

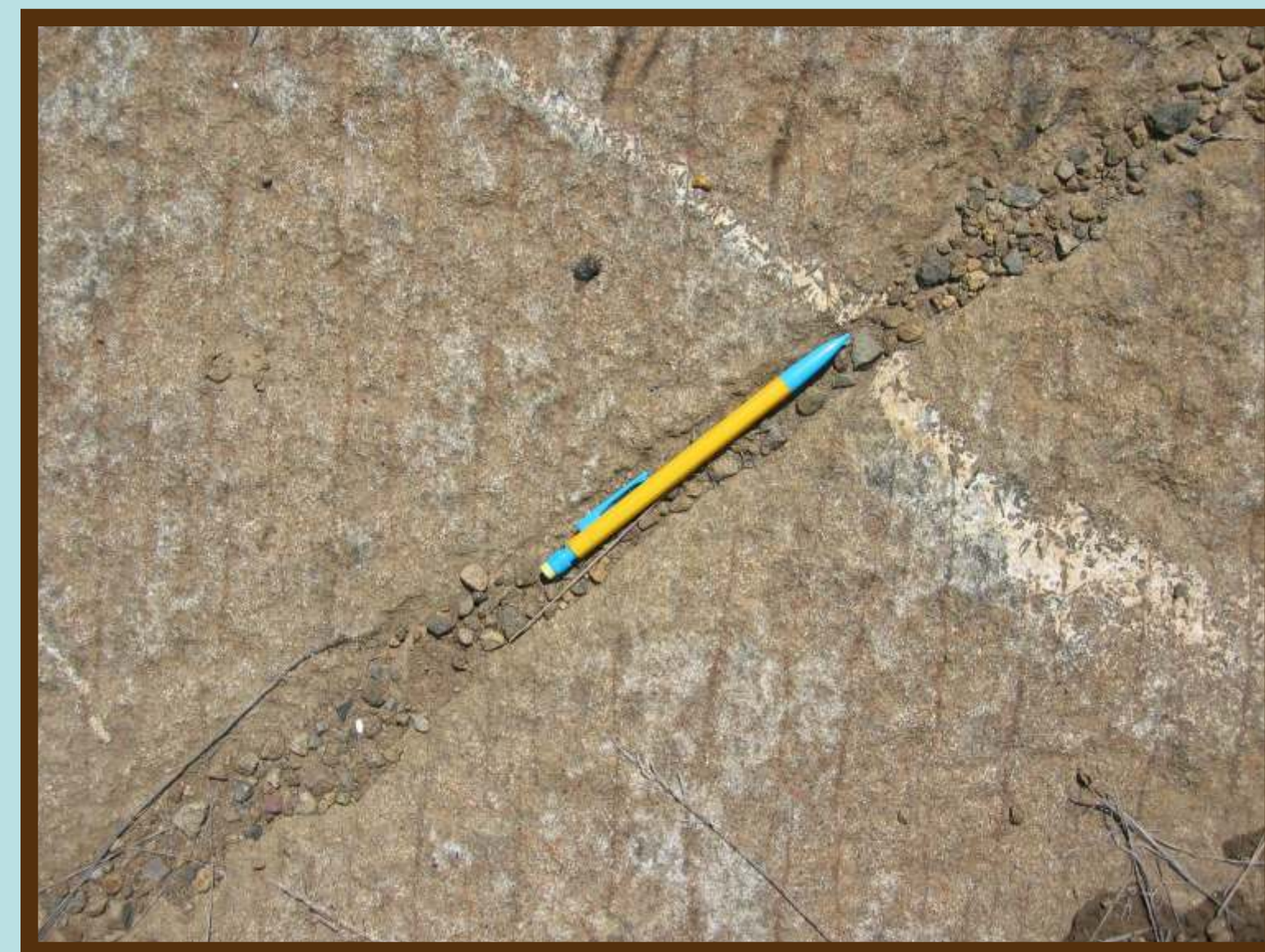
PROTEROZOIC PLATINUM GROUP ELEMENT MINERALIZATION OF THE NIPIGON EMBAYMENT, NORTHWEST ONTARIO

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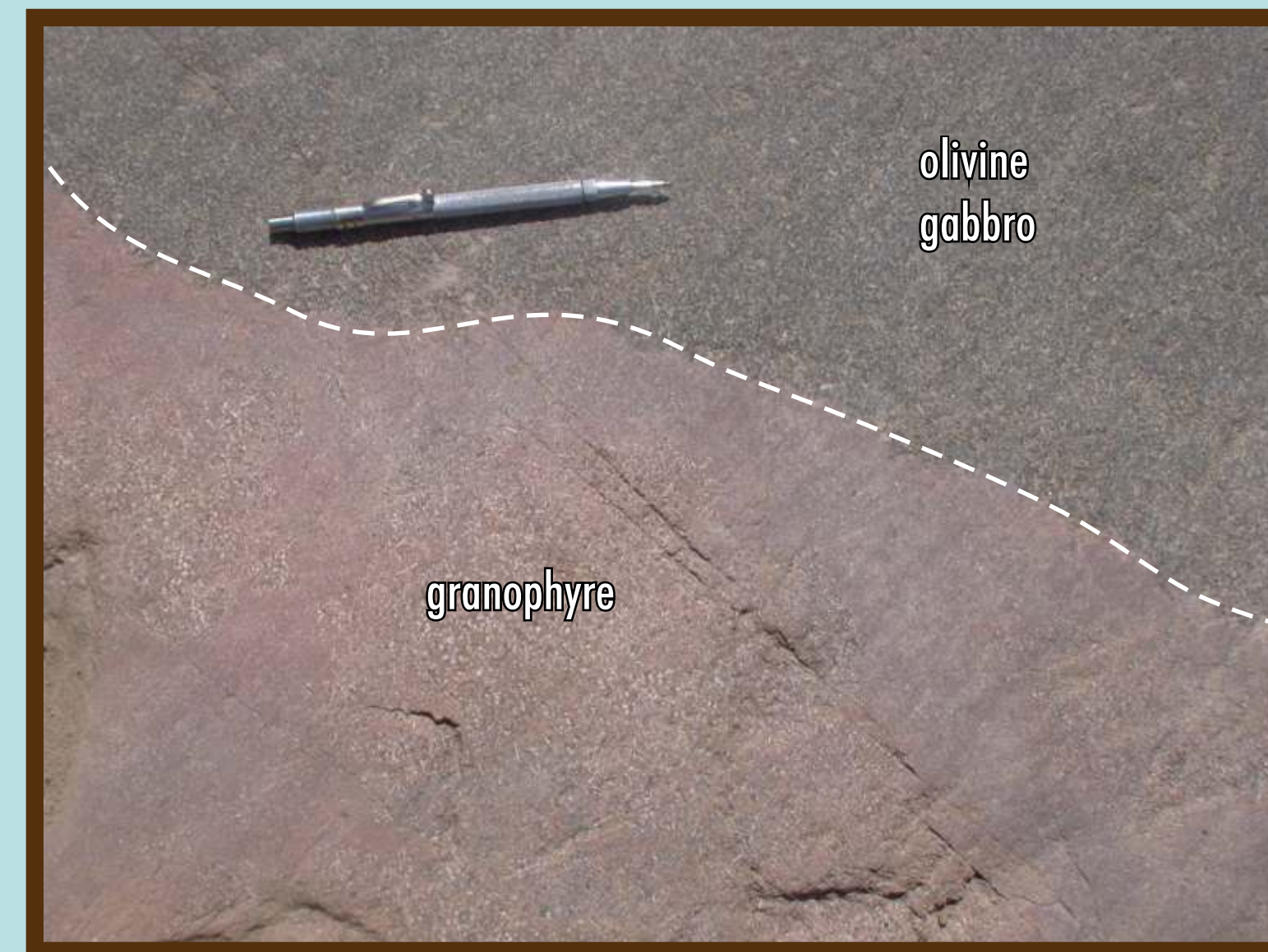
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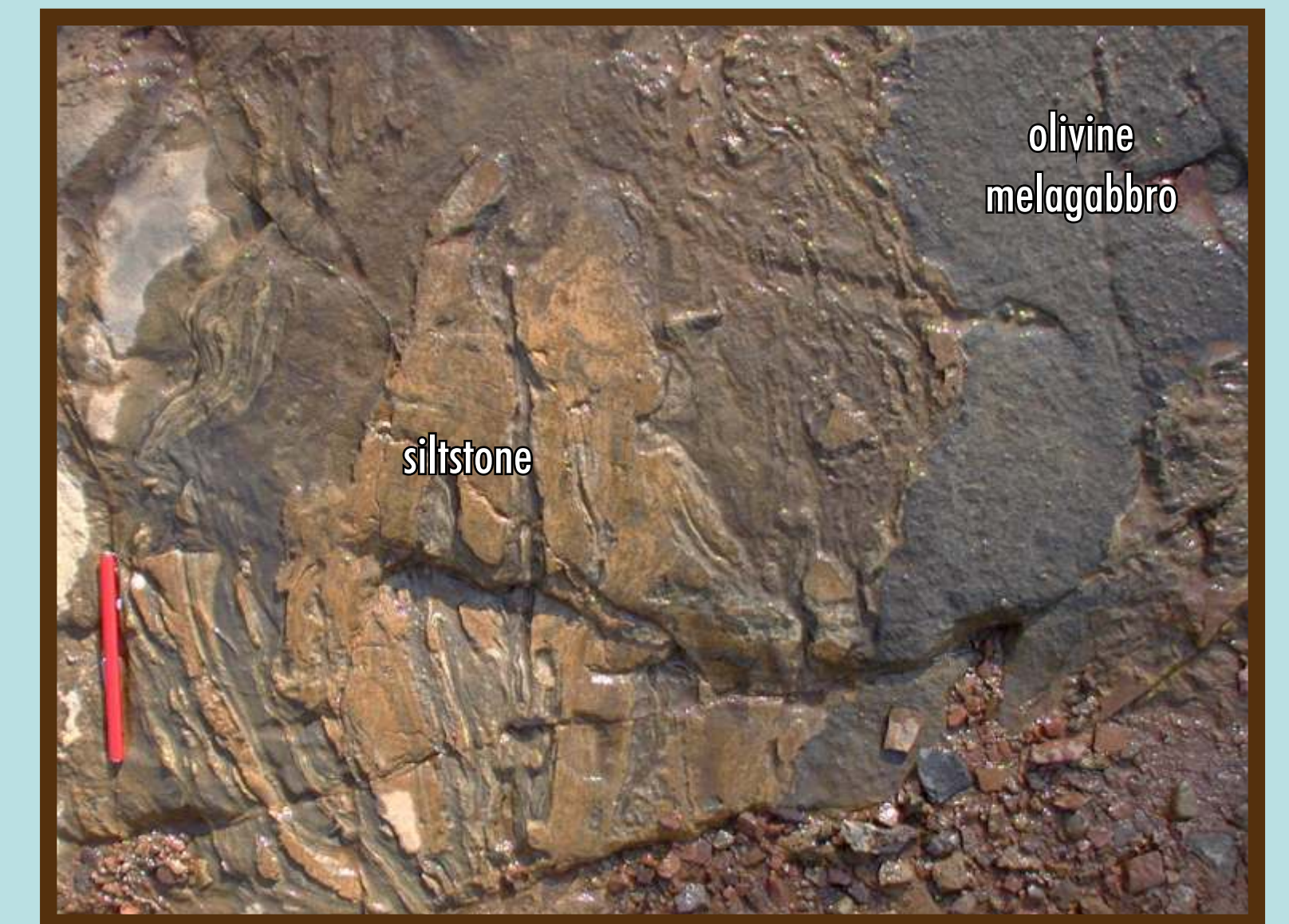
Abstract The platinum group element (PGE) bearing Seagull Intrusion is one of four Mid-Proterozoic mafic to ultramafic intrusions emplaced into the Mid-Proterozoic Sibley Group and underlying Archean rocks of the Nipigon Embayment, that are in turn intruded by Mid-Proterozoic sills of the Nipigon Diabase Sill Complex. The ultramafic intrusions have cumulate textured peridotite cores with olivine gabbro to olivine melagabbro border phases that are geochemically similar, with $[La/Yb]_{mn}$ ratios of 9-14 and weakly depleted Th, Nb, and Ta for all units. A series of thinner mafic sills occur scattered through the Embayment and they are geochemically similar to the ultramafic intrusions. These intrusions and sills can be reliably distinguished from the diabase sills using geochemistry (e.g., diabase: $[La/Yb]_{mn}$ 3-6). The similarities in the geochemistry of the thinner mafic sills and intrusions suggests that these sills may be indicators of additional intrusions in the Nipigon Embayment with a higher potential to host mineralization.



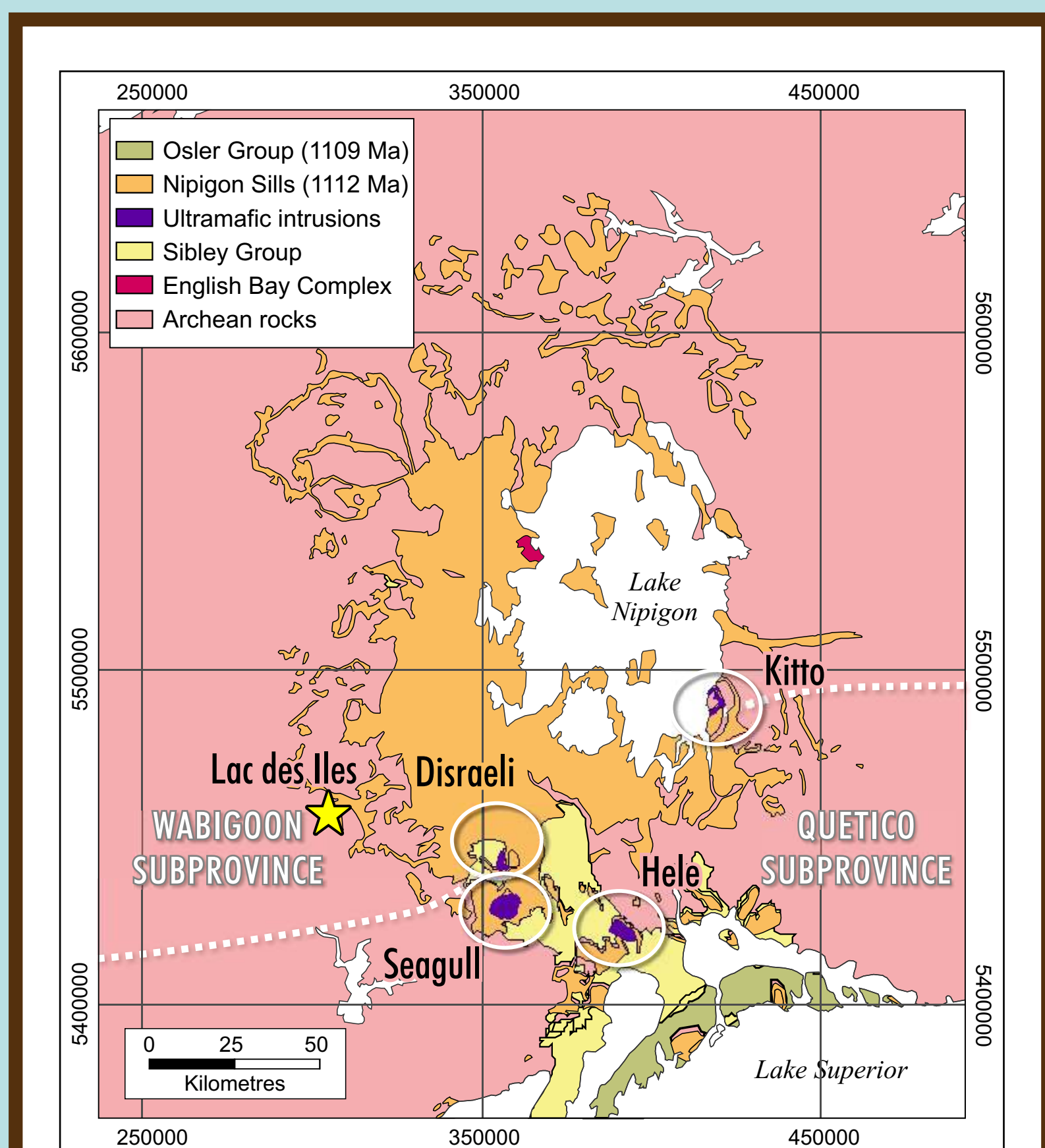
The intrusions are dominantly composed of cumulate dunites, lherzolites, wehrlites and olivine websterite, with phlogopite as a common accessory mineral. Alteration is limited to minor serpentine and phlogopite along fine parallel fractures (Disraeli Intrusion: station 03TRH-538).



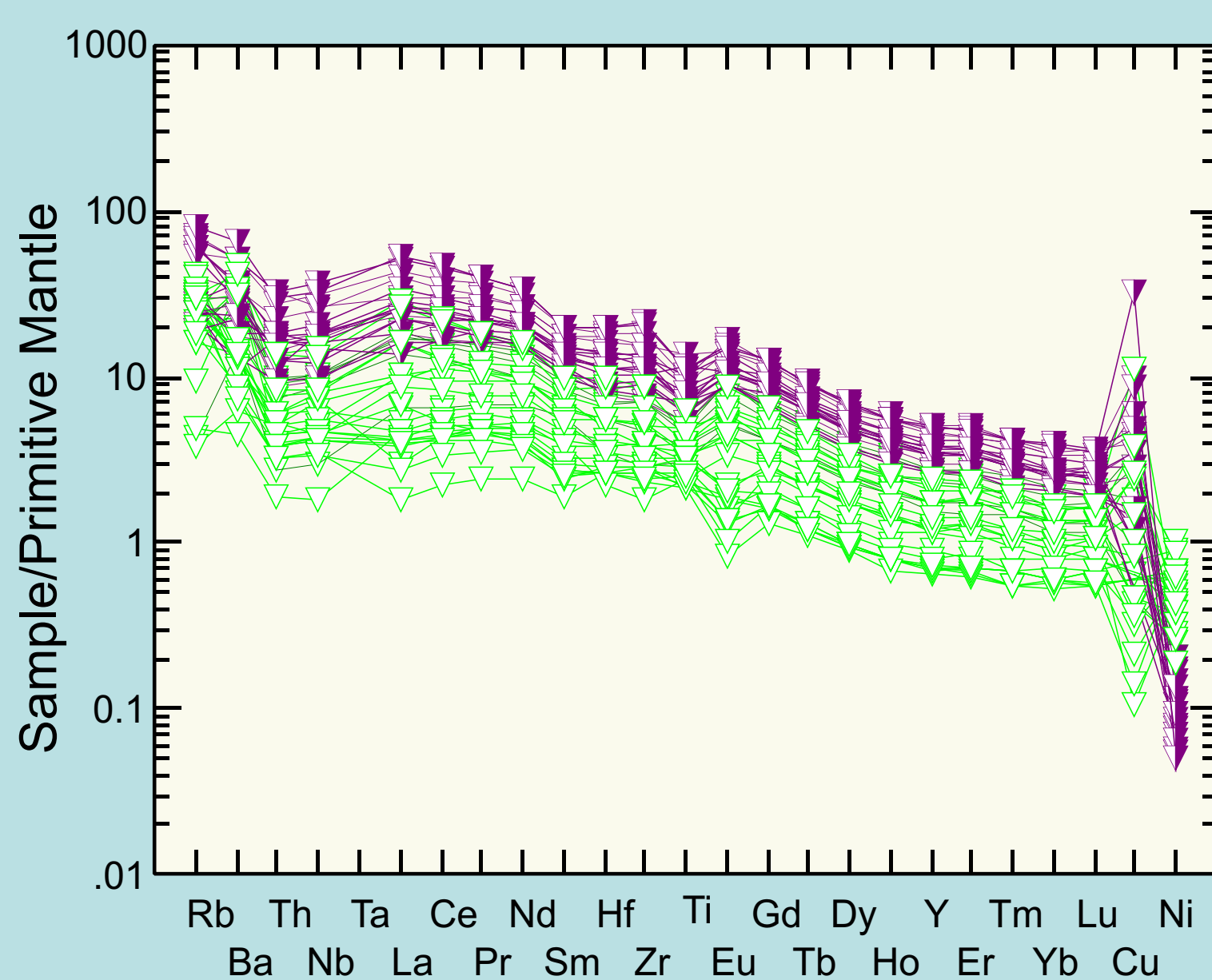
Olivine gabbros to olivine melagabbros form discontinuous borders to the intrusions, and irregular pods of fine- to coarse-grained granophyre, monzogabbro, may be hosted by the olivine gabbro close to the upper contacts. Whole rock geochemistry indicates that the granophyre, and the presence of pinkish feldspar in olivine gabbro, correlates with higher K₂O contents suggesting



Evidence of assimilation is exposed in a few outcrops of the upper contacts which are generally with sediments of the Sibley Group, such as this examples of siltstone xenoliths of the Kama Hill Formation in olivine melagabbro of the Seagull Intrusion (station 04TRH-1069). Lower contacts are only visible in diamond drill core and also appear to indicate assimilation of the Archean rocks.

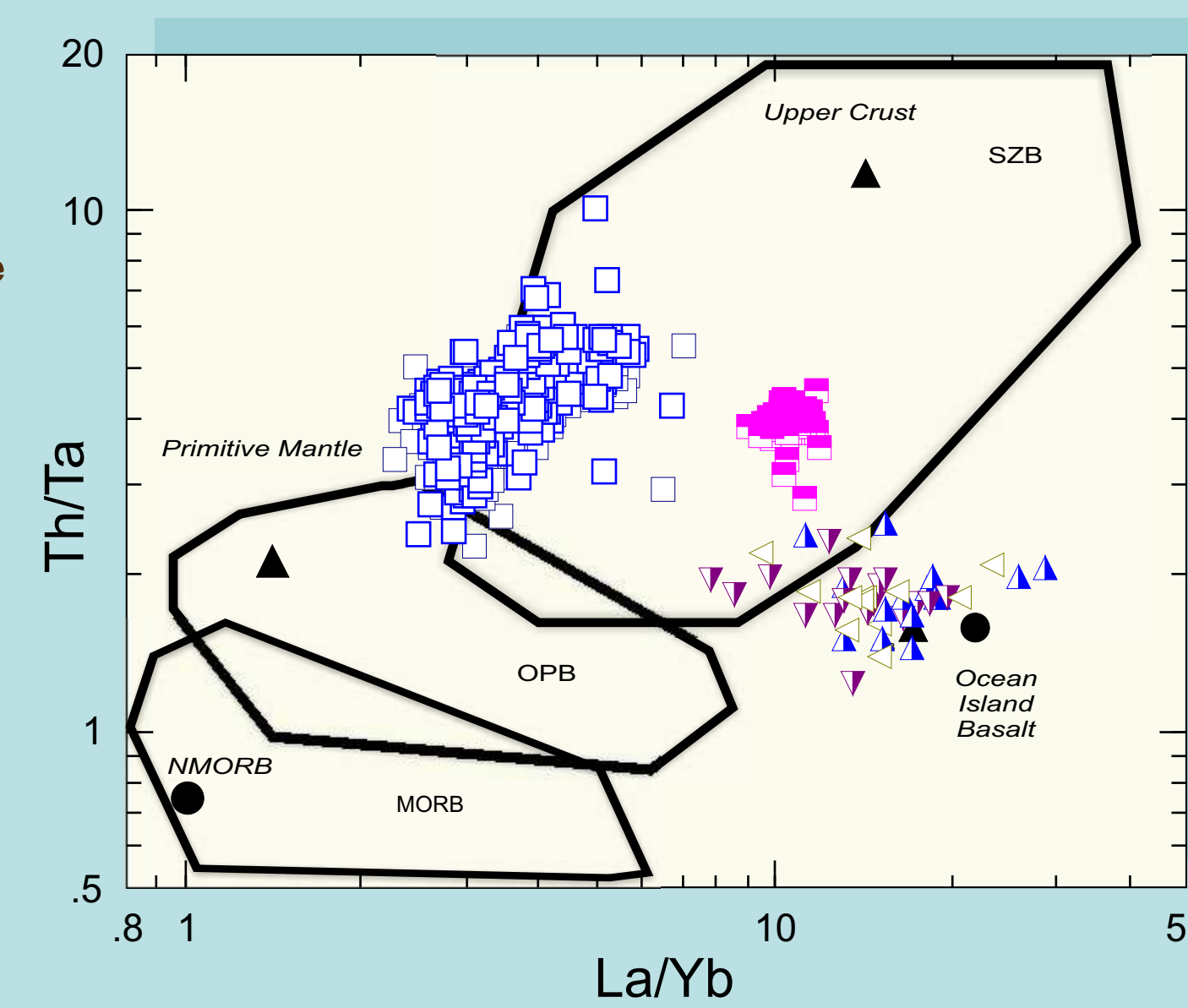


Four 1106-1124 Ma (Heaman et al. 2005) mafic to ultramafic intrusions were emplaced into the >1339 Ma Sibley Group (Franklin 1978), and Archean rocks of the Wabigoon and Quetico subprovinces. These intrusions are cut by diabase sills of the 1110 - 1114 Ma (Heaman et al. 2005) Nipigon Sill Complex. The Nipigon Embayment is defined by the occurrence of Sibley Group sediments and nearly continuous diabase sill coverage.

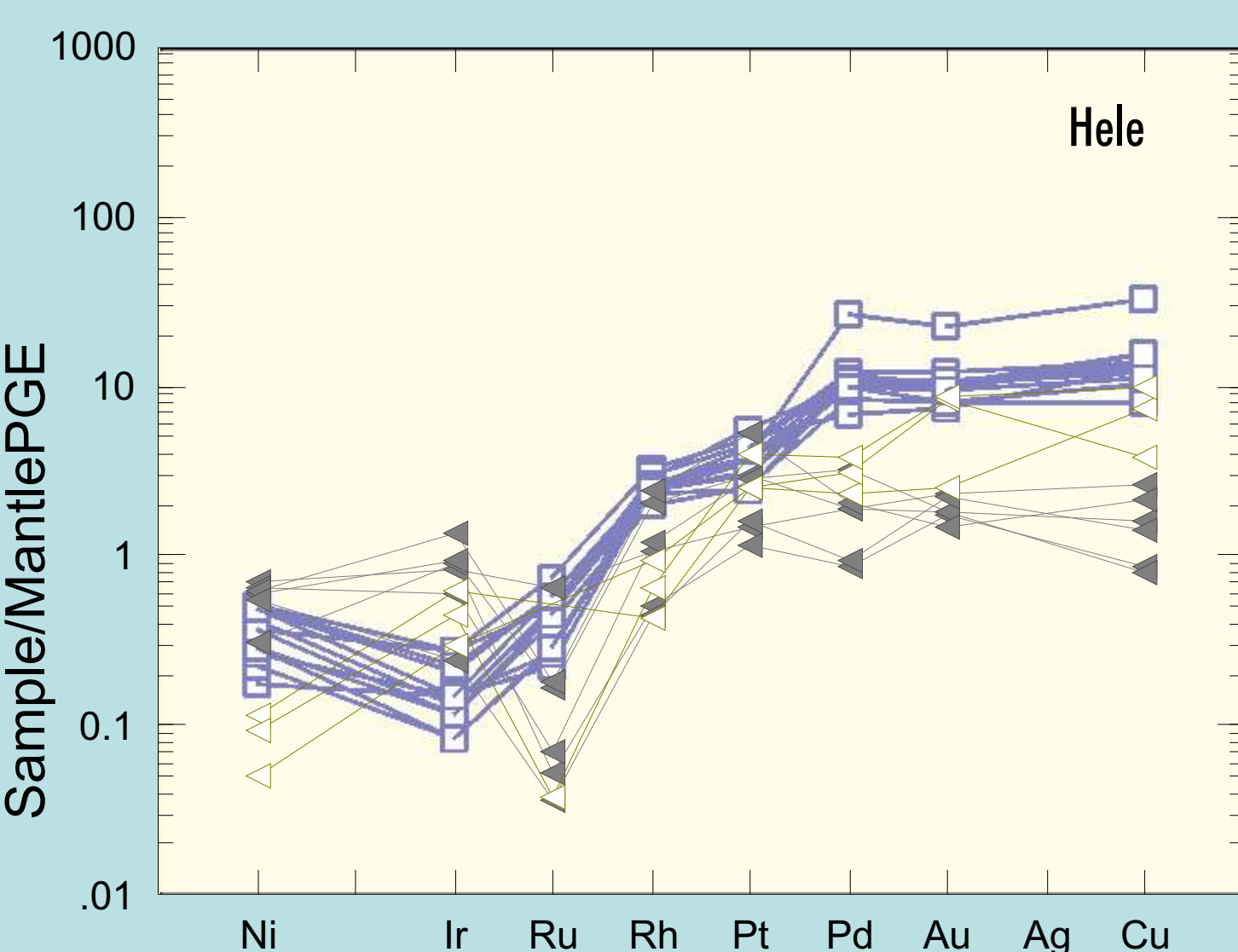
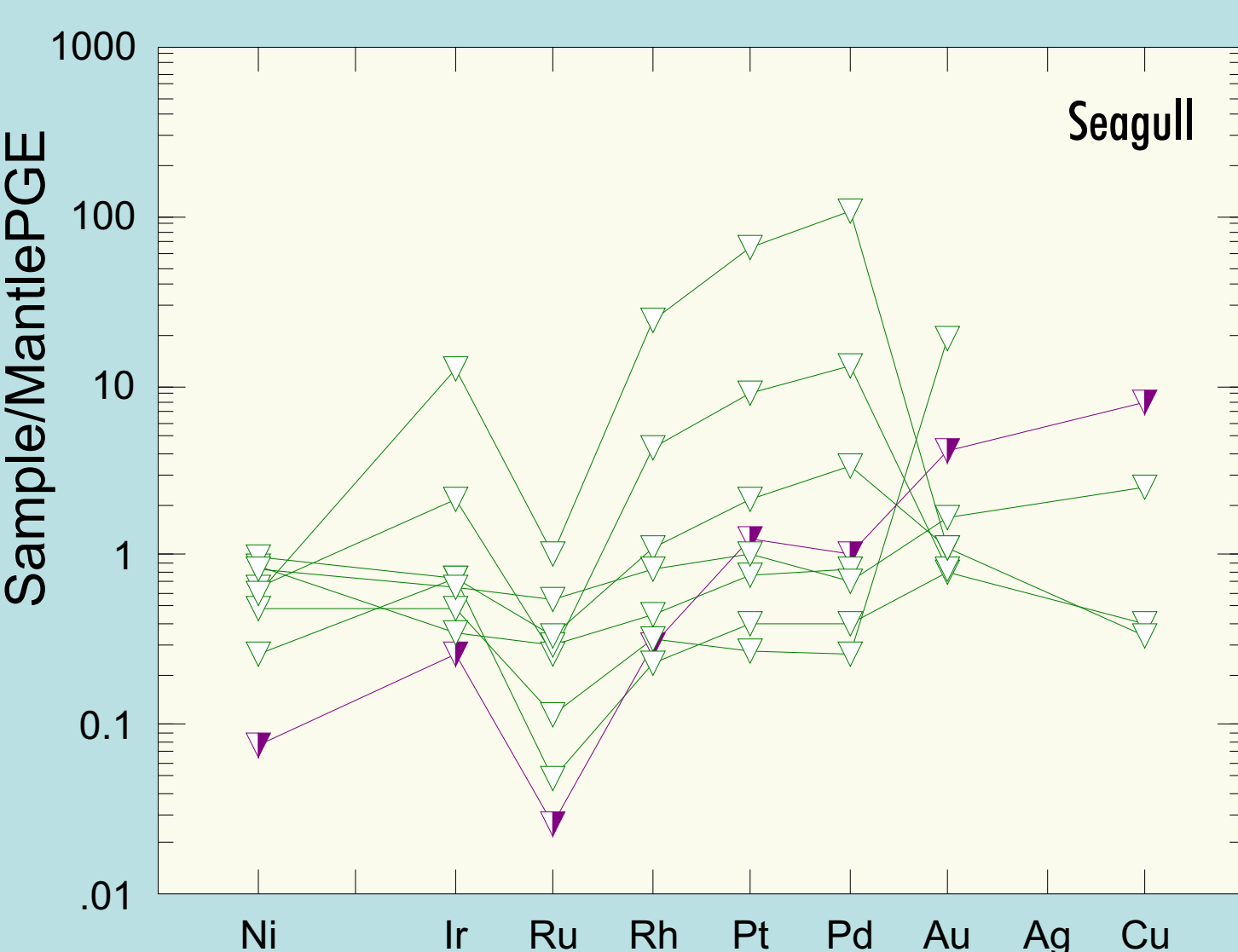


All of the intrusions are geochemically similar in composition with relatively uniform REE and HFSE contents with most samples containing $[La/Yb]_{mn}$ ratios of 9 - 14, and weakly depleted Th, Nb, and Ta on mantle normalized extended element diagrams (e.g. Seagull peridotite and olivine gabbro; Hart 2005, Hart and Magyarosi 2004). A wider range in ratios results if the coarser cumulate and granophyre samples are included in the data set.

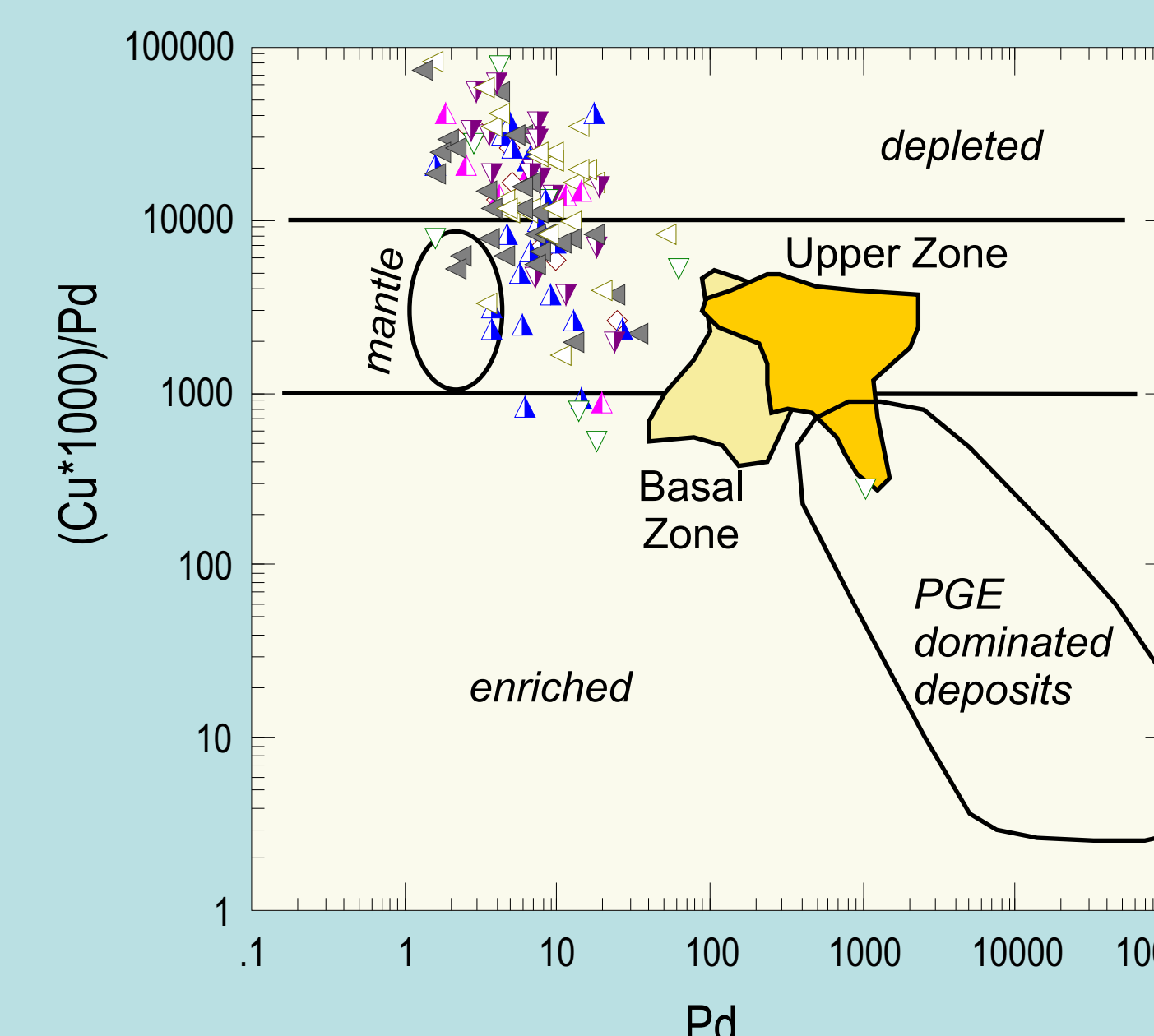
Least altered samples of the olivine gabbro, selected to more closely approximate an initial magma composition, plot close to the average for ocean island basalts on a La/Yb versus Th/Ta diagram (after Condie et al. 2002). For comparison, samples of the Nipigon diabase sills plot with higher Th/Ta and lower La/Yb ratios than the olivine gabbro samples suggesting a separate magma source (Hart 2005; MacDonald and Tremblay 2005).



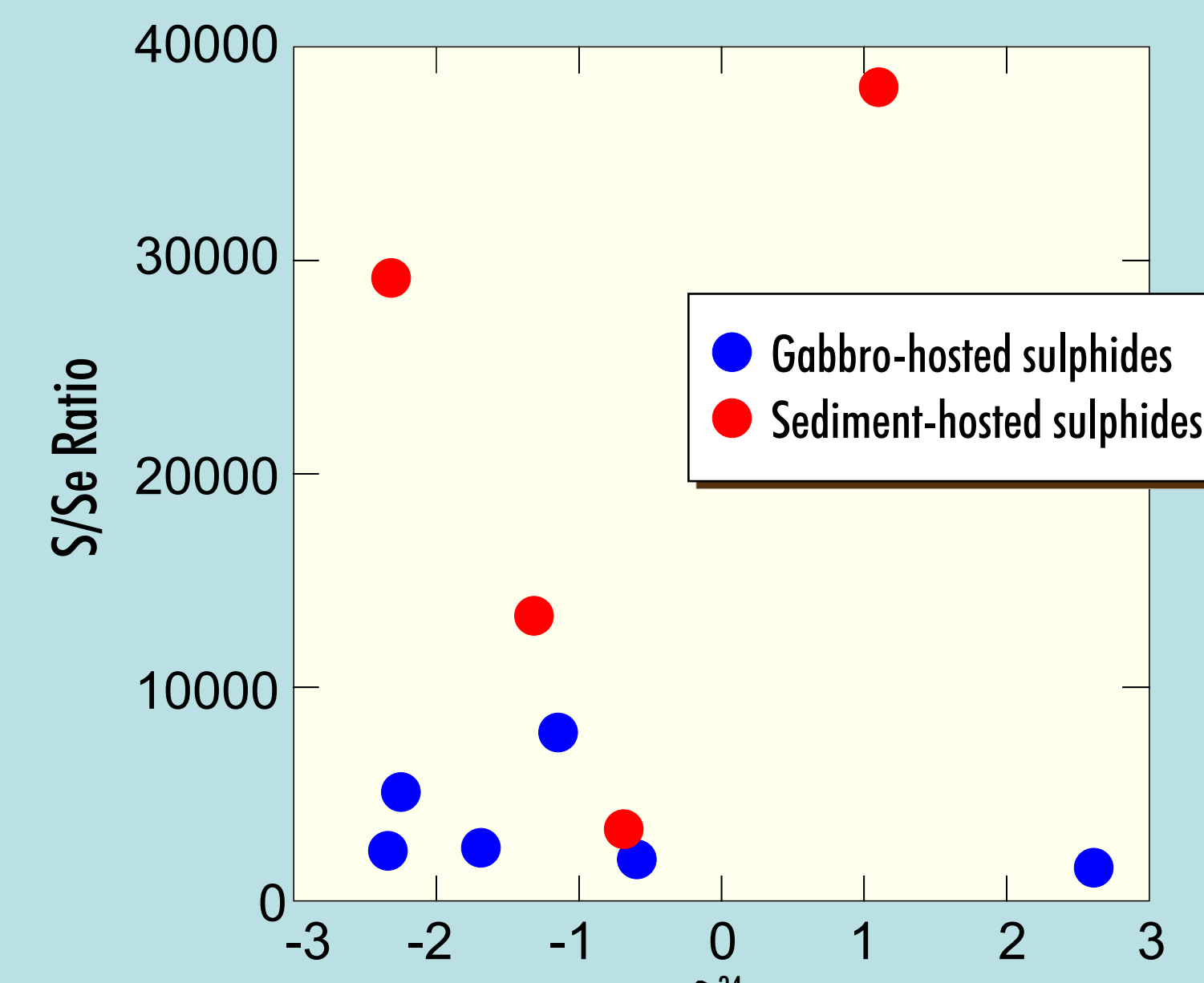
PGE mineralization has been identified in the Seagull and Kitchi intrusions (East West Resource Corporation 2004a; Hart et al. 2002). The Seagull Intrusion hosts at least three zones of disseminated sulphides containing potentially economic PGE mineralization hosted by the basal lherzolite or overlying dunites such as in this photo from drill hole WM05-20 @ 331.9m (from 331.68-332.12 m: 3690 ppb Pt, 3990 ppb Pd, 220 ppb Au, 674 ppb Ir, 891 ppb Os, 294 ppb Rh, 204 ppb Ru; Platinum Group Metals, 2005).



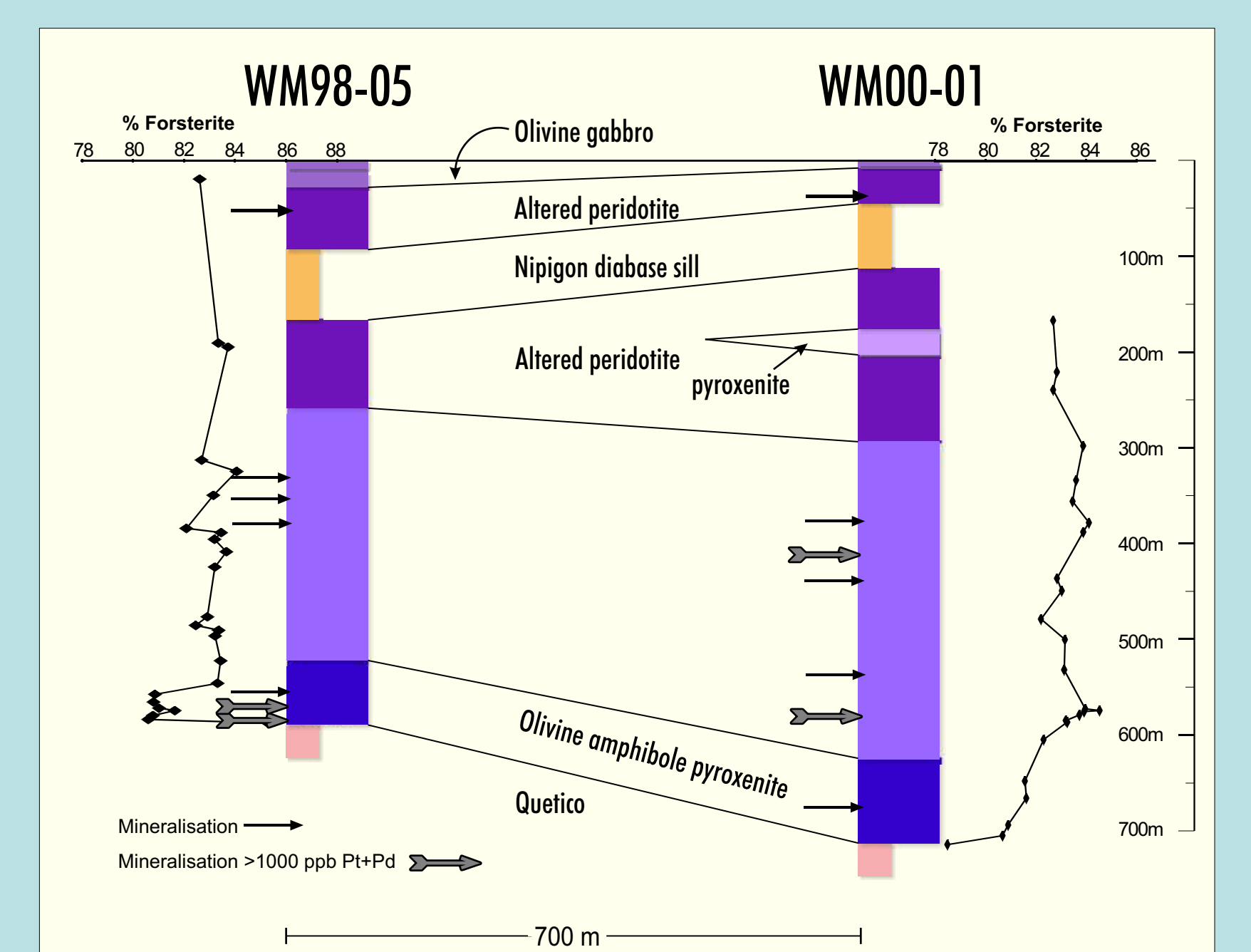
Most of the intrusions have relatively flat positive slopes on mantle normalized PGE diagrams and negative Ru anomalies, with average $Ni/Ir_{mn} \sim 460$, $Cu/Pd_{mn} \sim 3525$, and $Pd/Ir_{mn} \sim 3.2$ (Hart 2005). These patterns are in distinct contrast with the concave shape observed for samples of the Nipigon diabase sills. Mineralized samples from the Seagull Intrusion have the convex pattern typical of most PGE deposits such as the Merensky Reef noted by Barnes et al. (1993).



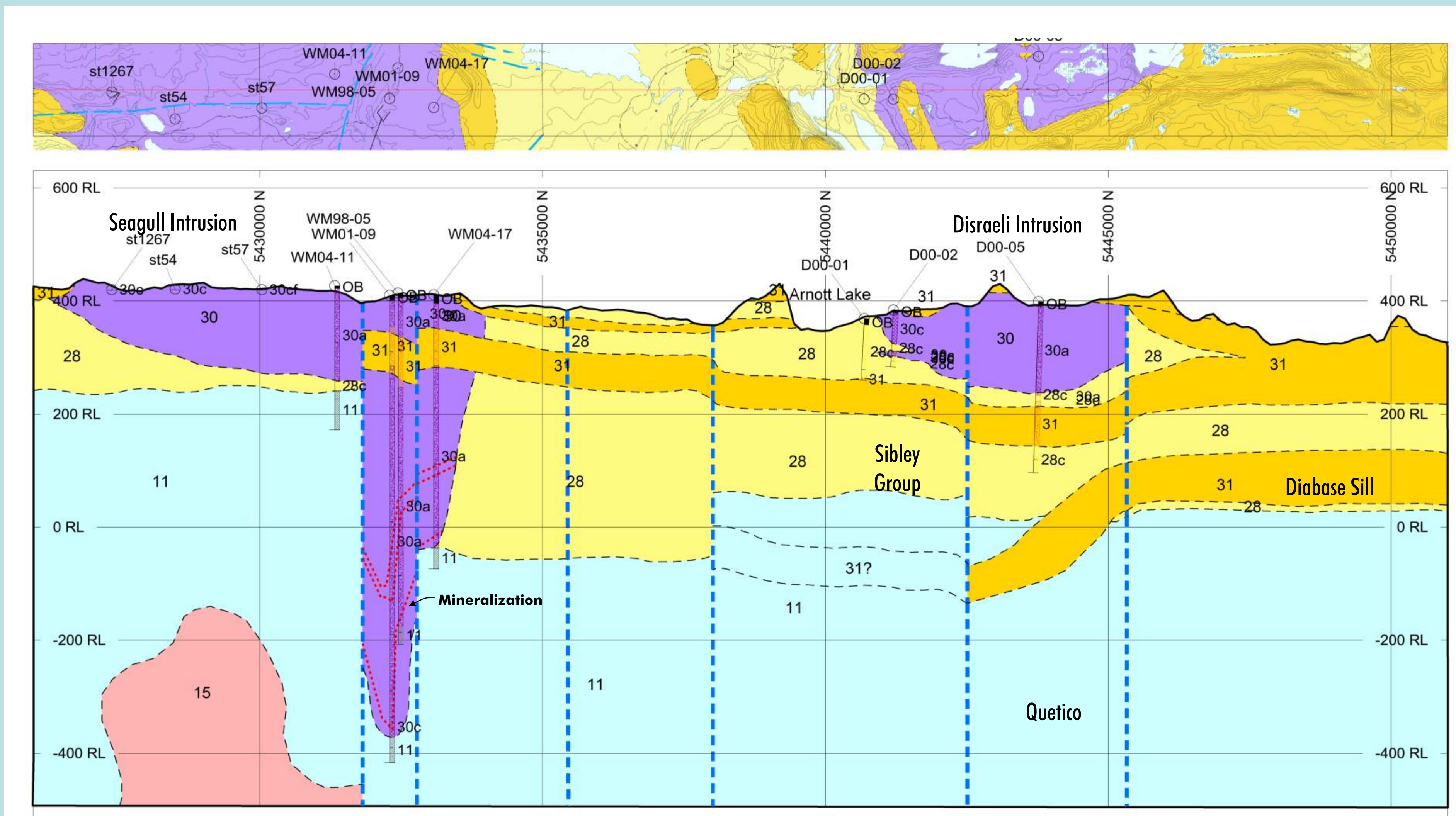
Elevated Cu/Pd ratios and Pd depletion in the peridotites mirrors the depleted Cu/Pd ratios and enriched Pd values associated with the PGE mineralization in the Seagull Intrusion (data from Hart 2005; East West Resource Corporation 2004a,b). Elevated Cu/Pd ratios in some of the other intrusions suggest that they may also be part of mineralized magmatic systems, but additional sampling is required to determine if mineralization was preserved or present in the intrusions (after Barnes et al. 1993).



Similarities in the sulphur isotopic values for sulphides from the Seagull Intrusion and the Quetico sediments cluster around 2 per mil, with single heavy samples, suggesting that the Quetico sediments may have been the source for at least some of the sulphur in the intrusion (Franklin 2001), and Rb-Sr and Sm-Nd isotopic data supports this interpretation (Heggie 2005). However, the Seagull Intrusion sulphides have lower S/Se ratios (higher Se contents) than the Quetico sediments and Franklin (2001) reported that higher Se correlates with a higher PGE content, which was interpreted to indicate that dilution by sedimentary-derived sulphide is a negative factor in generating high PGE contents.



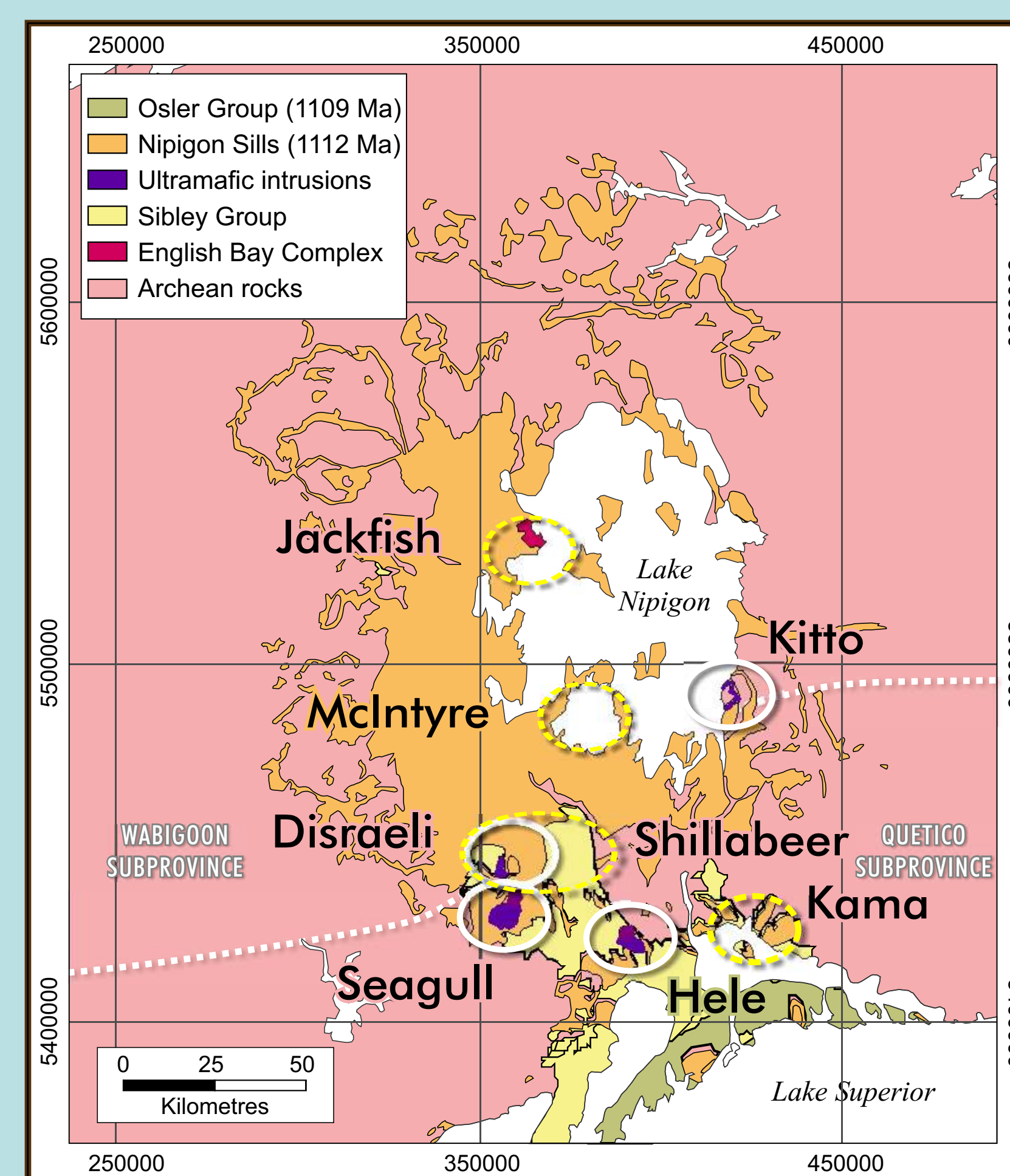
Identification of the PGE bearing zones is difficult due to a lack of mineralogical variation in the Seagull Intrusion, such as feldspar or oxide layering, that is commonly associated with PGE mineralization in other intrusions. Only minor variations occur in the mineral compositions through the Seagull Intrusion (e.g. olivine Fo80-Fo89), and a change from orthopyroxene and clinopyroxene to clinopyroxene is one of the few minor variations associated with PGE mineralization (Heggie 2005).



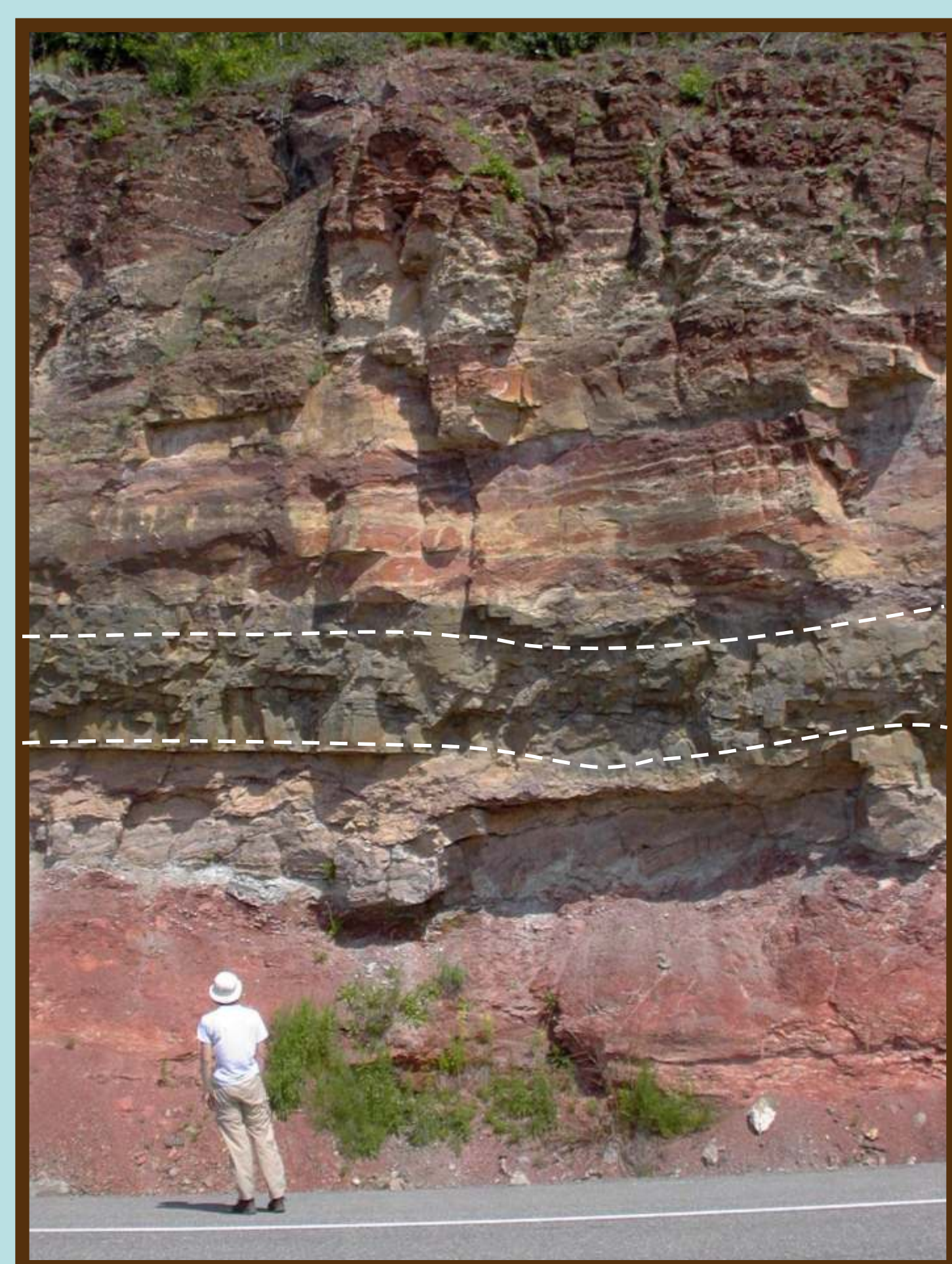
The intrusions have a sill-like geometry with areas of between 20 and 85 km² and thickness of 130 to 750 m. The PGE-bearing Seagull Intrusion is the largest intrusion, with a thicker central portion that may be a product of post-intrusion faulting or a result of emplacement into a pre-existing structure. Underlying, or peripheral, feeder structures have not been identified for any of the intrusions.

These intrusions may be the remnants of larger magmatic systems, flow through chambers, formed as a result of the passage of large volumes of magma with the occurrence of multiple PGE horizons in the Seagull Intrusion resulting from the passage of a greater volume of magma. There are current no known volcanic or intrusive equivalents to these dominantly cumulate mafic to ultramafic intrusions.

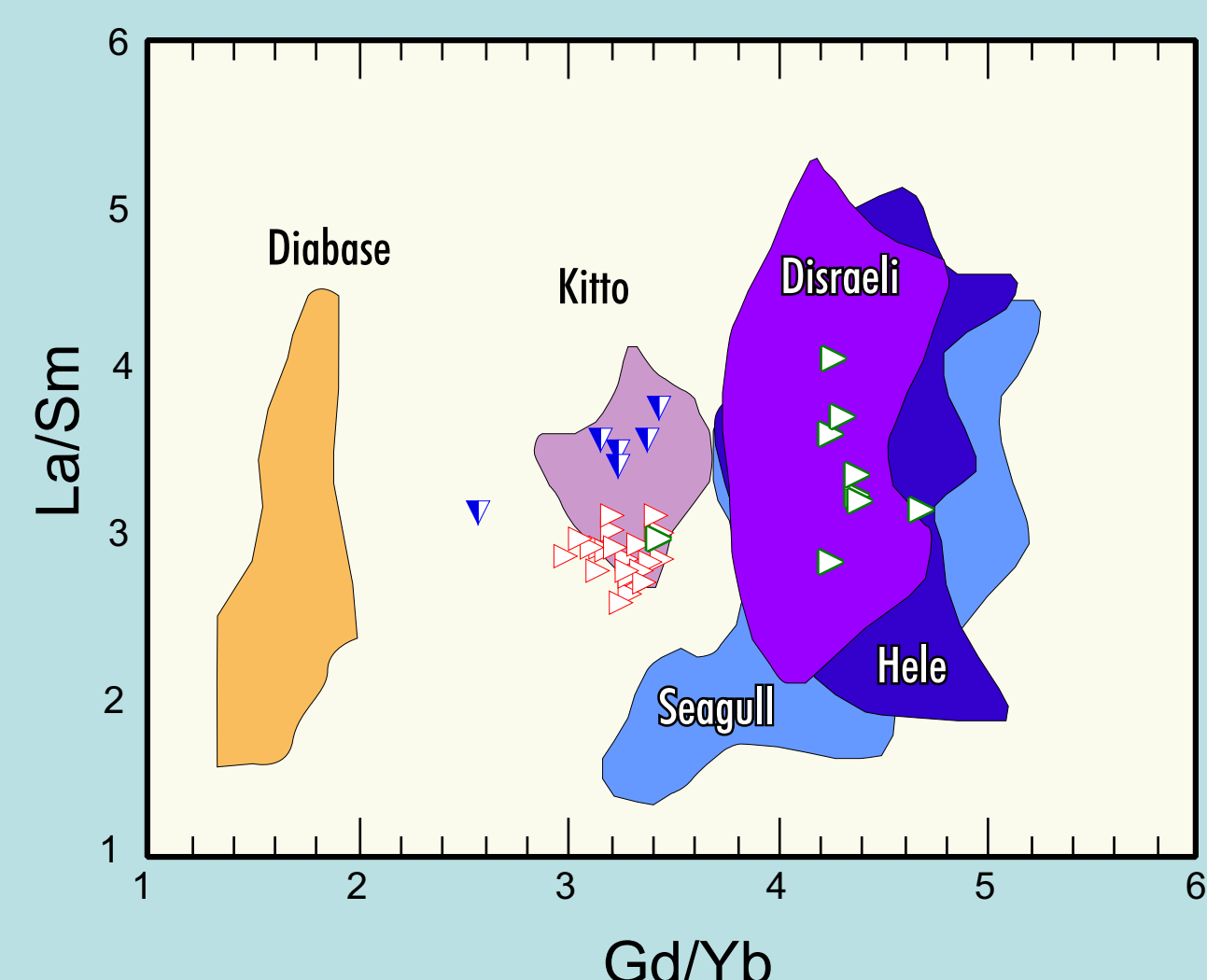
Recent mapping indicates that the intrusions were probably originally more extensive and may have been interconnected (e.g. the Seagull and Disraeli intrusions in the accompanying cross section). The peripheral portions of the intrusions consist of thin sills composed of olivine gabbro. (North-south cross section looking towards the west, vertical exaggeration of 10 times; Hart and Tolson 2005).



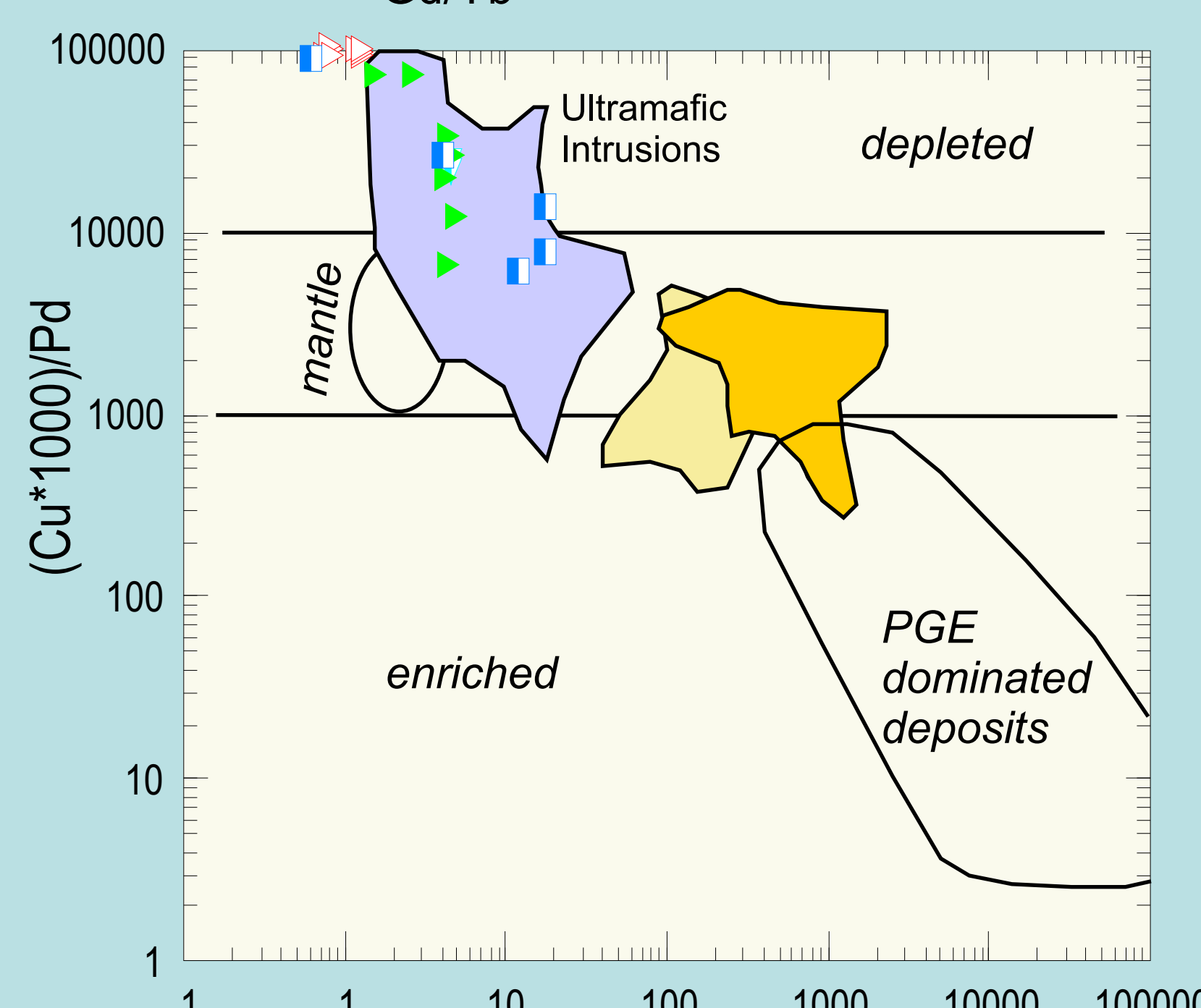
A series of high-Mg gabbro to olivine gabbro sills are scattered through the Nipigon Embayment, including the 50 to 60 m thick Jackfish Sill in the north west portion of the Embayment (MacDonald and Tremblay 2005), the McIntyre Sill southwest of Lake Nipigon (Richardson and Hollings 2005), the Shillabeer Sill (Richardson and Hollings 2005; Hart and Magyarosi 2004), and the 0.25-2.5 m sills in the Kama Hill area on Lake Superior (Hart 2005).



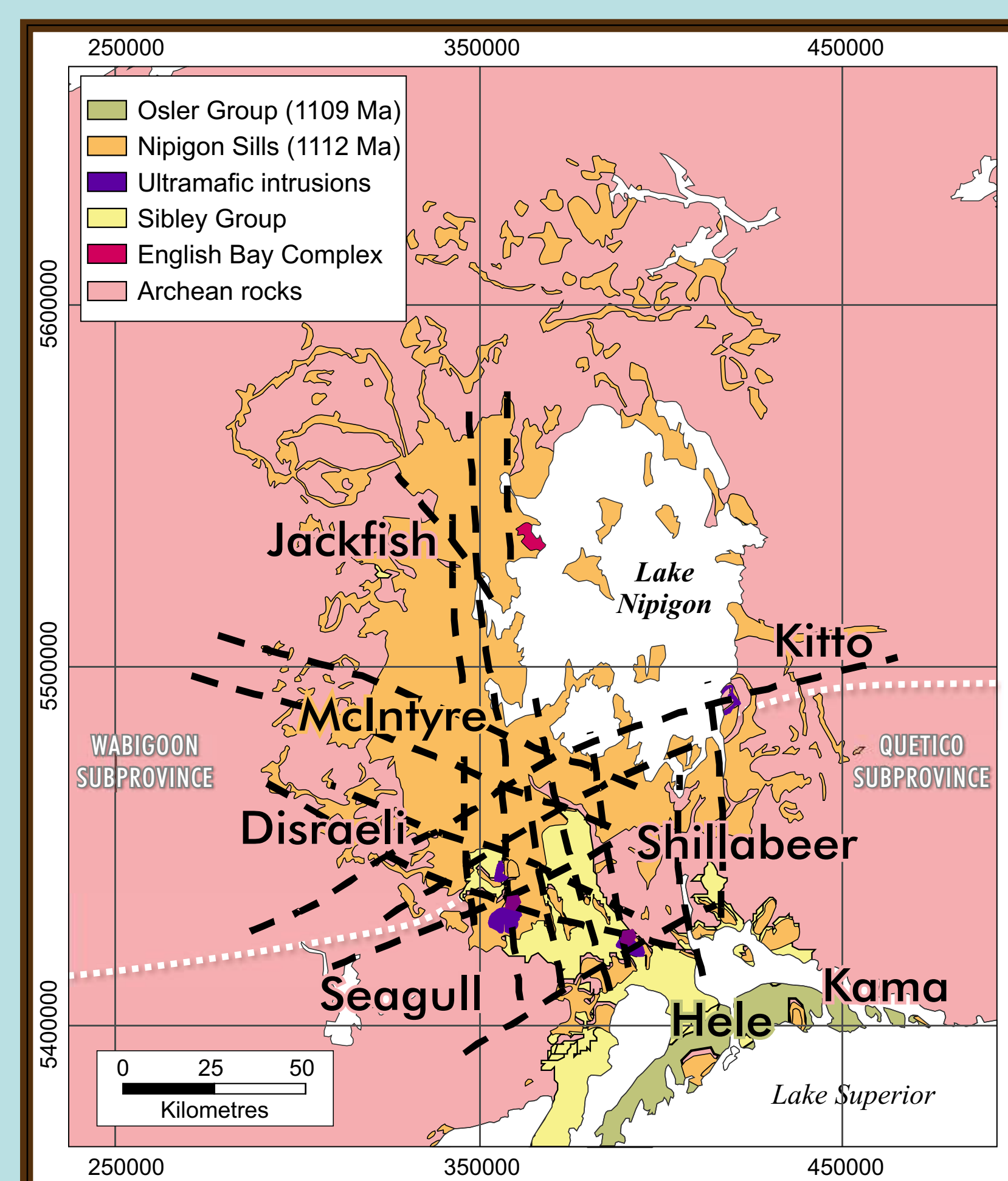
Most of the high Mg sills are fine to medium grained, massive gabbro to olivine gabbro commonly containing pinkish feldspar and elevated K₂O contents suggesting assimilation of the country rock (Sibley Group, Kama Hill, Hwy 17; station O4TRH-353). The Jackfish Sill, located on the northwest shore of Lake Nipigon is composed of olivine melagabbro to peridotite with 15-45% olivine (MacDonald and Tremblay 2005) suggesting that some of these sills could be lateral portions of larger unexposed intrusions, rather than just isolated sills.



These sills generally have moderate Gd/Yb ratios comparable to those of the Kitto Intrusion with lower La/Sm ratios in the Jackfish Sill possibly as a result of less crustal contamination in this thicker sill. The exception in the Shillabeer Sill which has ratios that more closely resemble the Disraeli, Seagull and Hele intrusions and may be related to a chilled sill that cuts the upper portion of the Disraeli Intrusion (Hart 2005; Hart and Magyarosi 2004; MacDonald and Tremblay 2004)



Some of the samples from the high-Mg sills have elevated Cu/Pd ratios that overlap with the ratios observed in the mafic to ultramafic intrusions, as well as Cu/Zr ratios of <0.6. These elevated Cu/Pd ratios suggest that these sills may also be part of a mineralized magmatic system, and may be an indication of additional mineralization in the Nipigon Embayment. This would be particularly significant if the high-Mg sills are peripheral portions of larger intrusions (after Barnes et al. 1993).



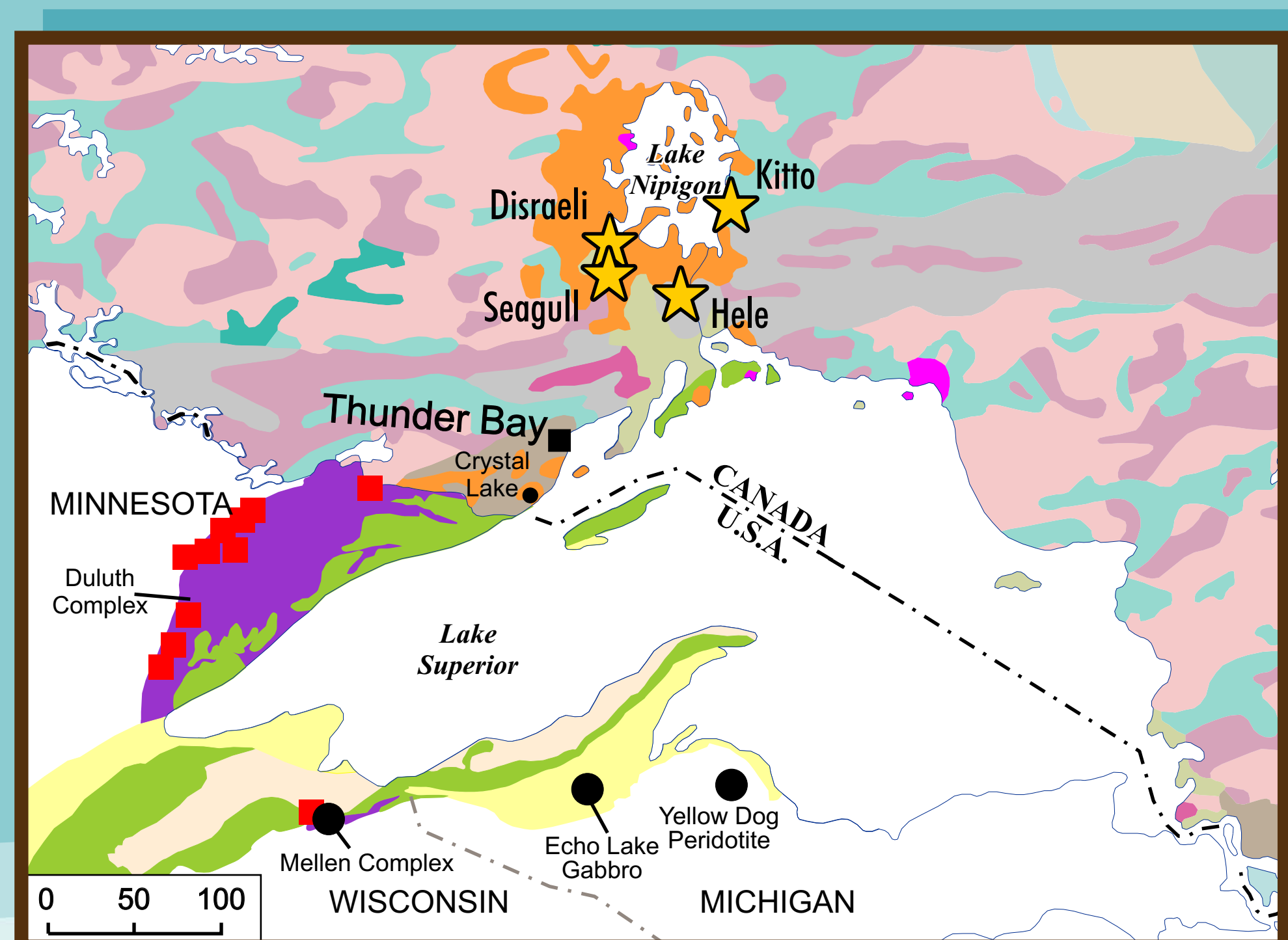
If PGE mineralization formed as a result of multiple pulses of magma, as appears to have been the case in the Seagull Intrusion, then other intrusions in the Nipigon Embayment may have the potential to host PGE mineralization. This includes known intrusions, as crude layering has been identified in the Hele Intrusion (Hart 2005), and yet unidentified intrusions, which may be indicated by the high-Mg sills. An understanding of the regional structures is important in the identification of additional potentially mineralized intrusions in the Embayment as the location of the mafic to ultramafic intrusions appears to have been controlled by a series north and northwest trending faults. These faults appear in many cases to be re-activated Archean structures (Hart 2005; MacDonald and Tremblay 2005).

Two models have been proposed for the formation of the Nipigon Embayment. Franklin et al. (1980) proposed that the Embayment is a result of a failed arm of the Mesoproterozoic Keweenaw Midcontinent Rift. Alternatively, Hollings et al. (2004) proposed that it is an intracratonic basin formed as a result of relaxation following the thermal upwelling that formed the 1547 Ma English Bay Complex (Heaman et al. 2005). Regardless of the age of formation of the Embayment, the 1106-1124 Ma (Heaman et al. 2005) ages for the mafic to ultramafic intrusions indicate that they are related to the development of the Midcontinent Rift.

Regional Implications

The mafic to ultramafic intrusions of the Nipigon Embayment have ages ranging from 1106-1124 Ma (Heaman et al. 2005), but are intruded by sills of the 1110-1114 Ma Nipigon Diabase Sill Complex (Heaman et al. 2005). Emplacement of the intrusions probably overlapped with the diabase sills as the Jackfish Sill has an age of 1112±3 Ma (Heaman and Easton 2005). These ages are generally older than much of the magmatism related to the Midcontinent Rift system further to the south, such as the 1105-1108 Ma Osler Group volcanics (Davis and Sutcliffe, 1985), the Cu-Ni-PGE mineralized 1099 Ma Crystal Lake Gabbro (Heaman and Easton 2005), and the ~1096 Ma Duluth Complex (Paces and Miller 1993).

Exploration activity south of Lake Superior has outlined 5 million tonnes of 3.68% Ni and 3.06% Cu with significant PGE contents (copper-rich veins hosted by the surrounding Paleoproterozoic sedimentary rocks in the Mesoproterozoic Yellow Dog peridotite (Rossell and Coombes 2004). Exploration about 300 km to the west intersected anomalous PGE mineralization in the Echo Lake gabbro (Billard 2003), which has an age of 1111 Ma (Cannon and Nicholson 2001). The similarity in age between the Echo Lake Intrusion and the intrusions of the Nipigon Embayment suggests that there may have been an early magmatic event which encompassed the entire Midcontinent Rift system.



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