Whole-Rock Geochemistry of the Mafic to Ultramafic Thunder Intrusion, Midcontinent Rift, Thunder Bay, Ontario

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This document summarizes the geochemistry and provides a brief interpretation of the data. These results form part of an MSc thesis study conducted by Brent Trevisan (Lakehead University) and supervised by Dr. Pete Hollings (Lakehead University) and Dr. Doreen Ames (Geological Survey of Canada). This study was a collaborative project between Lakehead University, the Geological Survey of Canada and the Ontario Geological Survey as part of the Nickel-Copper-Platinum Group Element-Chromium Ore Systems project in the Geological Survey of Canada's Targeted Geoscience Initiative 4 (TGI-4; Ames et al. 2012). A total of 104 samples were collected from surface exposures and diamond-drill core in order to characterize the petrology, mineralization and alteration footprint of the Thunder intrusion and place it within the context of the North American Mesoproterozoic Midcontinent Rift (Figure 1).

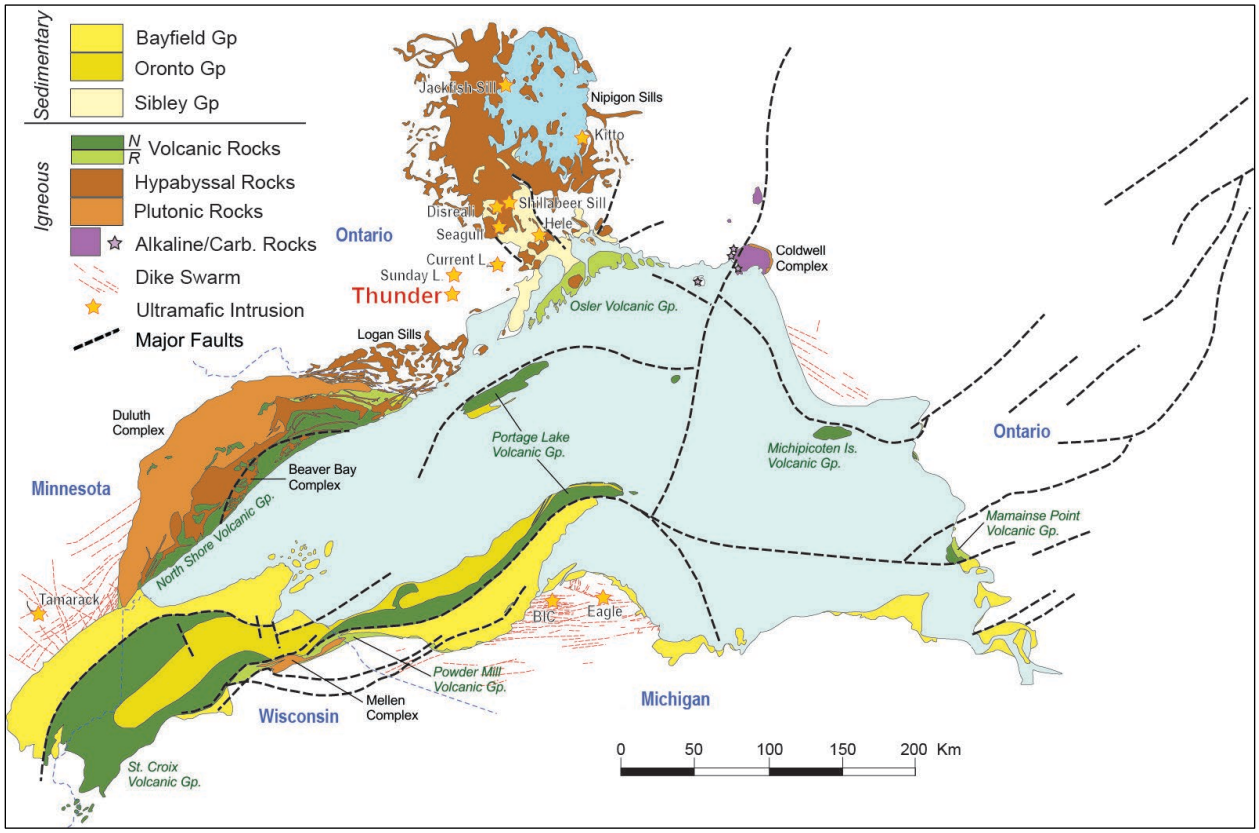

Figure 1. Present-day exposure of the Midcontinent Rift geology in the Lake Superior region. Labelled are the major volcanic and intrusive units. Stars (yellow-orange) indicate the locations of the known ultramafic intrusions associated with the early magmatic stages of Midcontinent Rift evolution. Figure *modified after* Miller and Nicholson (2013) and used with permission.

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The Thunder intrusion is a small, layered, mineralized, mafic to ultramafic intrusion located on the outskirts of Thunder Bay, Ontario, which is interpreted to be associated with the early tectono-magmatic stages of the Midcontinent Rift (Trevisan 2014). This intrusion is distinct from the other mineralized early-rift Midcontinent Rift intrusions as it is the only known occurrence hosted by the metavolcanic and metasedimentary rock assemblages of the Archean Shebandowan greenstone belt. Major textural and geochemical differences were used to divide the intrusion into a lower mafic to ultramafic basal unit consisting of feldspathic peridotite, melagabbro and gabbro, overlain by an upper gabbroic unit consisting of gabbro and hematized gabbro (Trevisan 2014). The 2 units have similar trace and rare earth element contents consistent with an origin from a single magmatic pulse that has undergone subsequent fractionation and cumulate processes (Trevisan 2014; Figure 2).

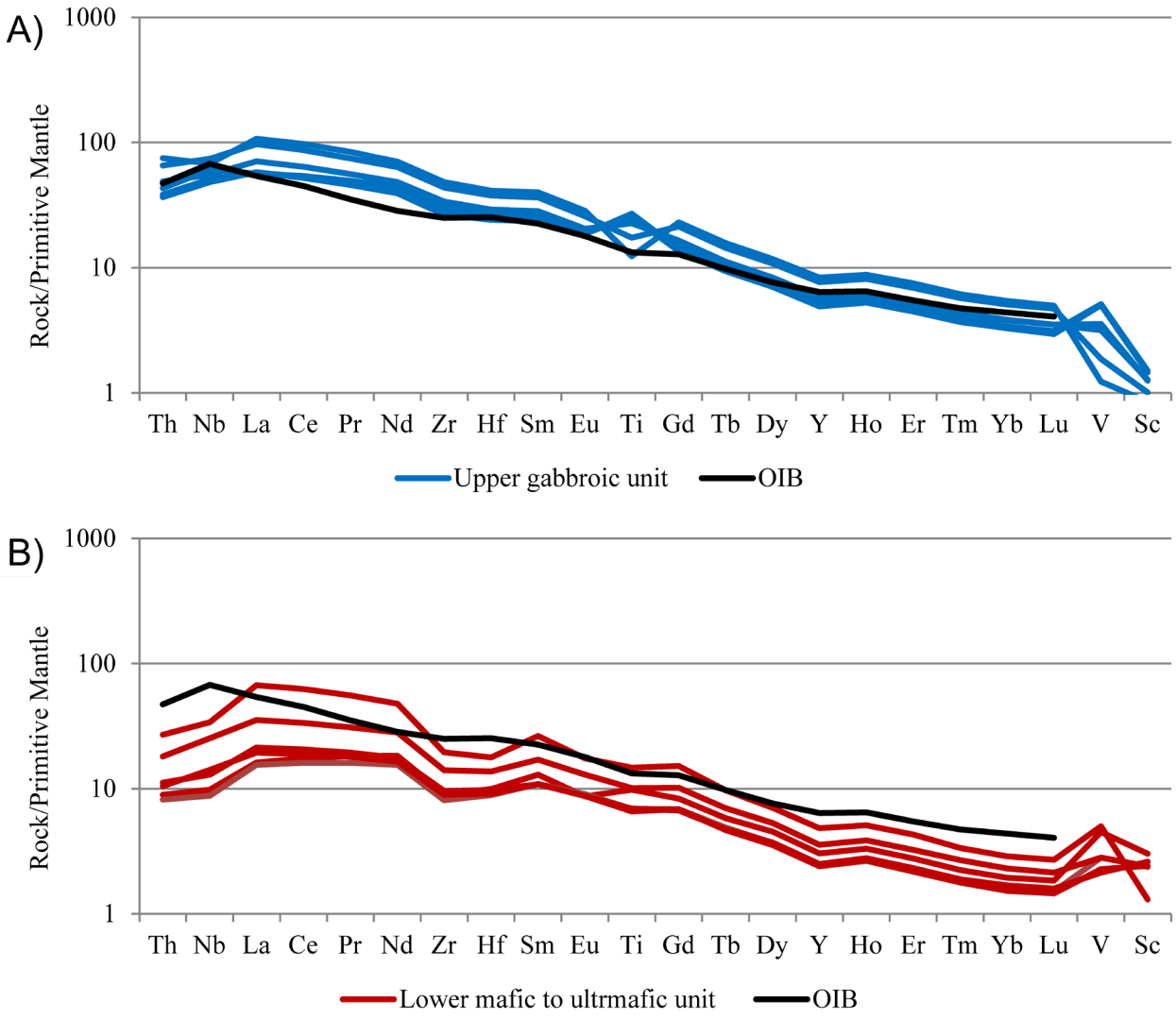

Figure 2. Primitive mantle–normalized profiles comparing the Thunder intrusive units with ocean-island basalt (OIB) using representative samples of A) the upper gabbroic unit and B) the lower mafic to ultramafic unit. Normalizing values and ocean-island basalt data *from* Sun and McDonough (1989). Upper gabbroic unit and lower mafic to ultramafic data *from* Trevisan (2014).

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The primitive mantle–normalized profiles of the Thunder intrusion are characterized by light rare earth element (LREE) enrichment and fractionated heavy rare earth elements (HREE) and are broadly comparable to modern plume-derived oceanic island basalts (OIB; Sun and McDonough 1989; *see* Figure 2) and other Midcontinent Rift early-rift mafic to ultramafic intrusions that exhibit OIB-like signatures within the Midcontinent Rift, for example, the Seagull intrusion (Figure 3; Heggie 2005). The presence of negative niobium anomalies in the uppermost section of the upper gabbroic unit, assimilation features including irregular quartz-rich fragments surrounded by pods of granophyre, and an uphole increase in thorium concentrations are consistent with progressive contamination by continental crust (Trevisan 2014).

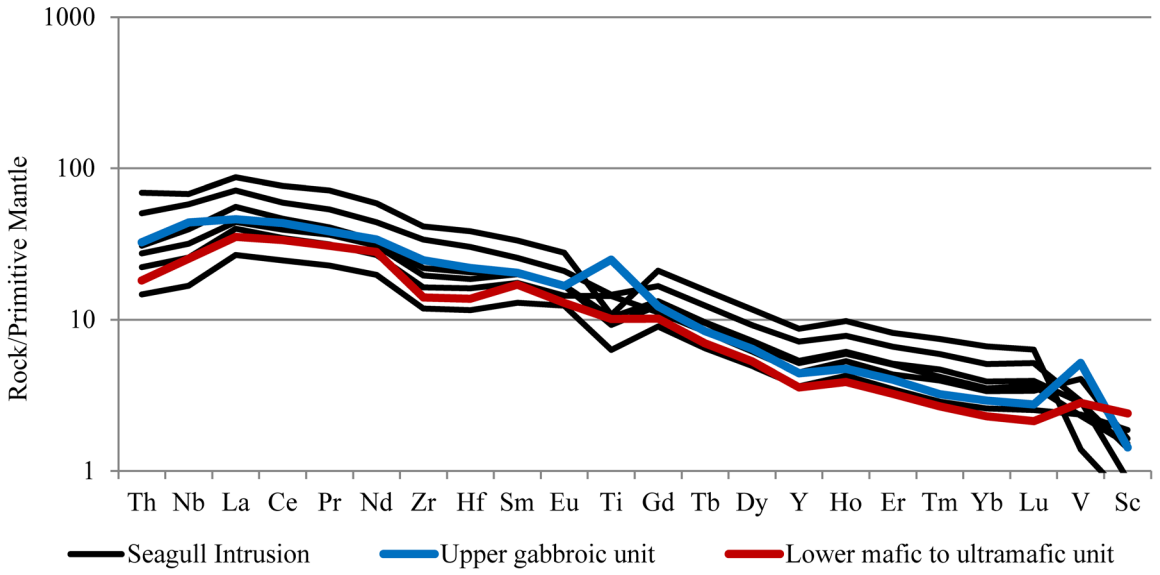

Figure 3. Primitive mantle–normalized profiles for 6 representative samples of the Seagull intrusion, one sample of the lower mafic to ultramafic unit (RTTC-BT-095), and one sample of the upper gabbroic unit (RTTC-BT-075). Normalizing values *from* Sun and McDonough (1989). Seagull intrusion data *from* Heggie (2005). Upper gabbroic unit and lower mafic to ultramafic unit data *from* Trevisan (2014).

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Hollings et al. (2007) showed that a plot of La/Sm_n versus Gd/Yb_n can be used to discriminate the intrusive units of the MCR (Figure 4). On this diagram, the upper gabbroic unit and lower mafic to ultramafic unit of the Thunder intrusion lie slightly above the field of the lower mafic to ultramafic intrusions and sills of the Nipigon Embayment on the Gd/Yb_n axis (e.g., Hele Intrusion and Shillabeer Sill, respectively) and within range on the La/Sm_n axis (i.e., between 1.00 and 3.00). The high Gd/Yb_n values are consistent with the interpretation of Hollings et al. (2007) that the parent magmas of the mafic to ultramafic intrusions of the Nipigon Embayment were derived from a deeper source than the diabase sills (e.g., Nipigon sills).

The primitive mantle–normalized nickel-copper-PGE patterns for both units of the Thunder intrusion are characterized by depletion in iridium group–platinum group elements (Ir, Ru, Rh; Figure 5) relative to platinum group–platinum group elements (Pt, Pd, Au; *see* Figure 5). Possible explanations for the fractionated PGE patterns observed in the Thunder intrusion include 1) the IPGEs may have partitioned into an earlier silicate phase, such as olivine, deeper in the magmatic system; and 2) the formation of an earlier sulphide liquid phase deeper in the system that concentrated the IPGEs, such as the monosulphide solution (Trevisan 2014). The nickel-copper-PGE patterns for the disseminated sulphide mineralization hosted by the lower mafic to ultramafic unit of the Thunder intrusion are similar to the upper massive and semi-massive sulphide zones and chalcopyrite-rich veins of the Eagle deposit (Ding, Ripley and Li 2011). The similarity between the Thunder intrusion and Eagle deposit nickel-copper-PGE signatures is consistent with the second model proposed indicating the possibility of an undiscovered sulphide horizon in the Thunder intrusion.

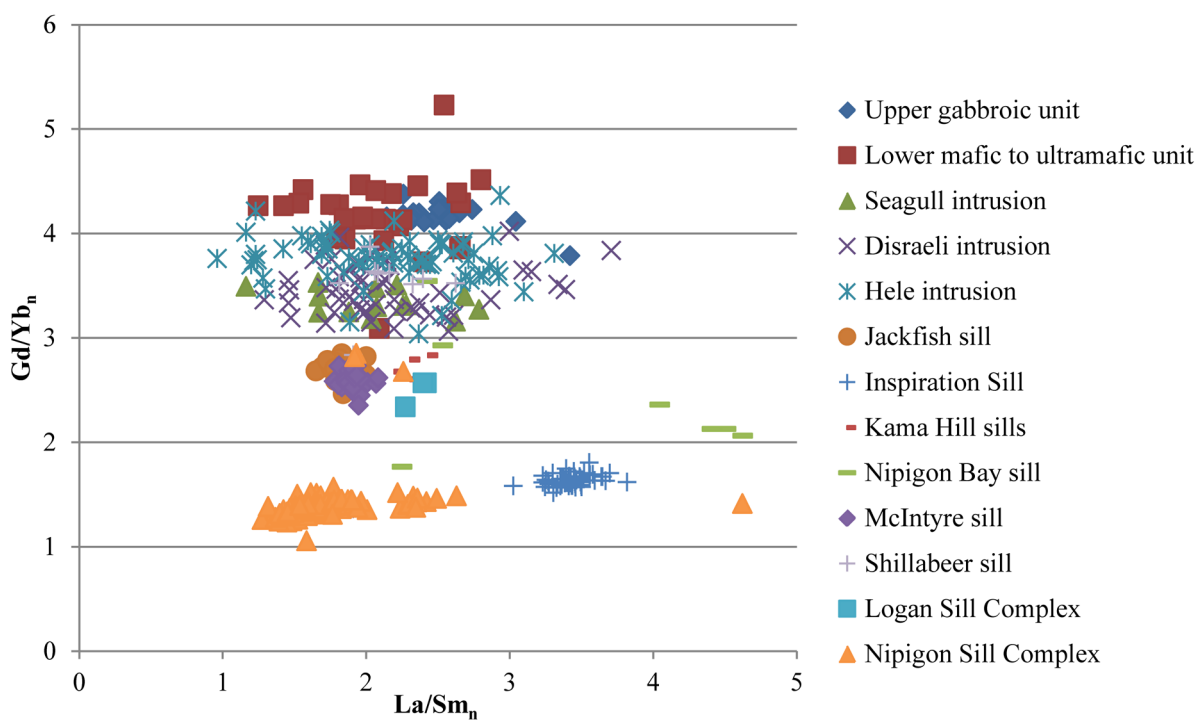

Figure 4. Plot of La/Sm_n versus Gd/Yb_n for the upper gabbroic unit and lower mafic to ultramafic unit of the Thunder intrusion and intrusions of the Nipigon Embayment. Chondrite-normalized rare earth element ratios calculated using the values of Sun and McDonough (1989). Data for the upper gabbroic unit and lower mafic to ultramafic unit of the Thunder intrusion *from* Trevisan (2014). Data for Nipigon Embayment intrusions are *from* Cundari et al. (2013).

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The contact metamorphic aureole produced by the emplacement of the Thunder intrusion is negligible and is limited to a 5 m zone characterized by static annealing textures that overprint the metamorphic fabric. Possible explanations for the lack of extensive contact metamorphic effects discussed by Trevisan (2014) include the small size of the intrusion (e.g., 800 by 1000 by 500 m), the poor permeability of the wall rock (hosted within a shear zone), the lack of highly contrasting compositions (i.e., mafic to ultramafic intrusive rock juxtaposed to mafic to intermediate volcanic rock) and pre-existing metamorphosed wall rock (i.e., low-grade metamorphic overprint) resulting in a cold "unreactive" host rock. In addition, no hanging-wall rocks are preserved at the Thunder intrusion, unlike other early-rift mafic to ultramafic intrusions that are typically buried, thereby limiting the investigation of the alteration footprint and the development of vectoring techniques for targeting buried mineralization (e.g., Sunday Lake; Transition Metals Corp. 2014).

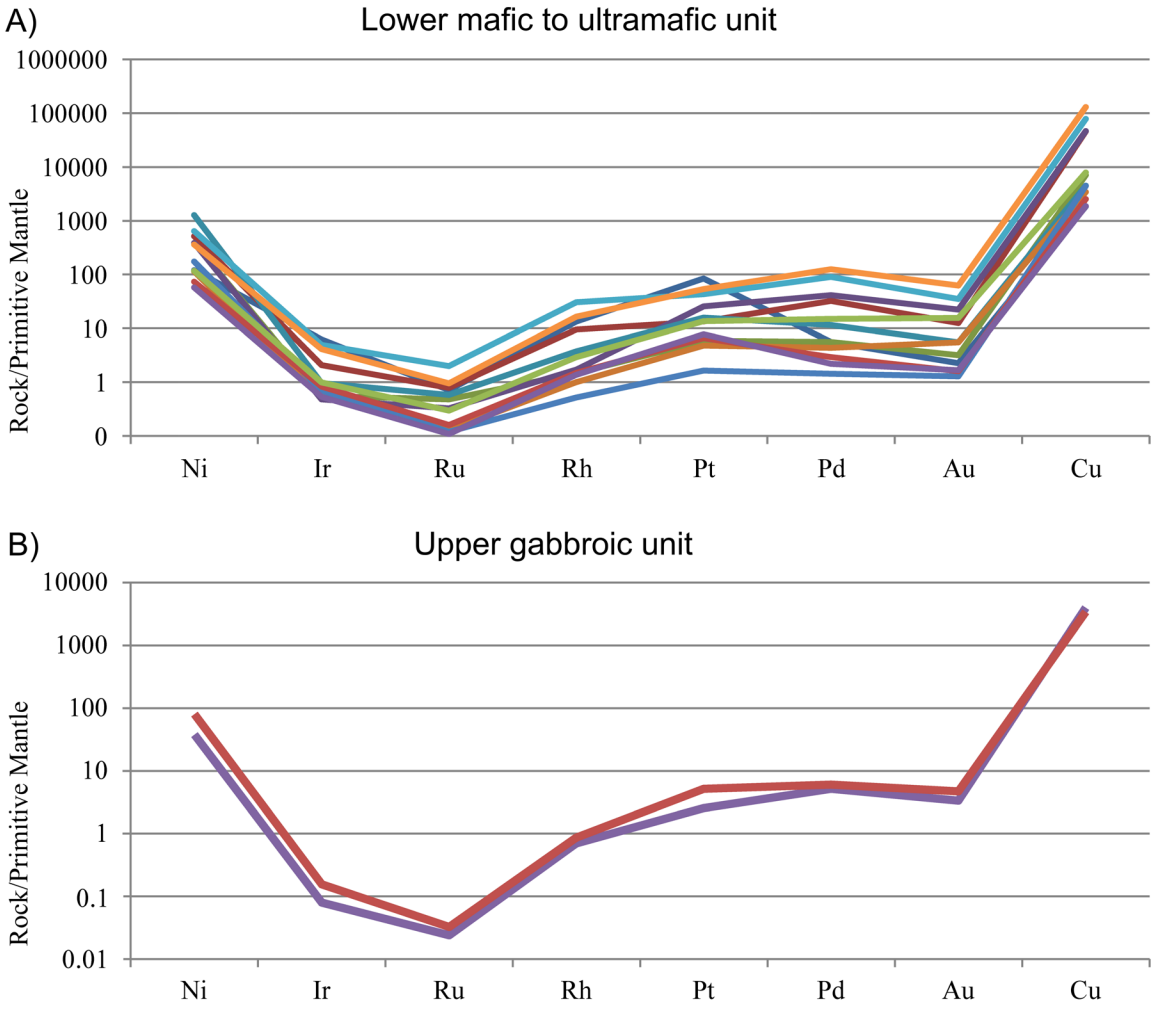

Figure 5. Primitive mantle–normalized whole-rock nickel-copper-PGE profiles for samples from diamond-drill hole 07TH004 from A) the lower mafic to ultramafic unit and B) the upper gabbroic unit. Primitive-mantle values are *from* McDonough and Sun (1995).

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