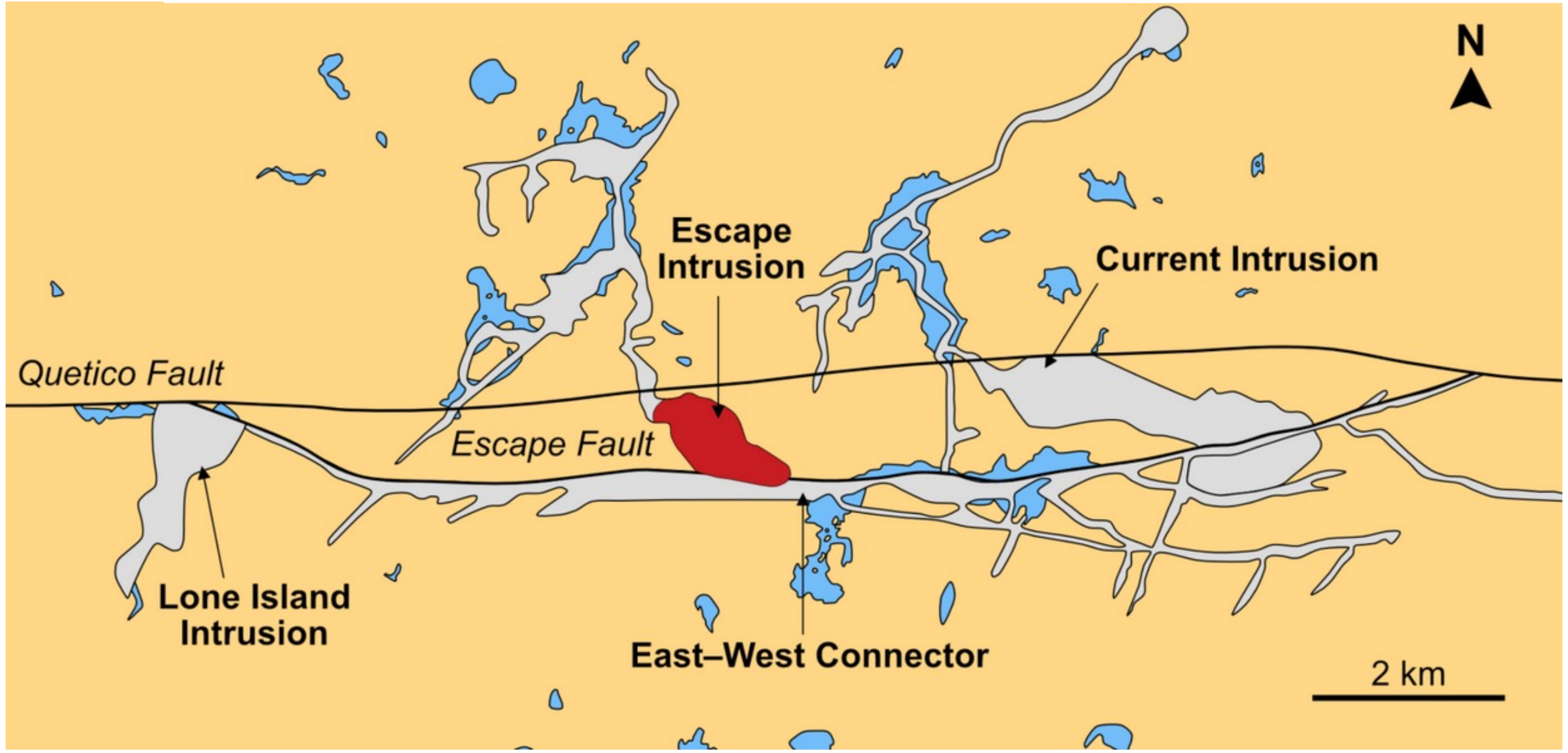
Magmatic and hydrothermal evolution of the PGE-Cu-Ni Current Deposit

Corredor, A.P., Hollings, P., Brzozowski, M., and Heggie, G.

Thunder Bay North Intrusive Complex

- Several **mineralized and non-mineralized** mafic-ultramafic intrusions [1] that **intruded the Quetico Basin** in the **early stages of the of the MRS** (Period of extension of the lithosphere with a massive magmatism; [2,3])

- Clean Air Metals is the current owner of the Thunder Bay North Project.

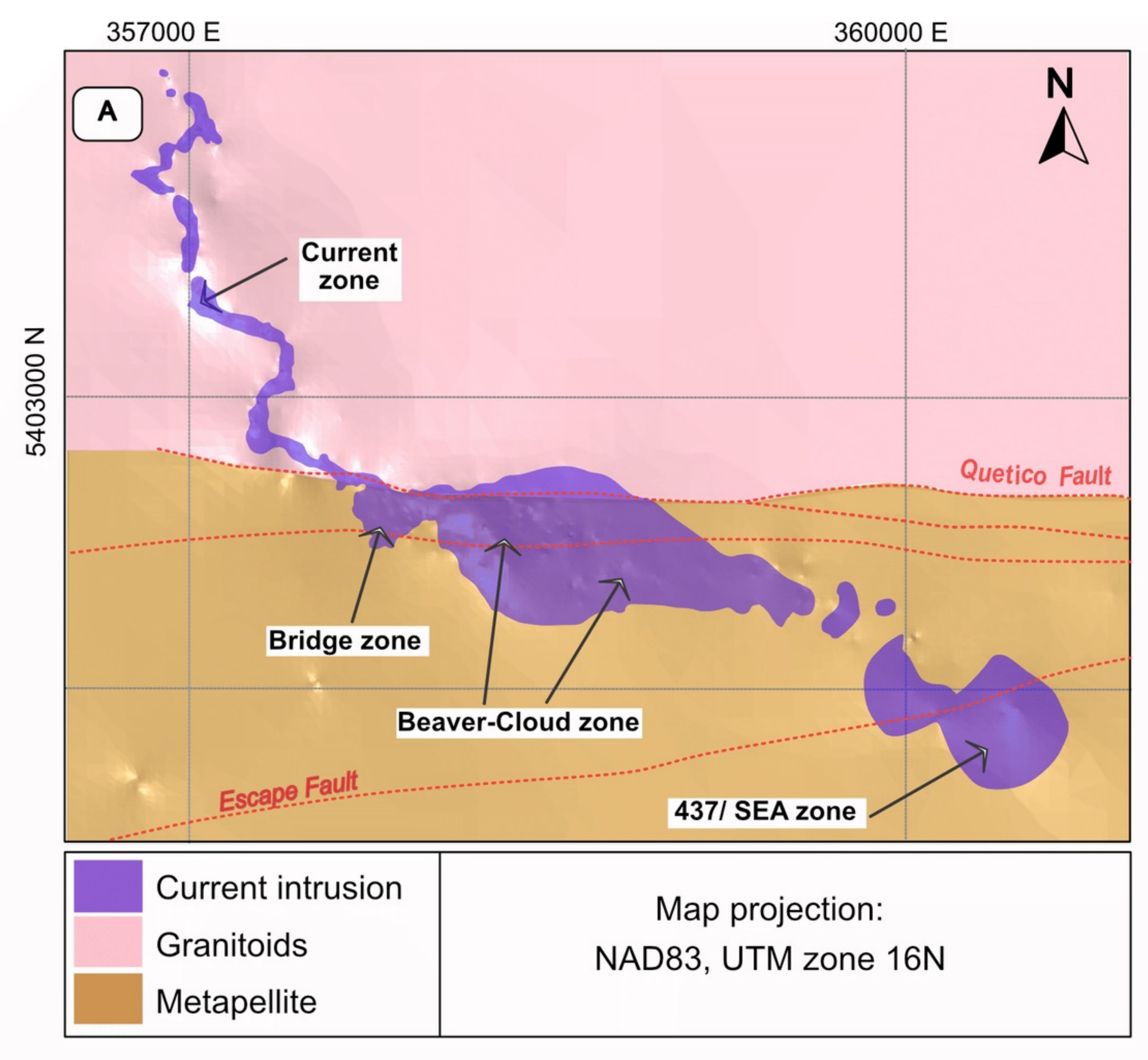


Thunder Bay North Project map [4]

[1] Bleeker et al. (2020)
[2] Woodruff et al. (2020)
[3]Hinze & Chandler (2020)
[4] Caglioti , 2022

Current Intrusion

- The 1,106.6 ± 1.6 Ma intrusion **hosts PGE-Cu-Ni mineralization** [1].
- The intrusion is associated with multiple **faults of the Quetico system** [5].
- Inferred mineral resource of 1.6 million tonnes, grading 0.32% Cu, 0.20% Ni, and 1.7 g/t Pt+Pd [7].

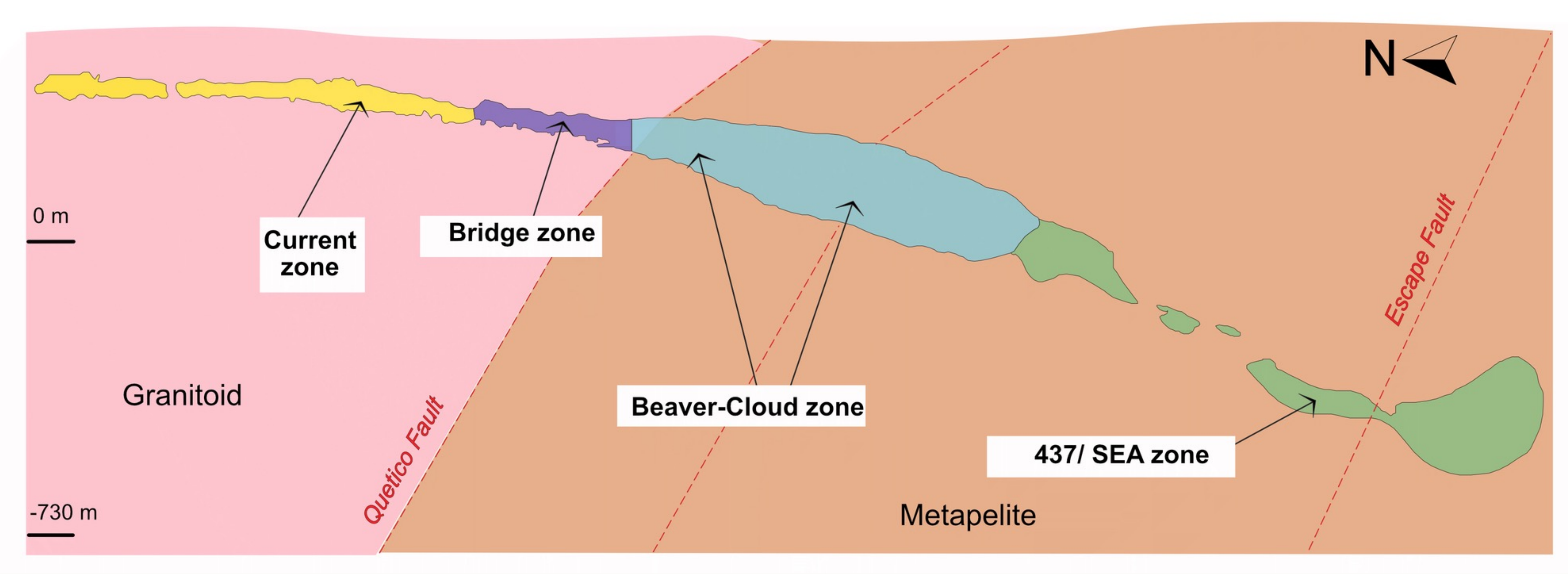


Current intrusion map [6]

[1] Bleeker et al. (2020)
[5] Williams (1991)
[6] Modified after Nordmin Engineering Ltd (2021)
[7] Clean Air Metals Inc, 2023

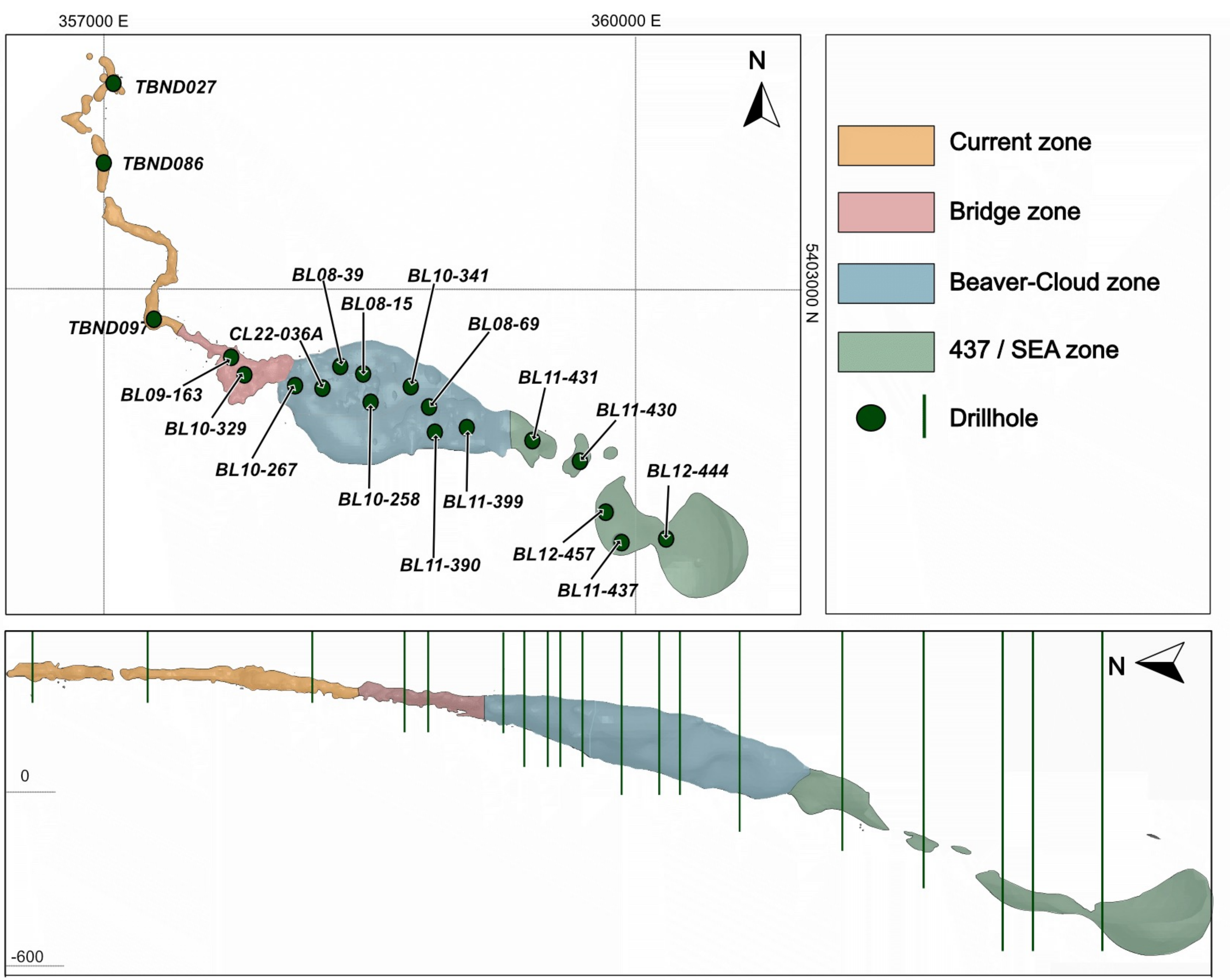
Current Intrusion

- Current intrusive is divided into: **Current zone, Bridge zone**, **Beaver–Cloud zone**, and **437 SEA zone** [8].



Current intrusion map

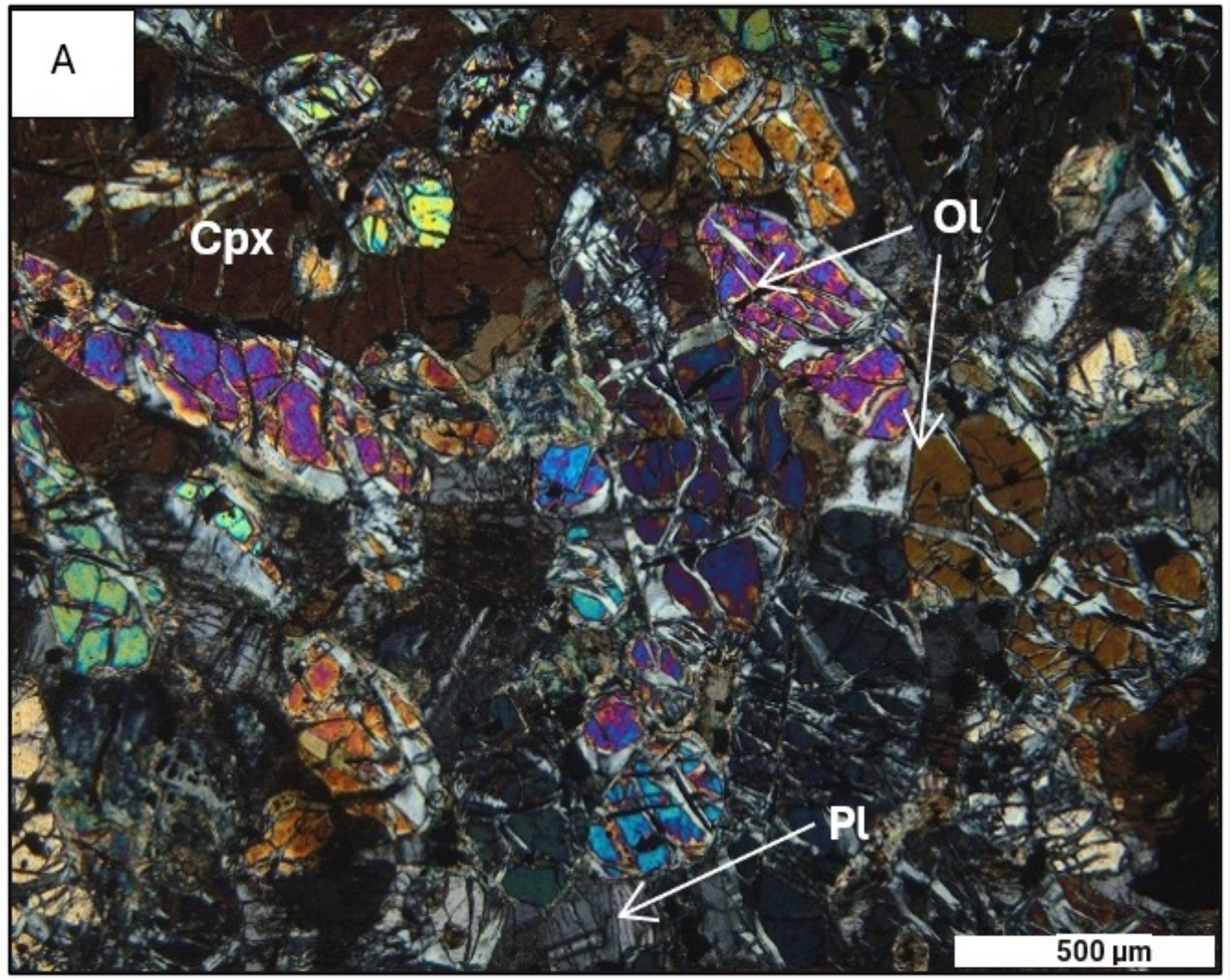
[8] Brzozowski et al. (2023)



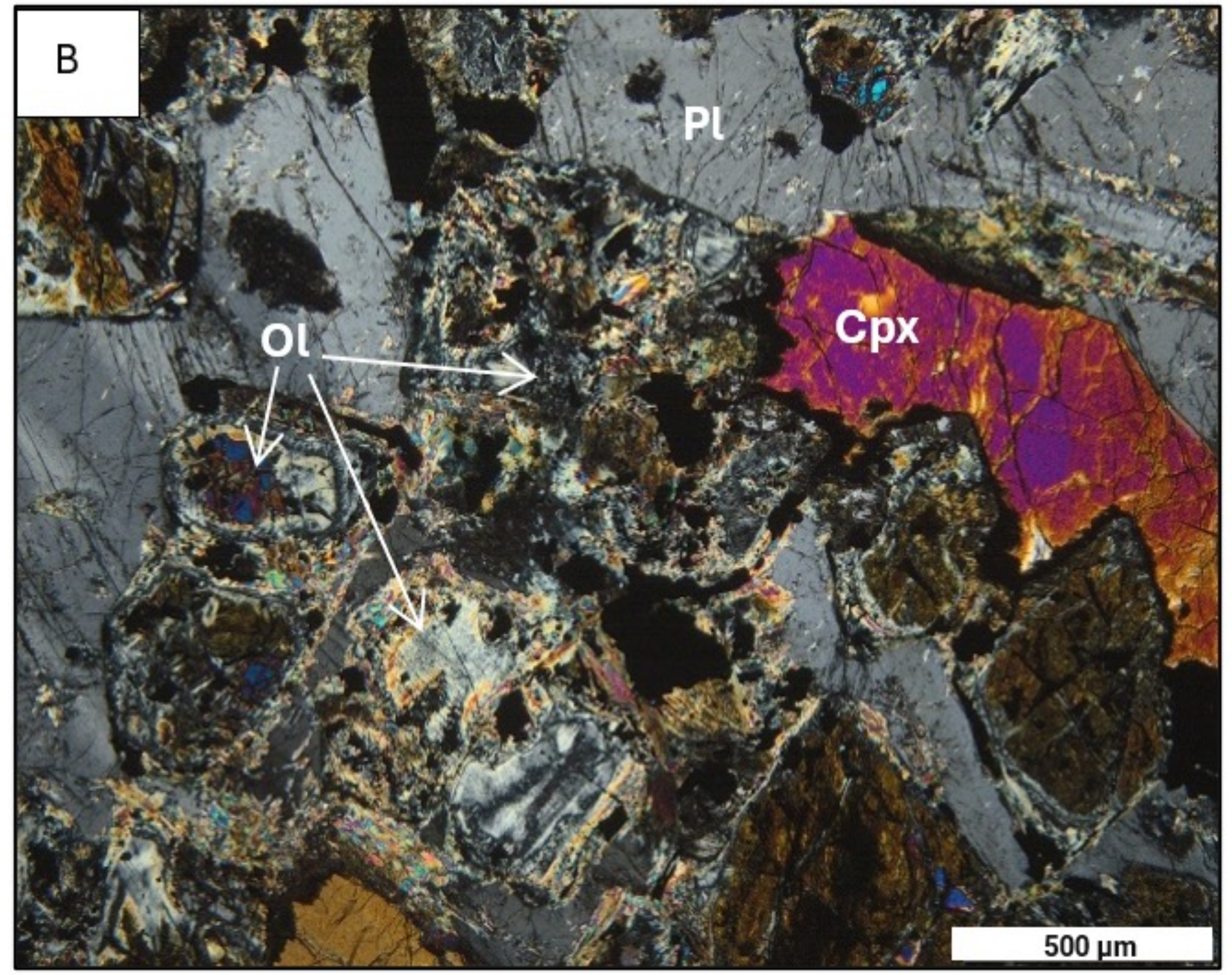
Sampling

- **Nineteen selected drillholes:**
  - **Thirty-six samples** for **petrographic examination** and **SEM-EDS.**
  - **Fifty-three samples** for **geochemical** studies.
  - **Thirty-eight samples** for **stable isotope analysis.**
  - **Ten samples** for **radiogenic neodymium and strontium isotope** analysis.

Petrography



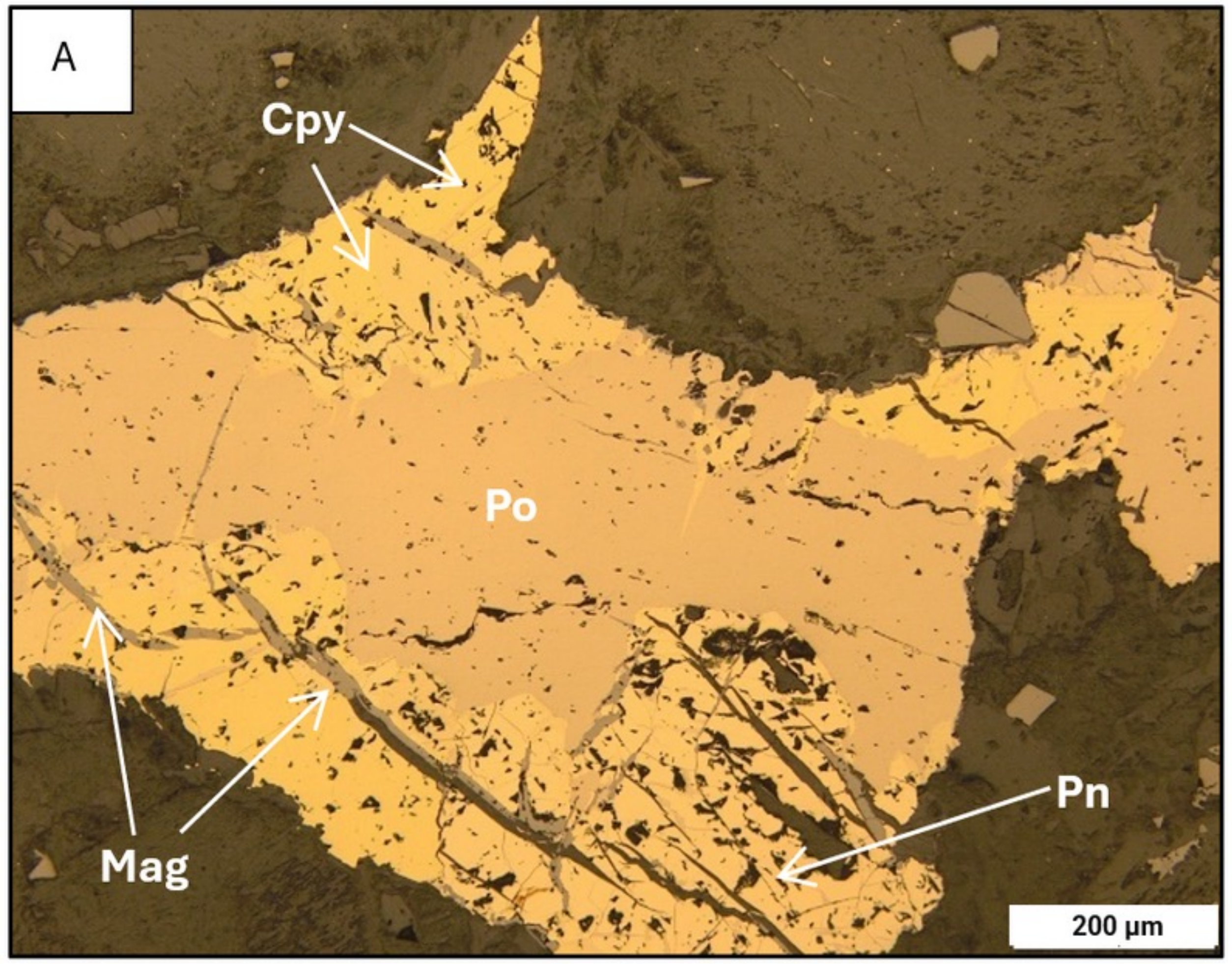
- **Fine-medium grained wehrlite and lherzolite**: 40-70% olivine, 0-3% orthopyroxene, 5-25% clinopyroxene, and 5-15% plagioclase.



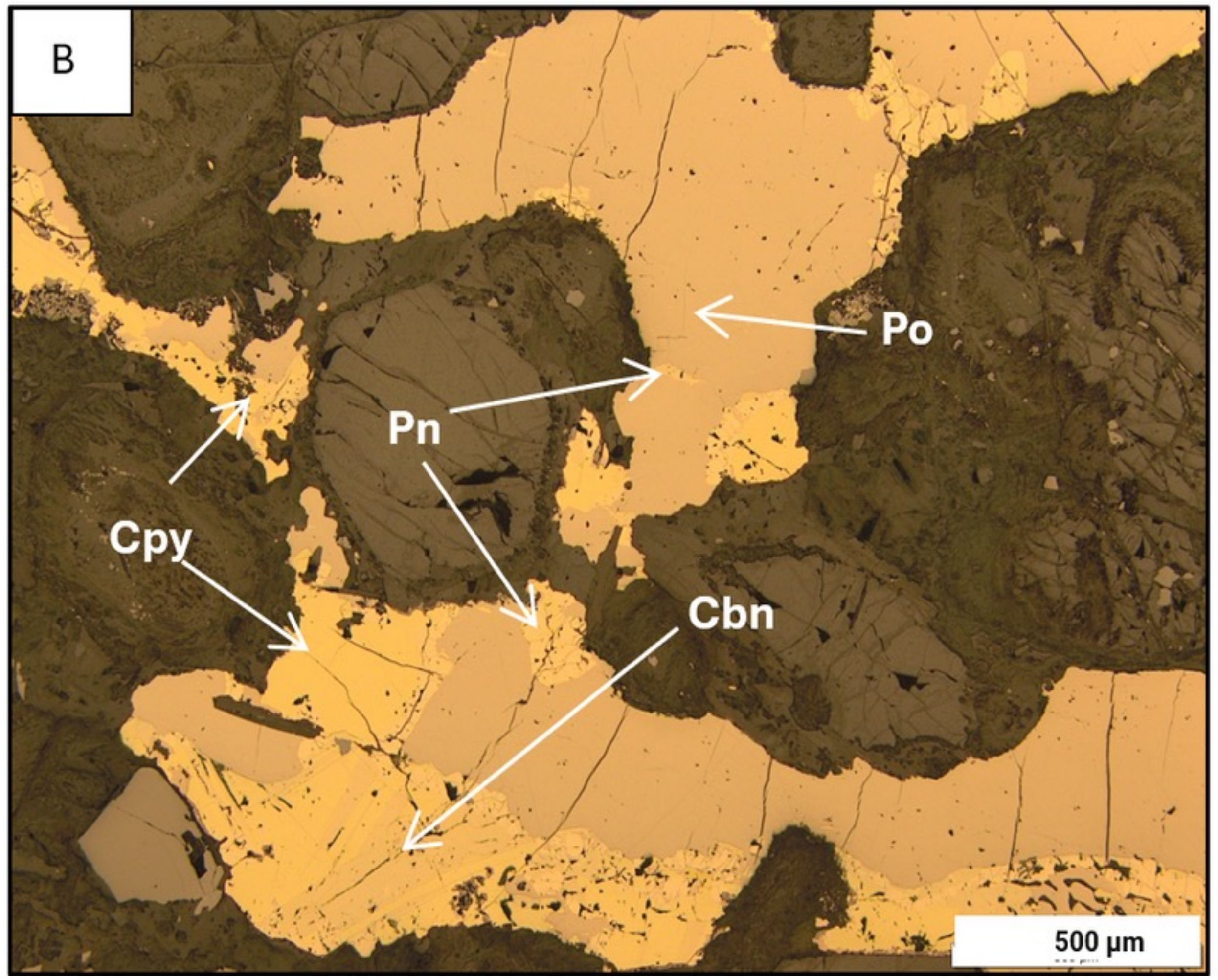
- **Fine- medium grained olivine gabbronorite ± troctolite**: 40-55% plagioclase, 35-45% olivine, and 5-10% pyroxene.

Petrography

Sulfides 0- 9%, averaging 50% pyrrhotite, 40% chalcopyrite, and 9% pentlandite, 1% cubanite.



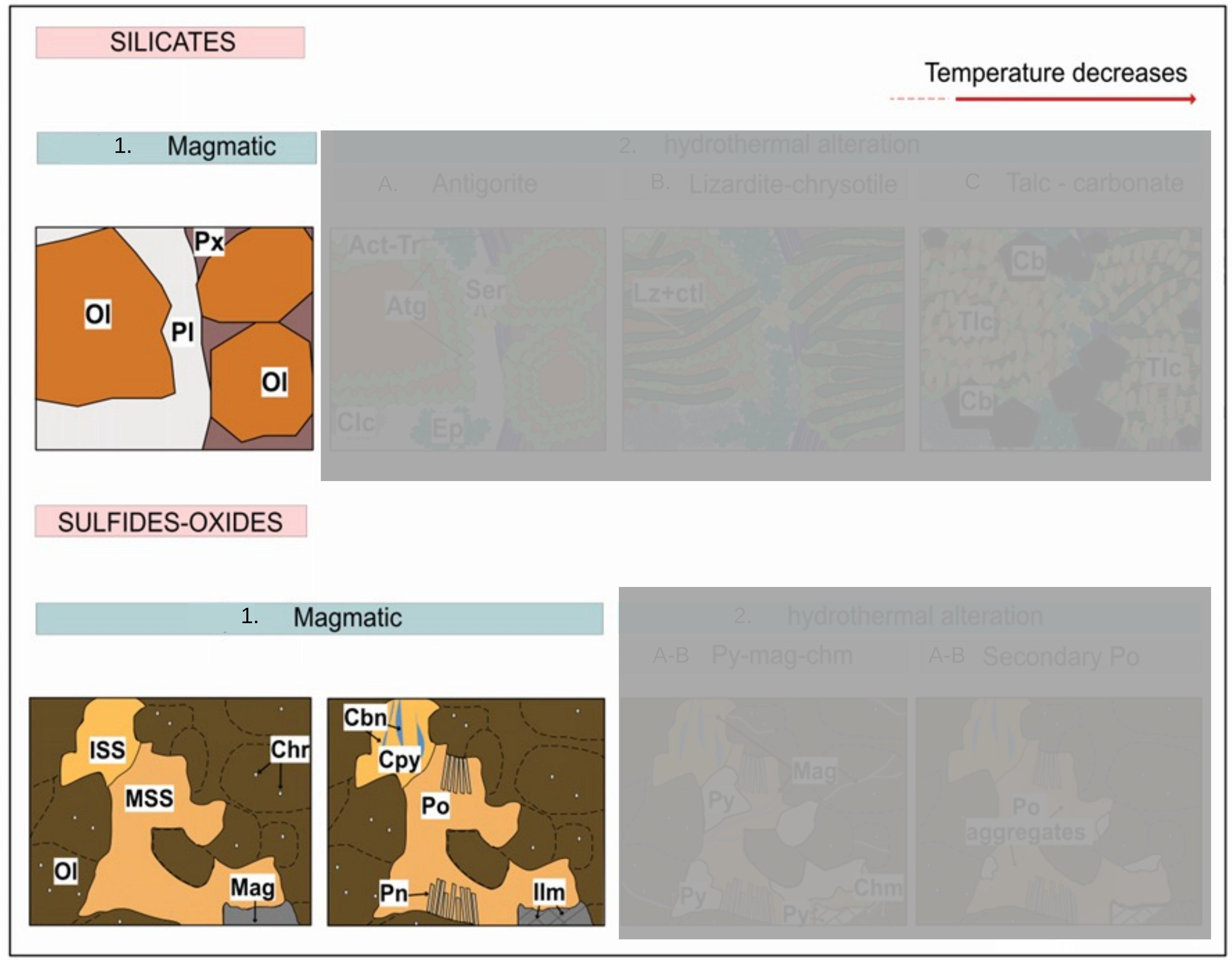
Fine-to-medium-grained pyrrhotite, fine-grained chalcopyrite, and fine-grained pentlandite. Pentlandite and chalcopyrite are weakly altered by magnetite.



Medium-grained pyrrhotite with very fine-grained pentlandite exsolutions. Medium-grained chalcopyrite with fine-grained cubanite exsolutions.

Paragenetic Sequence

Magmatic Phase



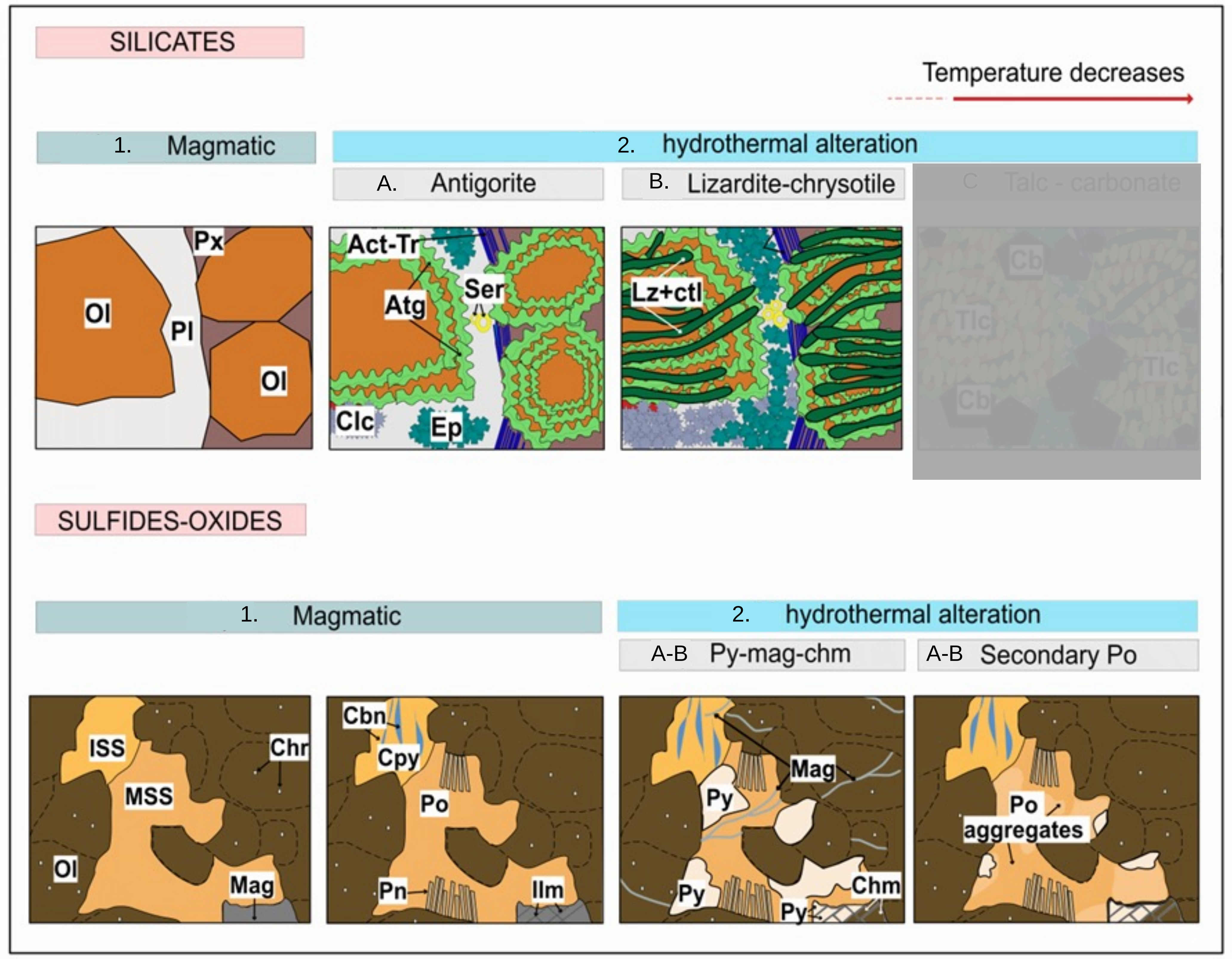
- **Early formation of olivine** phenocrysts enclosing **Cr-spinel** crystals, suggesting that the chromite crystallized before the olivine.

- **As the temperature** of the magmatic system **decreased**, oikocrysts of **pyroxene** enclosed the olivine crystals, with subhedral **plagioclase** subsequently filling the remaining interstices.

- **Oxides** and sulfides are interstitial to the mafic silicates, indicating **crystallization subsequent** to the olivine and pyroxene

Paragenetic Sequence

Hydrothermal Phase



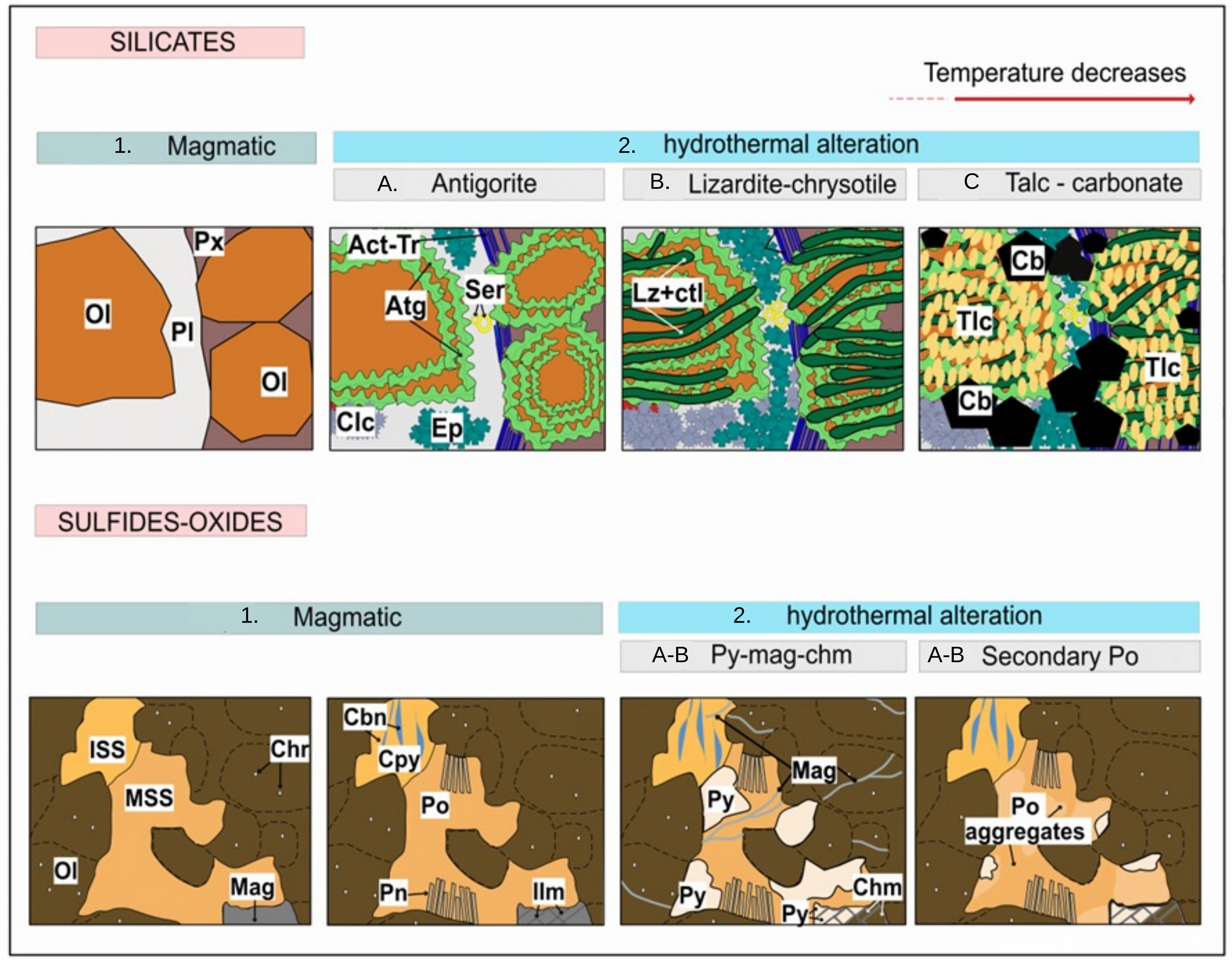
- **Domain A** is characterized by **antigorite,** actinolite-tremolite, clinochlore, epidote, sericite, pyrite, millerite, secondary pyrrhotite, chamosite, and secondary magnetite. Formed by **>300°C fluids ;** [10,11,12]) with **acidic pH** [13, 14].

- **Domain B** consists of **lizardite-chrysotile** and an increase in the modal abundances of clinochlore, epidote, sericite, pyrite, millerite, and secondary magnetite compared to Domain A. Formed by **<300°C fluids** [10,11,12) with **acidic pH** [13, 14].

[10] Evans (2004)
[11] Lagat (2009)
[12] Welch and Marshall (2015)
[13] O'Hanley (1996)
[14] Fulignati (2020)

Paragenetic Sequence

Hydrothermal Phase

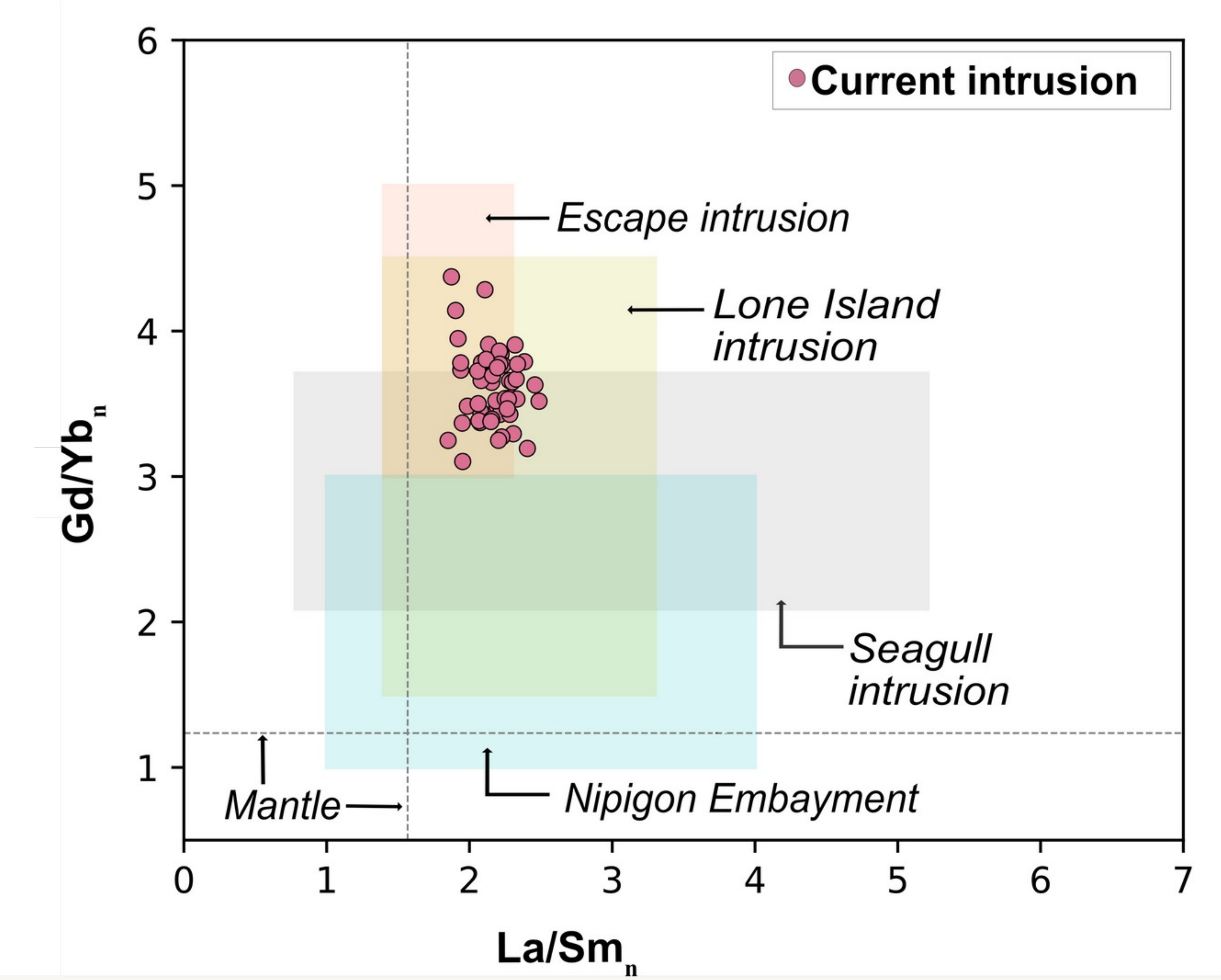


- **Domain C** comprises **talc and carbonate** minerals that have replaced the secondary minerals present in Domains A and B. Associated with **later fluids below 50°C** [15,16], **crystallizing under basic pH conditions** [17].

[15] Barnes et al. (1973)
[16] Kelemen and Matter (2008)
[17] Chaliulina (2019)

Magmatic Signature

Whole-Rock Geochemistry



Chondrite-normalized, whole-rock-trace variation for Current intrusion. Nipigon Embayment, Escape, Lone Island, and Seagull intrusion [12,29,35,36,37]. Mantle values and normalizing values from [33].

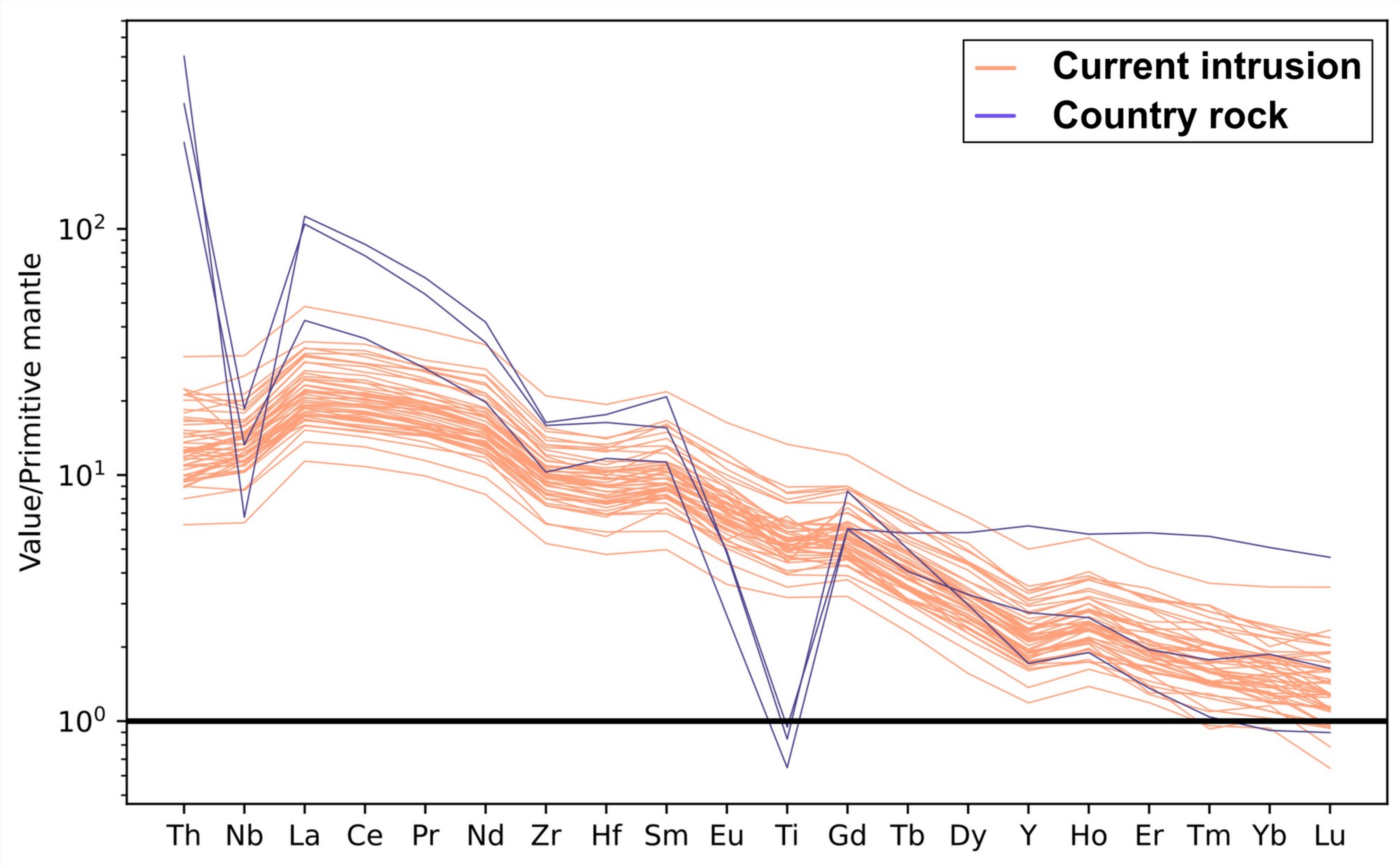
- The **La/Sm$_n$** values indicate a **basaltic magma derived from an enriched mantle plume** [35].

- The **Gd/Yb$_n$** values suggest a **lower degree of partial melting at greater depths**.

[12] Caglioti (2023)
[29] Hollings et al. (2007b)
[33] Sun and McDonough (1989)
[35] Nicholson and Shirey (1990)
[36] Heggie (2005)
[37] Yahia K (2023)

Magmatic Signature

Whole-Rock Geochemistry



Primitive mantle-normalized spider diagram for Current intrusion and Quetico country rocks. Normalizing values from [33].

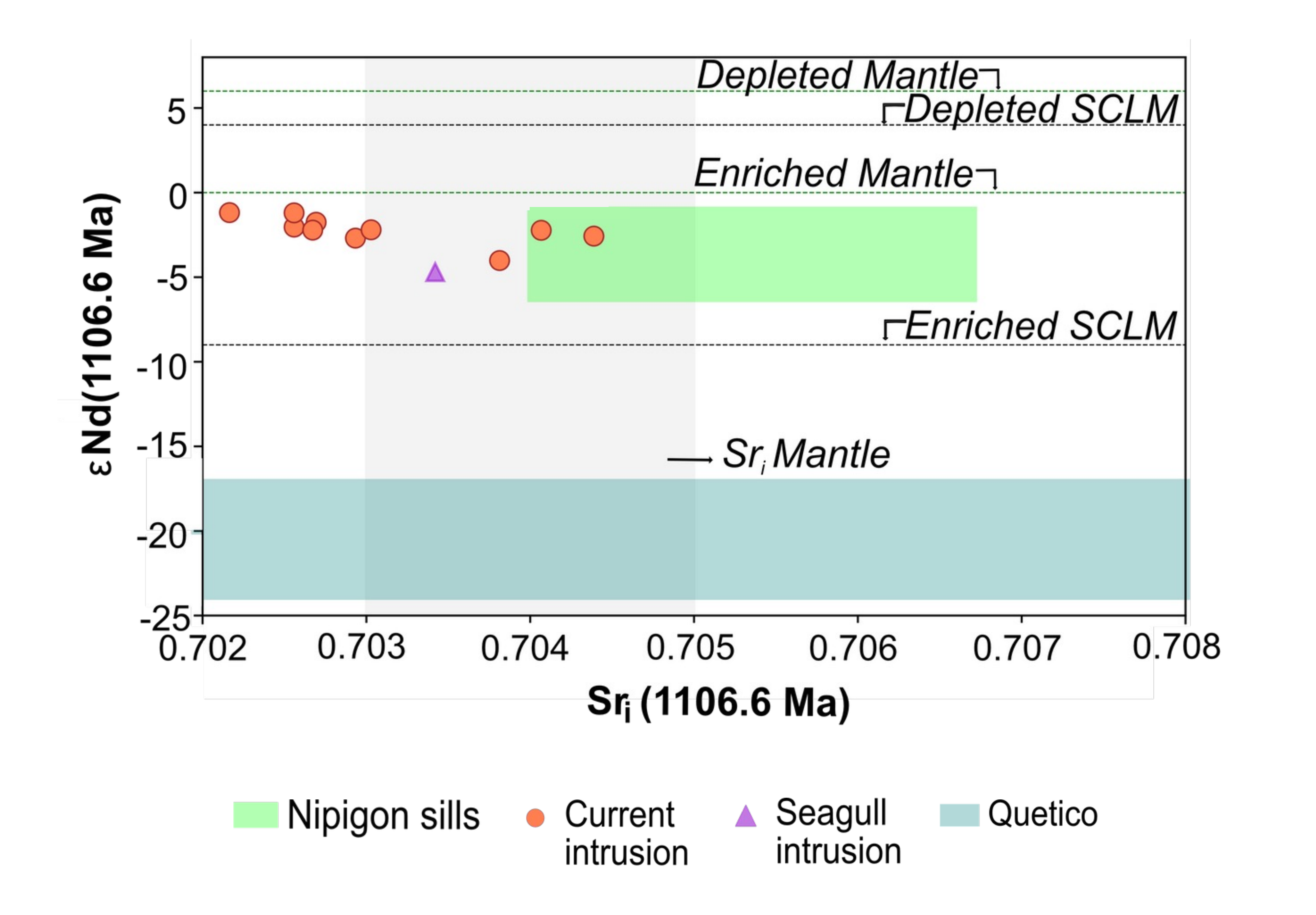
- The intrusion displays a **well-defined primitive mantle-normalized pattern** [33] characterized by LREE enrichment and slightly positive Nb, La, and Ce anomalies over Th, suggesting a lack of continental crust contamination [28,29,34].

- The Quetico country rocks show a greater degree of LREE enrichment, along with enrichment in Th.

[28] Hollings et al. (2007a)
[29] Hollings et al. (2007b)
[33] Sun and McDonough (1989)
[34] Hofmann (1997)

Magmatic Signature

Radiogenic Isotopes



Mantle, SCLM, and Quetico country rock values were taken from [35,38,39,40,41,42] and the Coubran volcanics, Nipigon sills, and Seagull intrusion data were taken from [29,31,36].

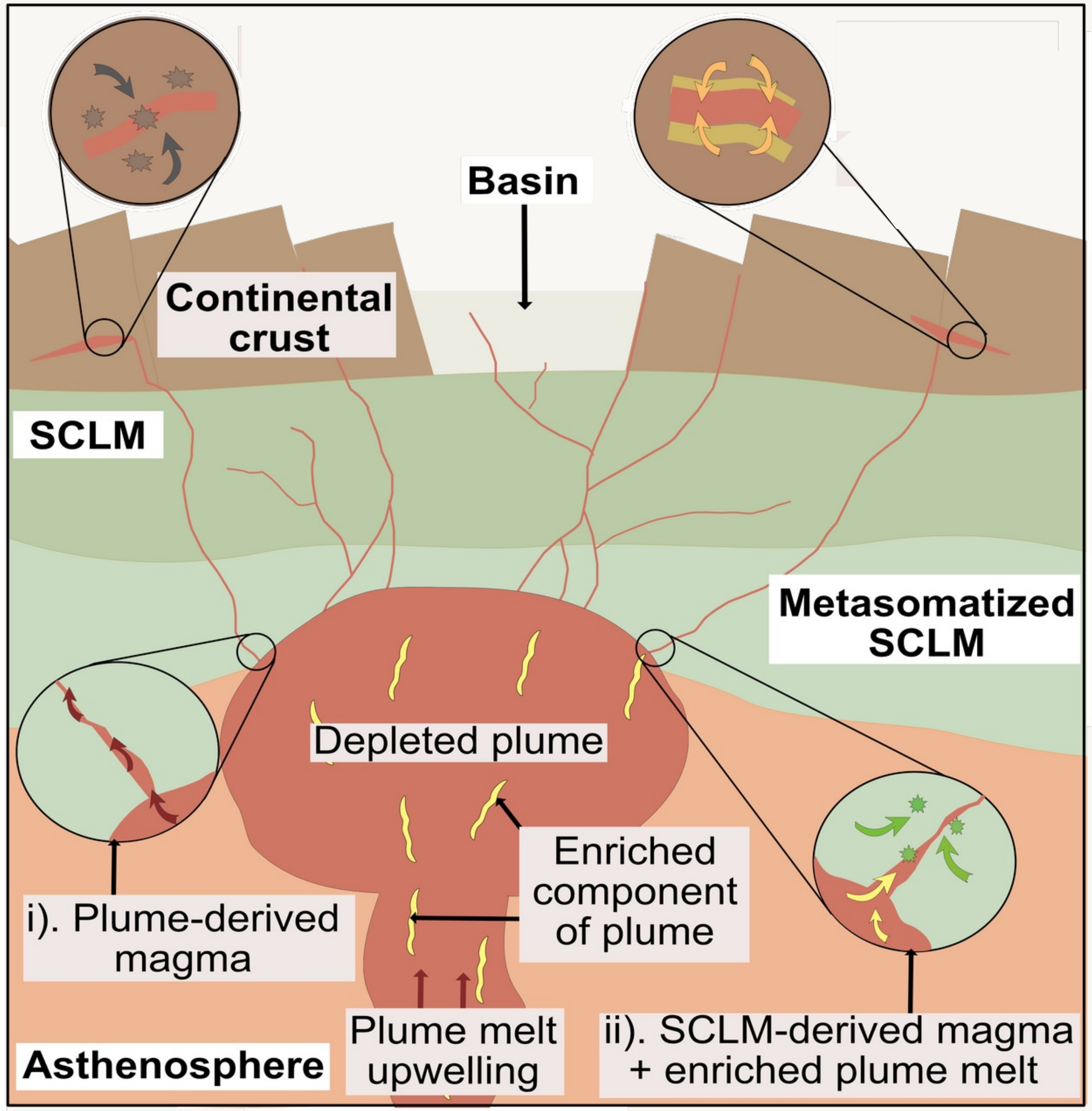
- The intrusion exhibits slightly lower **εNd** values compared to the typical values of the mantle source at 1100 Ma [35,38].

- The **absence of geochemical anomalies** indicating crustal contamination suggests that an **enriched** Subcontinental Lithospheric Mantle (**SCLM)** likely interacted with the **parental magma**.

[29] Hollings et al. (2007a)
[31] Cundari R (2012)
[35] Nicholson and Shirey (1990)
[36] Heggie (2005)
[38] Hergt et al. (1989)
[39] Shirey et al. (1994)
[40] Shirey (1997)
[41] Henry et al. (1998)
[42] Pan et al. (1999)
[43] Rooney et al. (2022)

Magmatic Signature

Magmatic Evolution



Schematic model of the Keweenawan plume interaction on its way to the crust.

- During the **transportation** of the melt from its source in the mantle through the **lithosphere** to the base of the crust, **varying levels of contamination** may occur for some magmas associated with the Keweenawan plume:

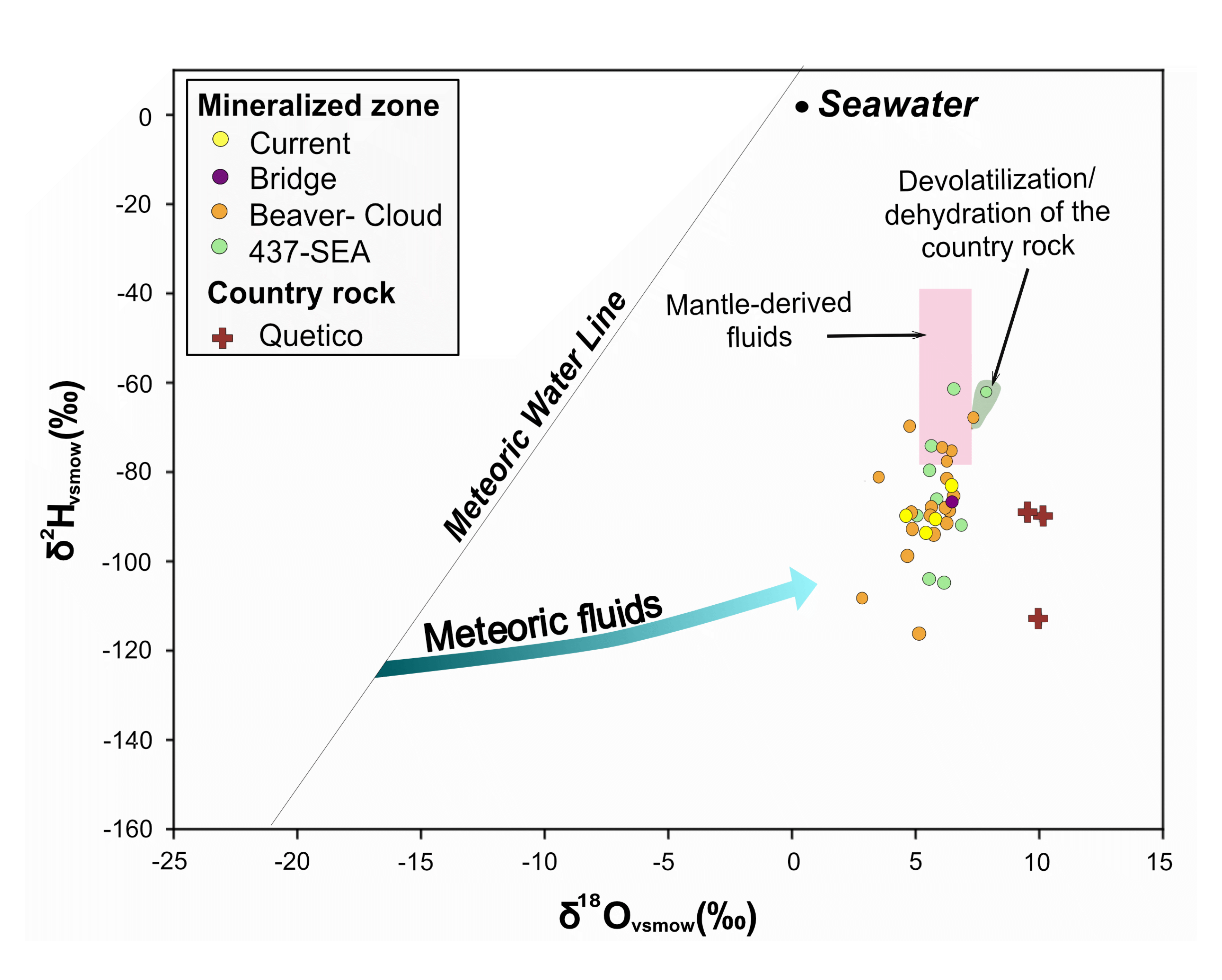
i) **depleted plume-derived magma + crustal contamination** (melting of xenoliths and/or boundaries of the crustal rock; [8]), scenario proposed for the **Coubran basalts** and **Nipigon sills** by [33].

ii) **SCLM-derived magma + enriched plume melt** + **sulfide saturation** by **thermal aureole** in the crust (thermal decomposition of sulfides present in the wall rock [8]), **scenario proposed for the Current intrusion.**

[8] Robertson et al. (2015)
[33] Brzozowski et al. (2022)

Hydrothermal Signature

Stable Isotopes



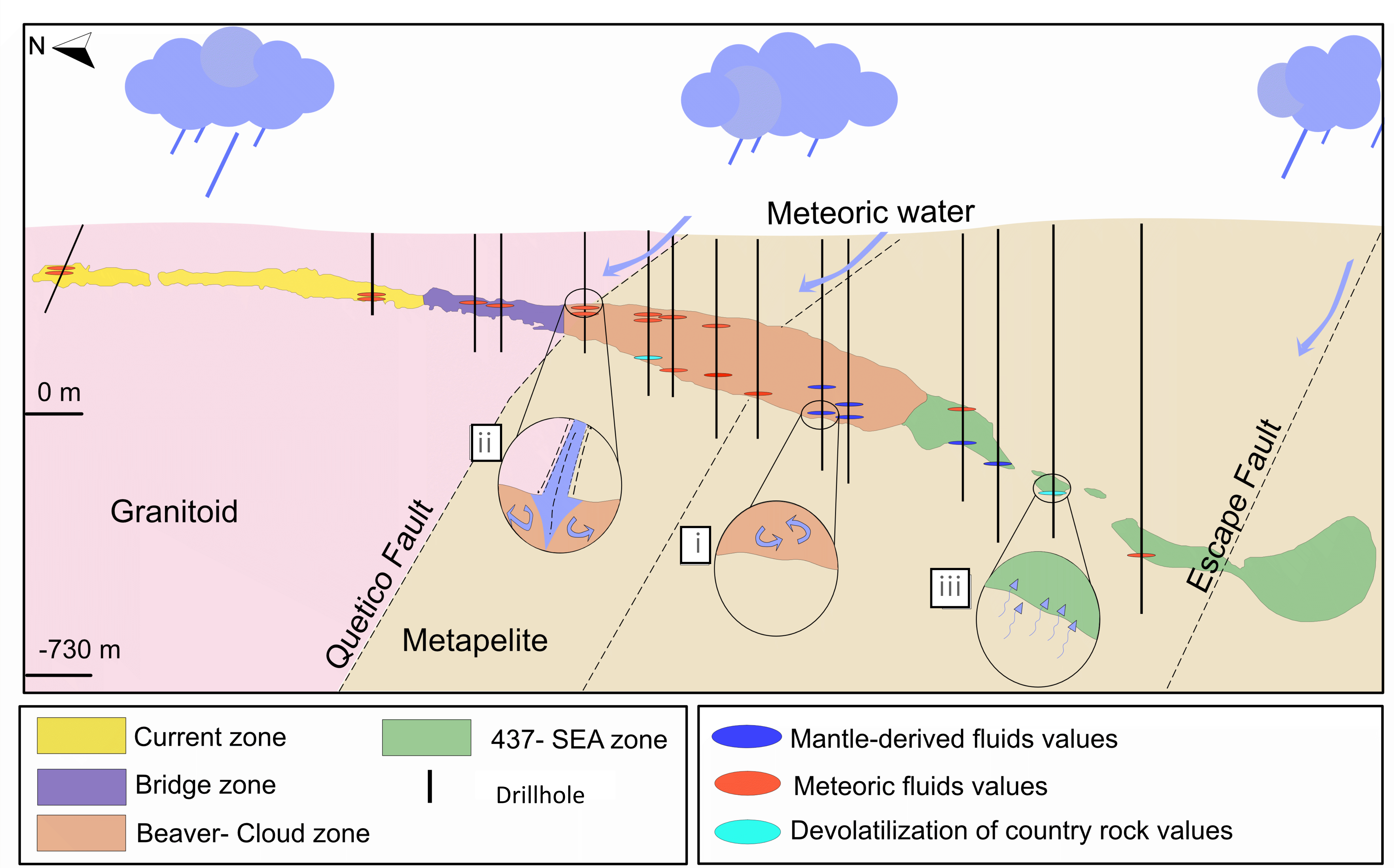
Stable isotopes values of bulk rock of the Current intrusion and the surrounding country rock.

- i) **mantle-derived fluids** (δ^2H from −40 to −80‰, δ^{18}O from 5.5 to 7.0‰ [47, 48,49,50,51,52,53].
- ii) **meteoric fluids** (δ^2H <-80‰, δ^{18}O <5.5‰; [55,56]).
- iii) **crustal-derived fluids by devolatilization/ dehydration** crustal-derived fluids by devolatilization/ dehydration (δ^{18}O >7‰; [54]).

[47] Taylor H (1968)
[48] Kyser et al. (1982)
[49] Mattey et al. (1994)
[50] Eiler (2001)
[51] Loewen et al. (2019)
[52] Moine et al. (2020)
[53] Bindeman et al. (2022)
[54] Ripley and Al-Jassar (1987
[55] Ripley et al. (1993)
[56] Park and Ripley (1999)

Hydrothermal Signature

Hydrothermal Evolution



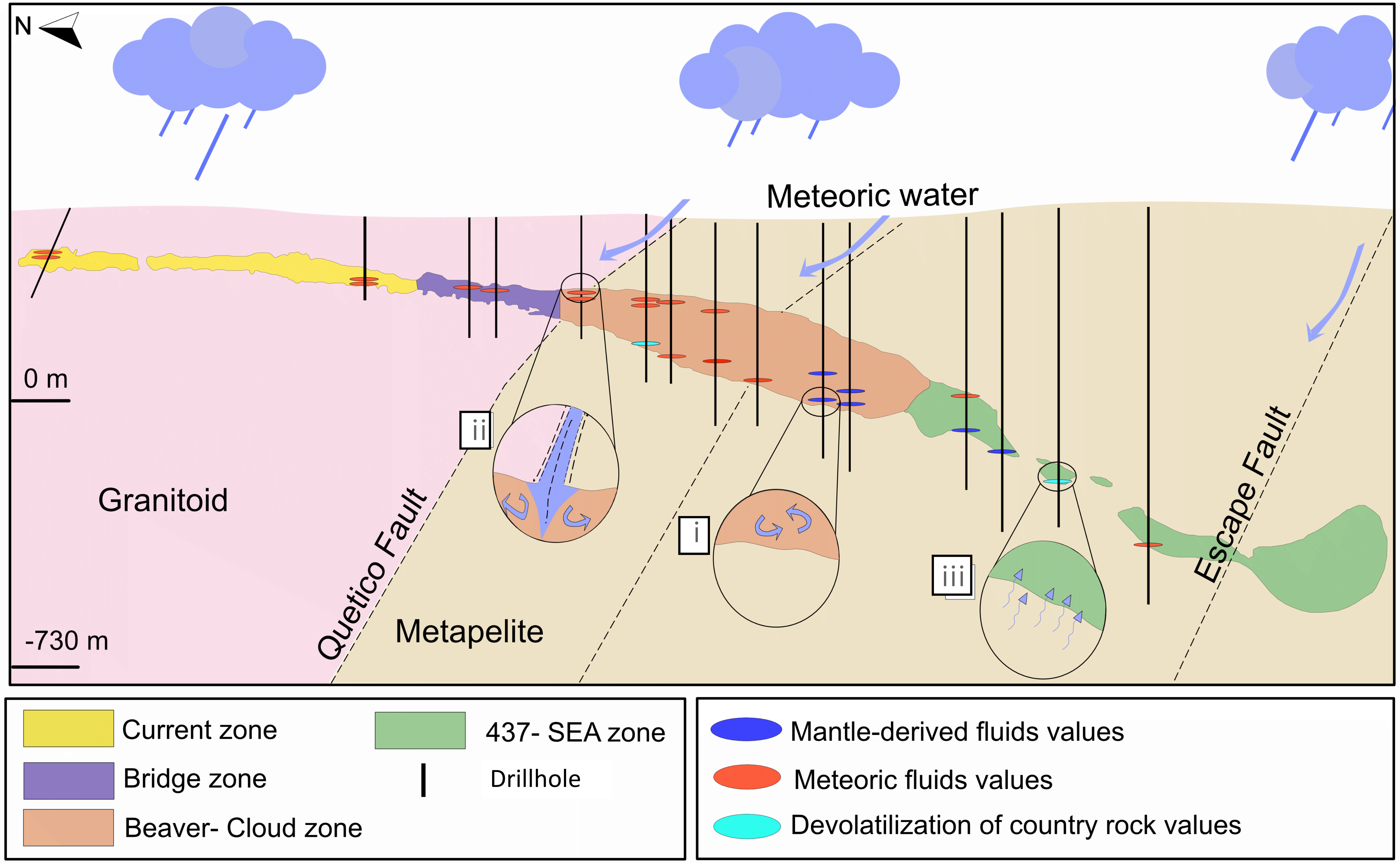
Schematic model illustrating the Current intrusion and its interaction with three sources of fluids: i) mantle-derived fluids; ii) meteoric fluids; iii) crustal-derived fluids.

i) **magmatic fluids** preserved chiefly at the **bottom** of the intrusion, generated the secondary mineralogical **assemblages of Domain A and B.**

ii) **meteoric fluids** recorded mostly at the **top of the intrusion**, generated a secondary **mineralogy similar** to the derived from the **magmatic fluids**.

Hydrothermal Signature

Hydrothermal Evolution



Schematic model illustrating the Current intrusion and its interaction with three sources of fluids: i) mantle-derived fluids; ii) meteoric fluids; iii) crustal-derived fluids.

iii) **crustal-derived** fluids by devolatilization/ dehydration of the country rock, evident in **Domain C.**

Conclusions

1

The Current deposit has a primitive mantle-normalized pattern and enriched nature of the magma suggests a basaltic magma derived from an enriched mantle plume with low partial melting at greater depths with no continental crust contamination.

2

The slightly lower ε_{Nd} values indicate interaction with an enriched SCLM.

3

Stable isotope analysis reveals interactions between:

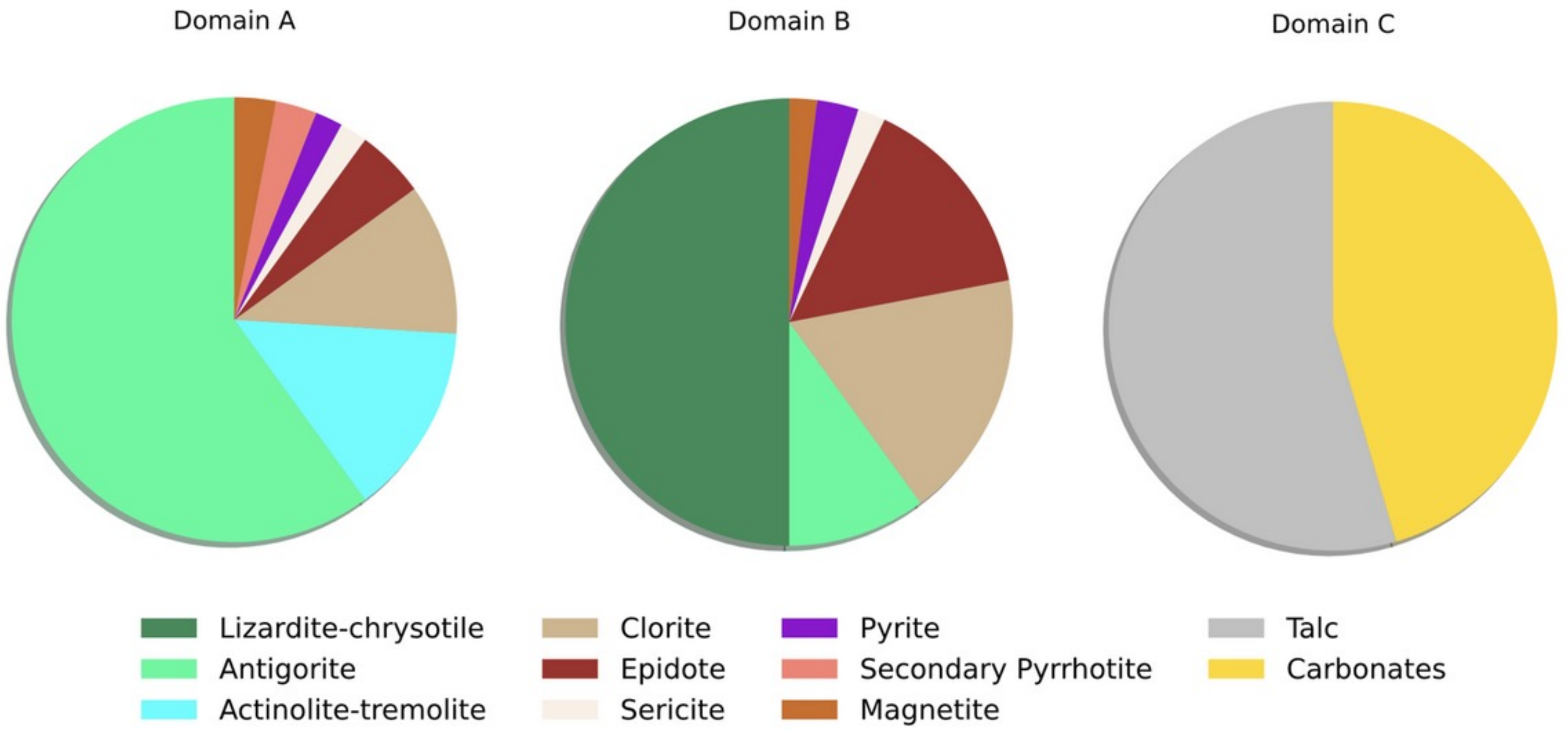
- Magmatic fluids.
- Meteoric fluids.
- Crustal-derived fluids.

Conclusions

	Secondary silicates							Secondary Sulfides		Secondary oxides	
Mineral domains	Antigorite	Lizardite-chrysotile	Chlorite	Epidote	Actinolite-tremolite	Talc	Sericite	Pyrite	Pyrrhotite	Magnetite	Carbonates
Domain A	+		+	+	+		+	+	+	+	
Domain B	+	+	+	+			+	+		+	
Domain C						+					+

4

The intrusion exhibits three distinct alteration domains:



Thank you