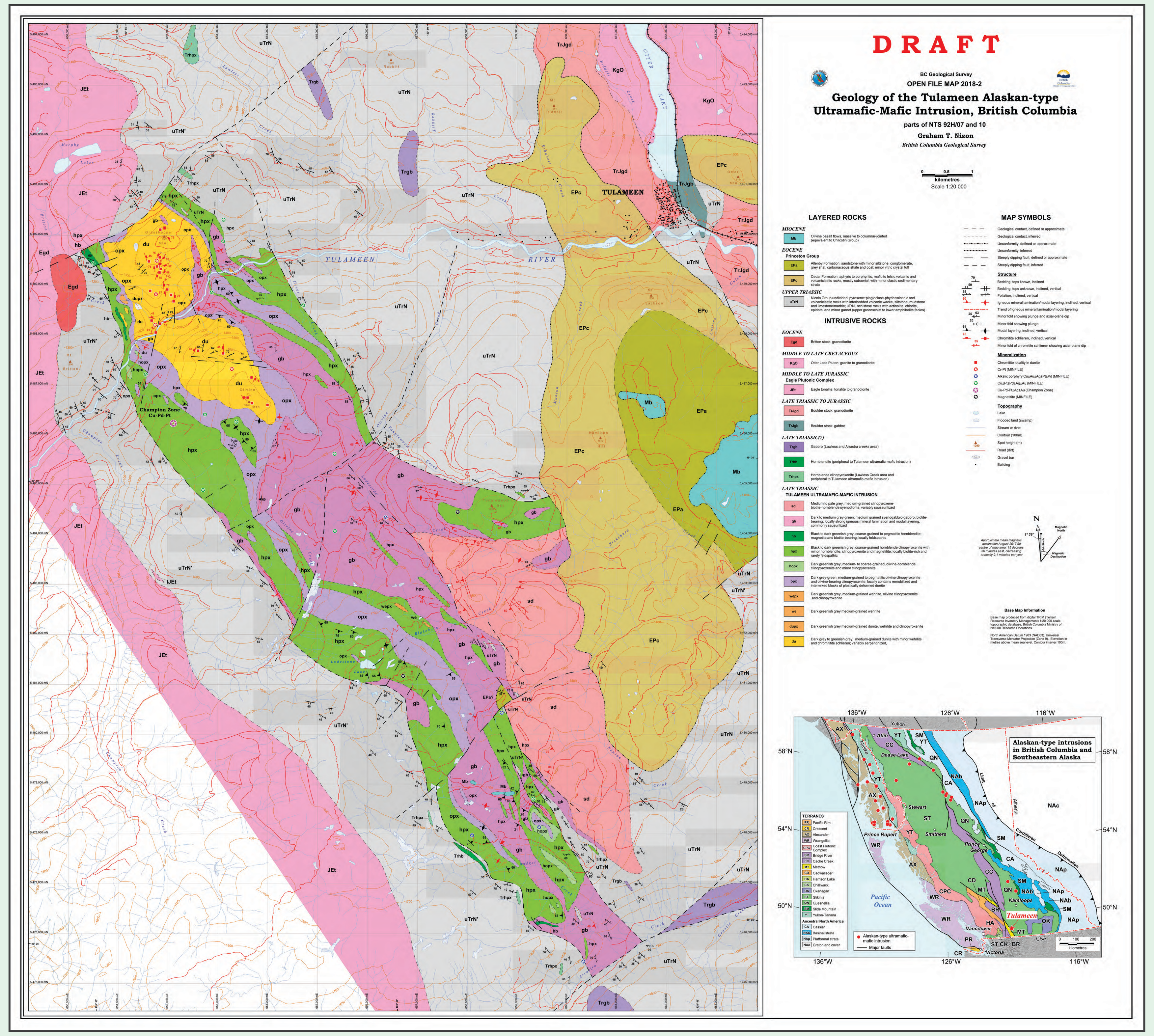
2) Interstitial sulphides

Chalcopyrite and less commonly bornite occur as interstitial primary sulphides. Sulphide grains typically show well-developed alteration rims of covellite/digenite. Fe oxides/hydroxides and malachite resulting from desulphurization and oxidation during weathering.



A) Magnetite hornblendite (plane-polarized light); Note the lack of alteration; B) Same view in reflected light showing interstitial chalcopyrite, bornite and magnetite; C) Bornite inclusions in chalcopyrite showing myrmekitic texture; D) Remnant grains of interstitial chalcopyrite with Fe-hydroxide rims in hornblende-magnetite clinopyroxenite; E) Interstitial chalcopyrite with Fe-hydroxide rim in magnetite hornblendite; F) Interstitial bornite grain in C showing fine chalcopyrite exsolution lamellae and well-developed covellite rim.

Geology of the Tulameen Ultramafic-Mafic Intrusion



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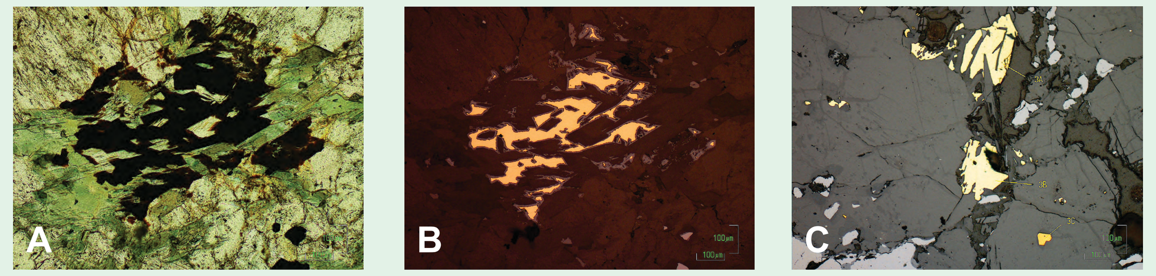
3) Recrystallized sulphides

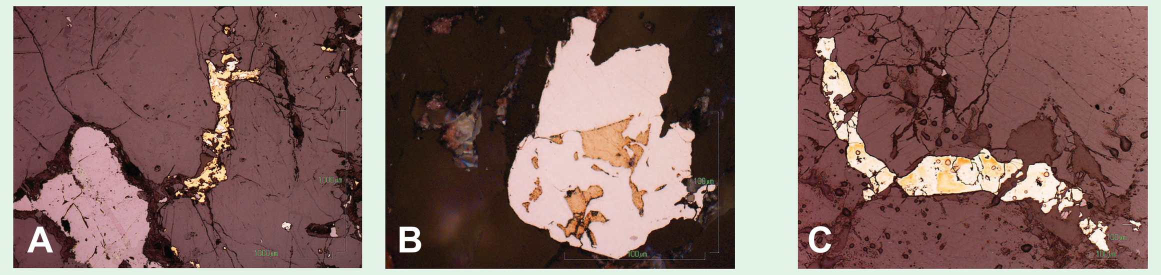
Interstitial sulphides, predominantly chalcopyrite, are locally recrystallized and intergrown with actinolite/actinolitic hornblende, epidote, chlorite and titanite due to upper greenschist to lower amphibolite facies metamorphism. Sulphide grains are typically angular due to control by secondary silicate grain boundaries. Sulphides are locally remobilized along microfractures and cleavage planes of primary silicates.



A) Interstitial chalcopyrite replaced by/intergrown with actinolite/actinolitic hornblende in hornblende clinopyroxenite (plane polarized light); B) Same view in reflected light; C) Acicular actinolite in interstitial chalcopyrite in magnetite hornblendite (note tarnished inclusion of chalcopyrite in hornblende, lower right).

4) Hydrothermal sulphides

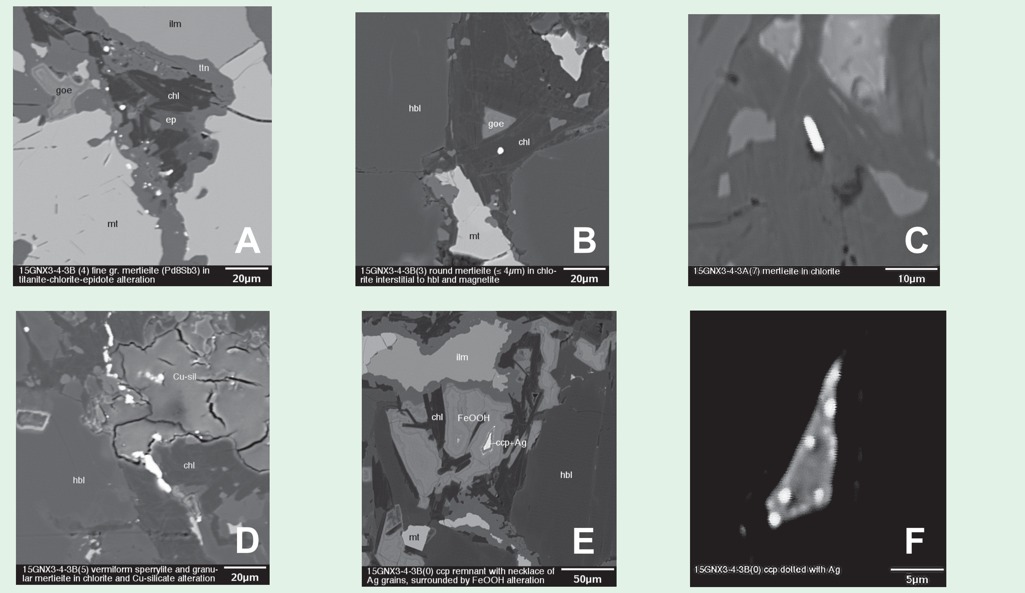
Pyrite occurs in fractures and veinlets and locally forms a more pervasive hydrothermal overprint replacing primary sulphides. Rarely, hydrothermal assemblages involve pyrite-chalcopyrite-pyrrhotite.



A) Pyrite (white) replacing interstitial chalcopyrite in hornblende-magnetite clinopyroxenite; B) Relict chalcopyrite in interstitial pyrite (white) in hornblende-magnetite clinopyroxenite; C) Interstitial pyrite containing ghost remnants of chalcopyrite in hornblende-magnetite clinopyroxenite.

Precious Metal Minerals

Platinum-group minerals include sperrylite ($PtAs_2$), mertieite [$Pd_8(Sb,As)_3$] and an unidentified Pd-Te-Sb mineral (or Pd-Te and Pd-Sb mixture). PGM grains are preferentially associated with secondary minerals (chlorite/epidote/actinolite) rather than base-metal sulphides. A silver mineral (AgS_2?) occurs in chalcopyrite.



SEM images: A) Fine-grained mertieite (white) in chlorite-epidote-titanite alteration; B) Mertieite grain in chlorite-goethite assemblage; C) Mertieite lath in chlorite; D) Vermiform sperrylite and granular mertieite grains in chlorite and Cu-silicate; E) Remnant grain of interstitial chalcopyrite in chlorite-Fe-hydroxide (magnetite hornblendite); F) Chalcopyrite grain in E showing necklace of Ag mineral (white dots).

LAYERED INTRUSION Cu-PGE REEFS

Key parameters for stratiform Cu-PGE reefs in selected layered intrusions from extensional tectonic settings are tabulated below. Host rocks are generally gabbroic and magnetite-rich and carry trace amounts of Cu-Fe sulphides. The reefs are characterized by anomalous to exceptionally high abundances of Pd and Pt with high Pd/Pt ratios. A resource estimate for the Platinova Reef is 23 Mt @ 2.3 g/t Au, 0.7 g/t Pd and 0.1 g/t Pt (contained metal 1.7 Moz Au, 0.5 Moz Pd and 0.04 Moz Pt) at a cut-off grade of 1.5 g/t equivalent Au.

In comparison, the Champion Zone exhibits similar low modal abundances of Cu-Fe sulphides, and preliminary assays reveal high Pt and Pd with Pd/Pt>1. Cu-PGE mineralization resides in an ultramafic host variably enriched in magnetite. The maximum PGE bulk rock abundances obtained to date (~1.9 g/t Pd+Pt) rank second highest to those in platiniferous chromitites in the dunite core of the Tulameen intrusion.

Cu-PGE Reefs in Layered Intrusions vs Champion Zone, Tulameen

Name	Age	Sulphides	maximum ppm Cu	maximum ppm Pd	maximum ppm Pt	Pd/Pt	Host Rock	Ref
Stella, S. Africa	3.0 Ga	Cp, Py	~100	7.6	7.3	~1	magnetitite	1
Nuasahi, India	3.1 Ga	Cp, Cc, Cv	826	3.3	0.24	6.7	magnetitite	2
Sonju, USA	1.1 Ga	Cp, Bn	700	0.36	0.07	~5.5	Fe-Ti oxide gabbro	3, 4
Coldwell, ON Geordie Lake	1.1 Ga	Cp, Bn	4000	0.59*	0.037*	~23	augite troctolite	5, 6
Coldwell, ON Marathon W Horizon	1.1 Ga	Cp, Bn, Pn, Po, Py, Mi	5600	45**	9**	<10	gabbro	5, 6
Rincon del Tigre, Bolivia	990 Ma	Cp, Bn, Cc, Cv, Py	~100	1.8	0.68	~2.6	magnetite gabbro	7
Skaergaard, Platinova Reef (Pd zone)	55 Ma	Bn, Cp, Dg	300	1-4	0.3	200	gabbro	8
Tulameen, BC Champion Zone	204-206 Ma	Cp, Bn, Py, rare Po	5200	1.15	0.79	~1.5	Mt-Hb clinopyroxenite; Mt hornblendite	This study

* average metal abundance for composite samples ** Conservative values; maximum abundances reported: 67 ppm Pd and 39 ppm Pt over 2m; Abbreviations: Cp, chalcopyrite; Bn, bornite; Cc, chalcocite; Cv, covellite; Py, pyrite; Po, pyrrhotite; Pn, pentlandite; Mi, millerite; Dg, digenite; Mt, magnetite; Hb, hornblende
References: 1) Maier et al. (2003); 2) Prichard et al. (2017); 3) Miller (1999); 4) Li et al. (2008); 5) Good et al. (2017); 6) Ames et al. (2017); 7) Prendergast (2000); 8) Holwell and Keays (2014)

IMPLICATIONS FOR EXPLORATION

The Cordillera of western North America hosts a significant number of ultramafic-mafic intrusions some of which are spatially associated with Cu mineralization. A new mineral deposit model for orthomagmatic Cu-PGE±Au±Ag sulphide mineralization hosted by such intrusions in convergent margin settings like the Canadian Cordillera will aid in discovering and evaluating new exploration targets.

A number of factors present significant challenges for exploration:

◆ unlike layered intrusions, there is no internal stratigraphy to guide target selection and evaluation of lateral continuity

◆ the thickness of mineralized zones may vary from tens of centimetres to tens of metres and intensive sampling is required

◆ mineralization typically occurs in minor to trace amounts and PGE enrichment may be highly variable thereby requiring careful analysis

◆ the Cu-rich sulphides (chalcopyrite, bornite) are also common to Cu porphyry systems and where remobilized may pose as vestiges of porphyry mineralization