# Mineralization of the Escape PGE-Ni-Cu sulfide deposit, Thunder Bay North Igneous Complex, Northwestern Ontario

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## I. Introduction and Geologic Background

- The 1.1 Ga Midcontinent Rift System (MRS) preserves abundant extrusive and intrusive magmatism formed during the failed attempt to break apart the North American craton. MRS rocks are located around the Lake Superior region, with several mafic–ultramafic intrusions host to orthomagmatic Ni–Cu–PGE mineralization (Fig. 1A; Woodruff et al., 2020).
- The Thunder Bay North Igneous Complex (TBNIC) comprises a series of related mafic–ultramafic intrusions, some of which contain abundant Ni–Cu–PGE mineralization (Fig. 1B). The complex is located ~40 km northeast of Thunder Bay, Ontario, within the Archean Quetico Basin of the Superior Province.
- The TBNIC has been dated to 1106.6 ± 1.6 Ma (Bleeker et al., 2020) placing it within the Plateau Stage of MRS development.
- The complex is situated between the E–W-trending Quetico and Escape faults, and consists of the Current, Escape, Lone Island, and East–West Connector intrusions (Fig. 1B).
- Country rocks include pelitic to psammitic metasedimentary schists and foliated granitoids (ranging from tonalite to granite).
- Lithostratigraphy of the TBNIC intrusions includes an upper hematized, silica inclusion-rich gabbroic unit (i.e., the Hybrid), a middle, volumetrically minor gabbro to olivine clinopyroxenite unit, followed by the mineralized ultramafic unit.
- The Escape Intrusion of the TBNIC is a mineralized chonolith that contains economic concentrations of orthomagmatic sulfides.
- This project focuses on evaluating the effect of contamination on the Escape parental magma and the extent of enrichment of the sulfide ores in order to contribute to a genetic model of the mineralizing system.

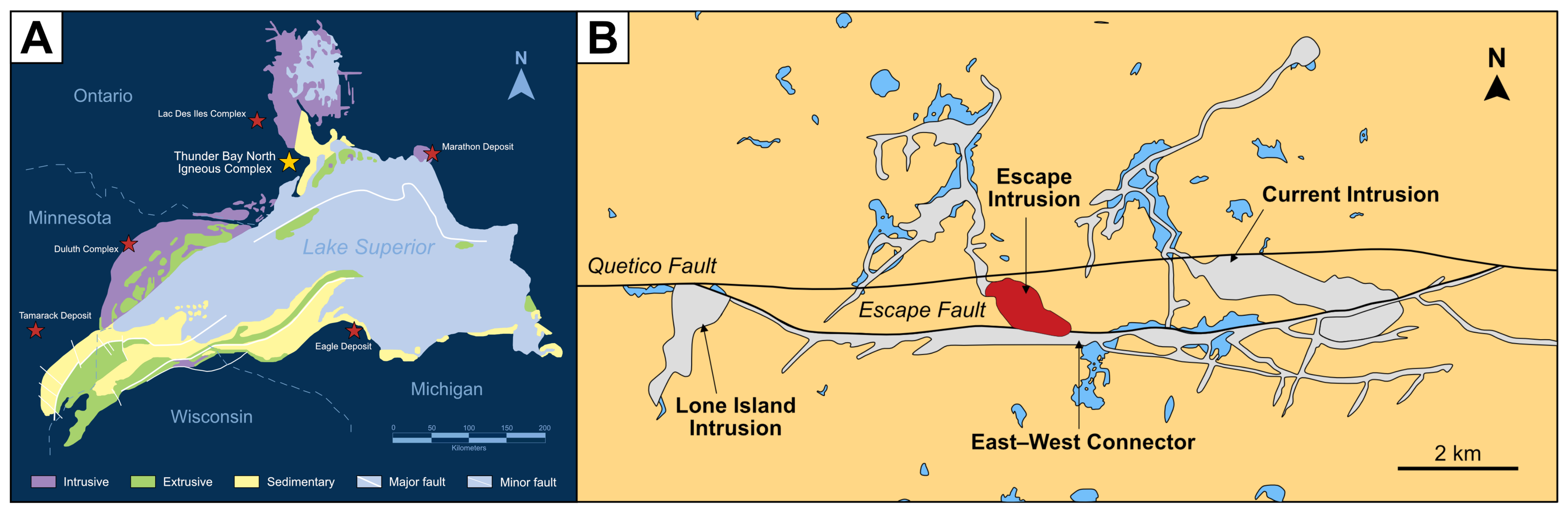


**Figure 1**: **A**: Simplified geologic map of the Midcontinent Rift System rocks around the Lake Superior region with various other mineralized intrusive deposits marked, as well as this project's study area.
**B**: Simplified map of the Thunder Bay North Igneous Complex. Outlines are drawn from a combination of drillhole intercepts and interpreted geophysical signatures. Grey = intrusive complex, red = study/sample area, beige = country rocks, blue = lakes.

## II. Petrographic Characterization

- Samples taken from within and around the Escape deposit high-grade zone are mafic–ultramafic in composition and constitute a spectrum from wehrlite, to feldspathic wehrlite, to melanocratic gabbro.
- Samples exhibit a poikilitic texture with subhedral to euhedral cumulus olivine, oikocrystic clinopyroxene, and intercumulus plagioclase (Fig. 2A,D).
- The extent and mineralogy of alteration is variable, ranging from fresh (unaltered) to pervasive.
- Common alteration includes serpentinized olivine, sericitized plagioclase, and interstitial chlorite.
- Primary sulfide mineralization is disseminated to net-textured, and consists of pyrrhotite, pentlandite, and chalcopyrite (fine-grained platinum-group minerals (PGMs) are associated with sulfides; Fig. 2B,C).
- Lesser, and possibly secondary, mineralization comprises sulfides occurring as blebs and veinlets, the mineralogy of which is similar to the primary assemblage, but occurs as complex intergrowths. (Fig. 2E).
- Where alteration is extensive and coincides with disseminated mineralization, the sulfide assemblage is often altered, with native copper occurring locally (Fig. 2F).

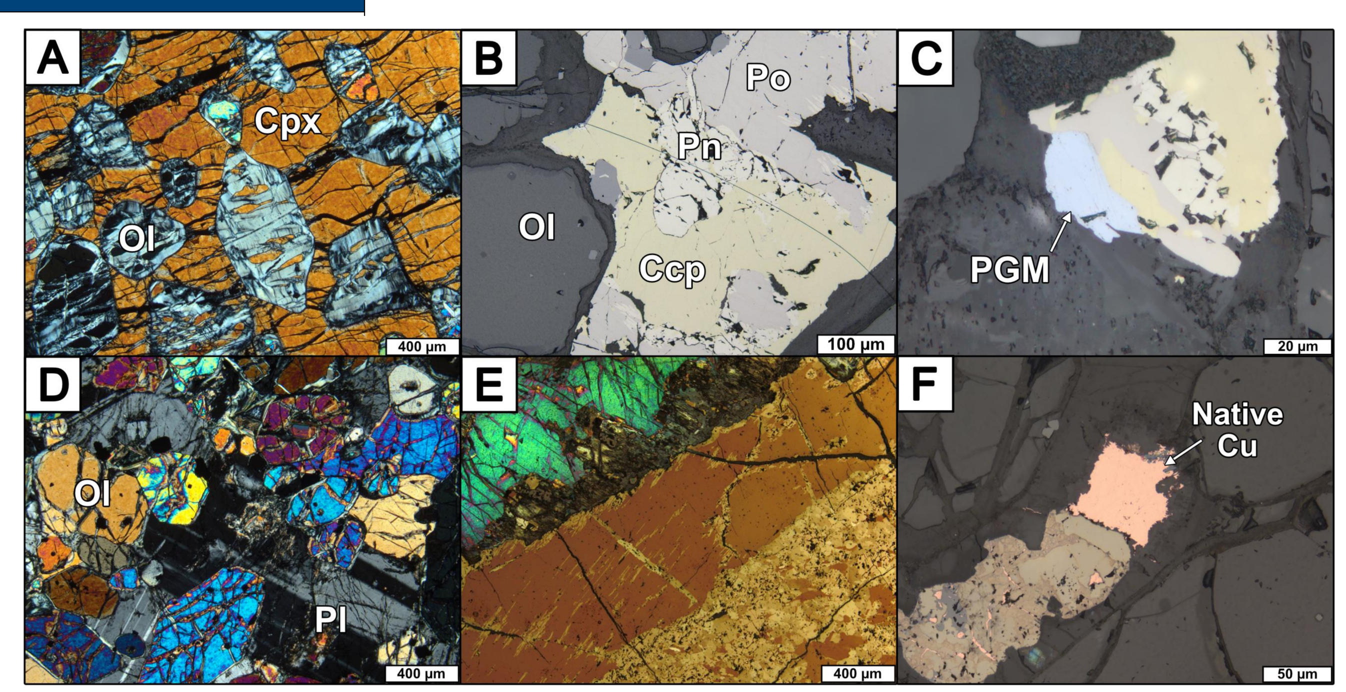


**Figure 2**: **A**: serpentinized olivine chadacrysts within clinopyroxene oikocryst from diamond drillhole ELR20-002; transmitted XPL.
**B**: net-textured sulfide mineralization from diamond drillhole ELR20-002; reflected PPL.
**C**: net-textured sulfide mineralization and associated PGM from diamond drillhole 11CL0005; reflected PPL.
**D**: cumulus olivine with interstitial, weakly sericitized plagioclase in feldspathic wehrlite from diamond drillhole ELR20-018; transmitted XPL.
**E**: margin of sulfide veinlet with mosaic sulfide textures from diamond drillhole ELR20-011; reflected XPL.
**F**: native copper grain associated with disseminated sulfide assemblage from diamond drillhole ELR20-004; reflected PPL.

## III. Melt Source and Contamination

- On a primitive mantle-normalized extended trace-element diagram, the pattern for Escape rocks resembles an ocean island basalt (OIB), consistent with a plume mantle source (Fig. 3).
- The Escape pattern is similar to other MRS-associated Ni–Cu–PGE mineralized mafic–ultramafic intrusions, such as the Disraeli, Hele, Kitto, and Seagull intrusions.
- Given that contamination of the parental magma may lead to the formation of immiscible sulfide liquid (e.g. due to addition of external S or silica) it is necessary to investigate whether this process occurred at Escape.
- As is common for Archean Quetico rocks, the country rocks to the Escape Intrusion display pronounced Th enrichment and Nb depletion.
- These anomalies are not reflected in the Escape mafic-ultramafic rocks, which supports the interpretation that the Escape magma(s) did not assimilate significant quantities of the surrounding metasedimentary rocks.

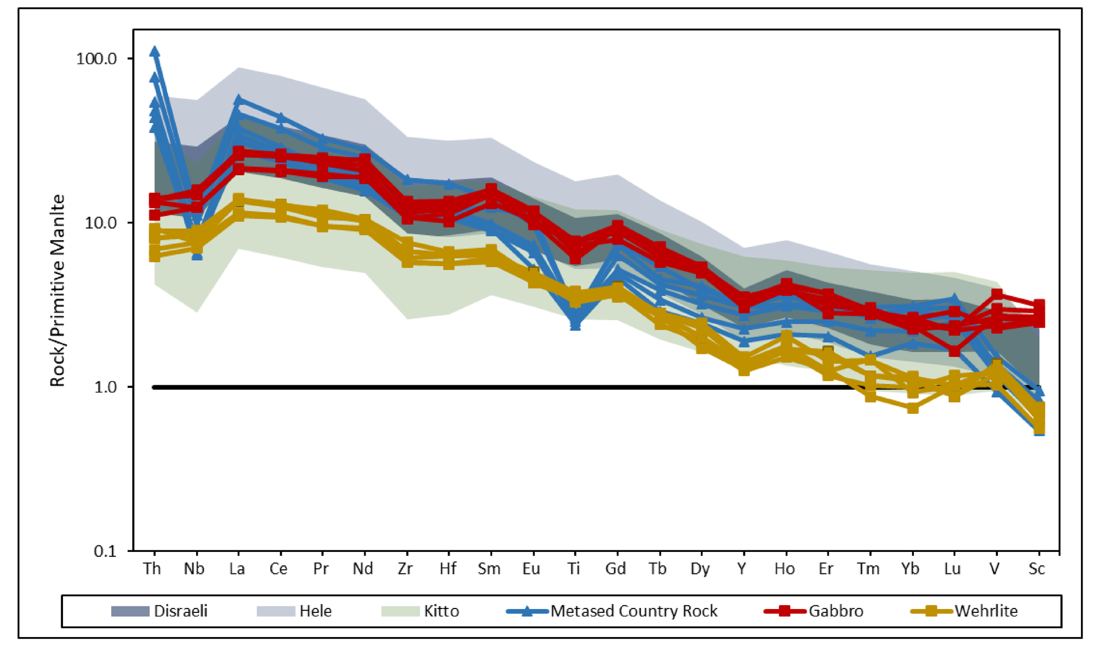


**Figure 3**: Primitive mantle–normalized extended trace-element diagram illustrating a gently sloping negative pattern for Escape rocks that are similar to OIBs. For each rock type sample population is n=6. MRS intrusion field data from Cundari et al. (2021).

## IV. Sulfide Mineral Chemistry

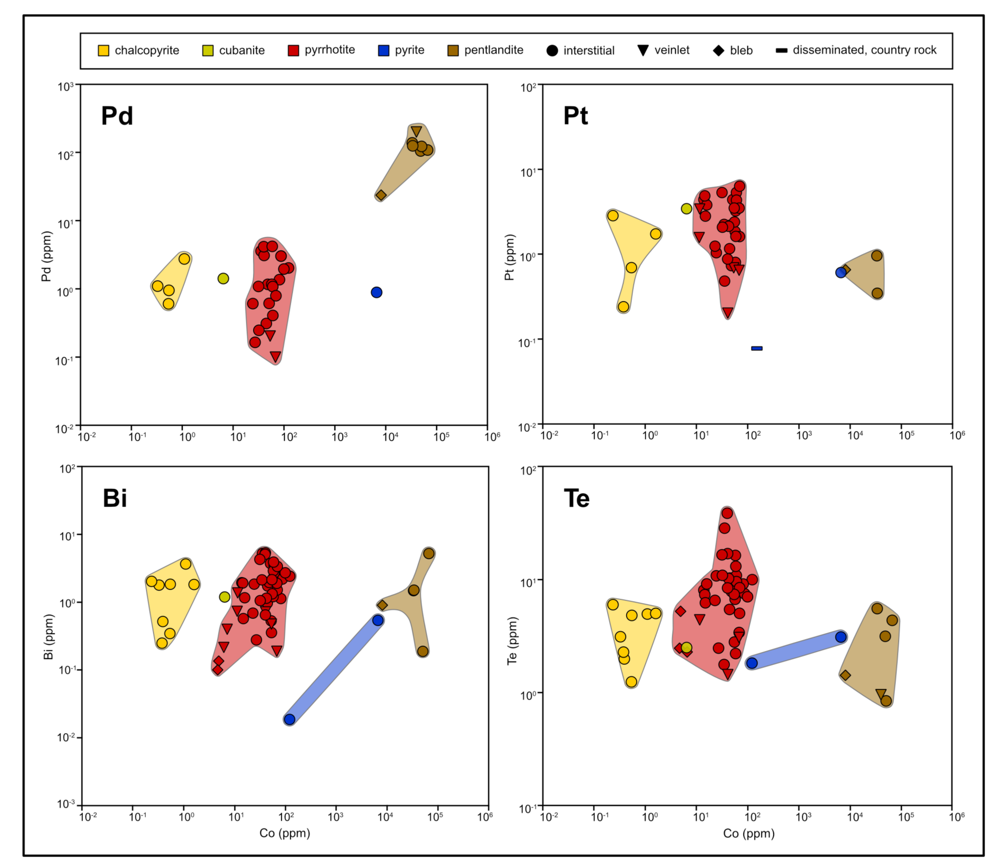


**Figure 4**: Binary plots of Co versus selected platinum-group elements and semi-metals. Concentrations are from areas within sulfide grains, with ablation lines excluding PGMs. Fields have been drawn around sulfide mineral data clusters.

- Using laser-ablation inductively coupled plasma mass spectrometry, mineral chemistry was obtained from selected sulfide phases for each mineralization style (i.e., interstitial, blebs, and veinlets).
- Pentlandite is enriched in palladium owing to the metal's preferential incorporation into the mineral's crystal lattice (Fig. 4).
- The concentration of platinum is consistently low amongst the sulfides, corresponding to the fact that the metal likely occurs as PGMs.
- The concentrations of semi-metals Bi and Te are consistently low within the sulfides; this, in conjunction with the low Pt concentration, is supportive of the occurrence of Pt as PGM.

## V. Metal Enrichment

- In Pd vs. Cu/Pd space, most sulfide mineralization at Escape plots within the range of mantle values with moderate R factors between ~1000 to 10000 (with most in the range of ~7000) (Fig. 5).
- The modeled values are lower than other world class PGE–Cu–Ni deposits, such as Norilsk, Marathon, and Jinchuan.
- These values indicate that the Escape system was not as dynamic compared to those world class systems (sulfides underwent relatively less interaction with silicate magma during deposit formation).
- When the concentration of Se from sulfides is compared to whole-rock data in S/Se vs. Cu/Pd space, the data also plot within the range of mantle values, and R factors between 1,000 and 10,000.
- Given the petrographic observations and numerical modelling, it is likely that the Escape deposit experienced moderate degrees of metal upgrading (when compared to economic deposits of the same class).
- In particular, it is possible that the parental magma and, more importantly, the segregated sulfide liquid at Escape interacted with multiple pulses of fractionated magmas (or crystal mushes); this is evidenced by the irregular modal layering of plagioclase throughout the intrusion.

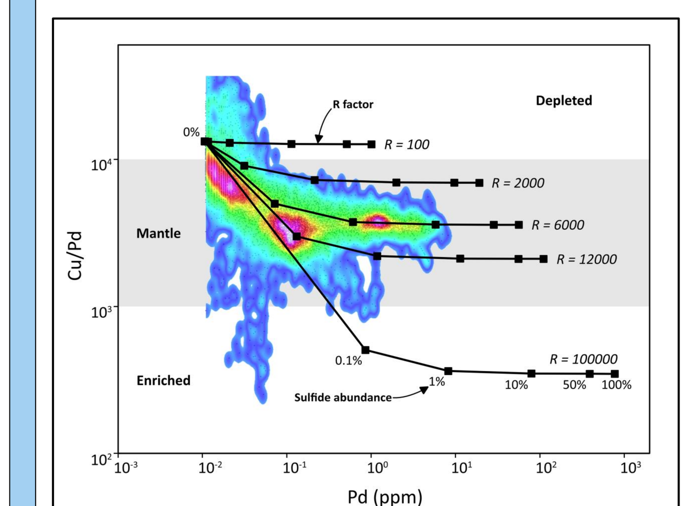


**Figure 5**: Binary diagram illustrating the variation in Pd and Cu/Pd of sulfide mineralization at Escape. Data is plotted as a point density cloud with warmer colours indicating a higher concentration of data. Overlain are model curves illustrating the approximate R factor experience by the sulfide liquid. Percentages indicate the % sulfide in the rock. Starting model values are 136 ppm Cu and 0.01 ppm Pd, which are calculated TBNIC parental magma values reported by Heggie (2012). Filter cut-off (Pd > 0.01 ppm).

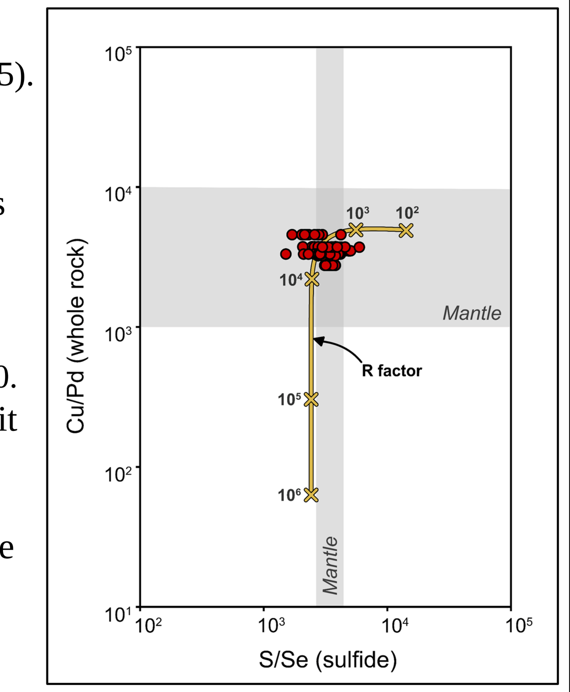


**Figure 6**: Binary diagram illustrating the S/Se values of sulfides and whole-rock Cu/Pd values of their corresponding host rocks from Escape. The gray fields represent the range of mantle values for Cu/Pd (1,000-10,000) and S/Se (2,632-4,350). The gold curve represents the modelled variation in Cu/Pd and S/Se as a function of variations in R factor. Similar starting model values used as the previous plot.

## VI. Conclusions and Further Work

- The Escape intrusion magma is interpreted to have formed from a mantle plume source.
- Palladium is commonly hosted within pentlandite, while platinum is interpreted to be present as discrete PGM. Mineral liberation analysis will be conducted to characterize these PGMs at Escape.
- R factor modelling of both whole-rock and mineral chemistry indicates moderate upgrading of ore and no apparent loss of sulfide liquid.
- The degree of contamination of the magma is inconclusive at this time; this will be assessed further using multiple sulfur isotopes.
- $\Delta^{33}S$ signatures for Archean and Paleoproterozoic country rocks will be compared to those measured at Escape to assess the input of external S in the S saturation history of the deposit.
- All results will be integrated into a coherent framework for the processes that led to the formation of the Escape deposit, and will contribute to a greater understanding of the TBNIC mineralized system.
- Continued petrographic investigation of the different styles of sulfide mineralization will be completed to further characterize the textural relationships of the primary and altered sulfide assemblages.
- Follow up LA–ICP–MS analyses will be completed on key textural assemblages to assess whether hydrothermal alteration affected the mobility and concentration of metals in the system.

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## VIII. References

- Barnes, S.J, Cruden A.R., Arndt, N., and Saumur, B.M., 2015. Ore Geology Reviews, 76: 296-316.
- Bleeker, W., Smith, J., Hamilton, M., Kamo, S., Liikane, D., Hollings, P., Cundari, R., Easton, M., and Davis, D., 2020. Geological Survey of Canada, Open File 8722.
- Cundari, R.M., Puumala, M.A., Smyk, M.C. and Hollings, P. 2021. Ontario Geological Survey, Miscellaneous Release—Data 308 – Revised.
- Heggie, 2012. Magma Metals Inc., Internal Report.
- Naldrett, A.J., 2004. Germany: Springer Berlin Heidelberg.
- Woodruff, L.G., Schulz, K.J., Nicholson, S.W., and Dicken, C.L., 2020. Ore Geology Reviews, 126: 103716.