Geology of the Mount Mollie Dike, Midcontinent Rift, Northwestern Ontario

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OVERVIEW OF STUDY AND INTERPRETATION

The interpretation presented herein is part of a Miscellaneous Release—Data (MRD) that provides whole-rock geochemistry for a total of 77 drill core and 24 outcrop samples collected of the Mount Mollie dike during an MSc study carried out at Lakehead University by the lead author (O'Brien 2018). The samples were analyzed at Geoscience Laboratories (Geo Labs), Ontario Geological Survey, in Sudbury as part of Project Unit (PU)15-009. The geochemical analyses described in this MRD, along with detailed petrography described in O'Brien (2018), were carried out in order to petrogenetically characterize the Mount Mollie dike. Preliminary results related to this project were reported in O'Brien et al. (2015) and O'Brien, Hollings and Miller (2015, 2016).

The Mount Mollie dike is an arcuate, 60 to 350 m wide, macrodike that extends for 35 km along the northwestern shore of Lake Superior (Figure 1)(Smith and Sutcliffe 1989). The Mount Mollie dike is part of the 1.1 billion-year-old Midcontinent Rift (MCR) and was emplaced into the Paleoproterozoic Rove Formation of the Animikie Basin, approximately 50 km south-southwest of Thunder Bay. A U/Pb

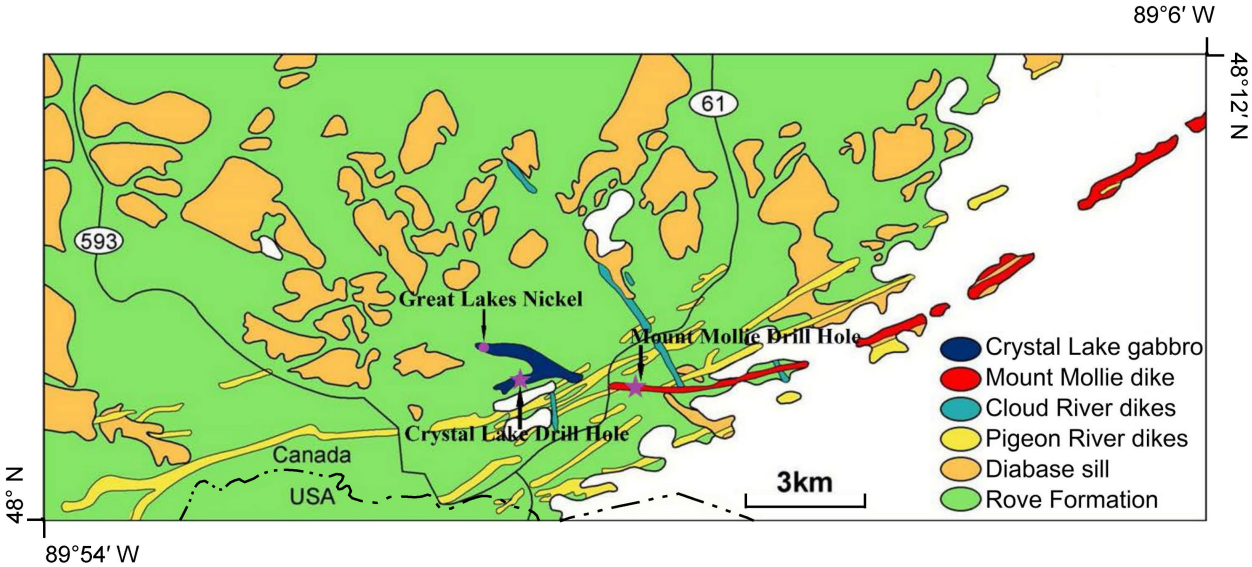

Figure 1. Generalized geology map of Crystal Lake gabbro, Mount Mollie dike and surrounding rocks. Figure *from* O'Brien et al. (2015).

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baddeleyite age determination on the Mount Mollie dike suggests that it formed at 1109.3 ± 6.3 Ma (Hollings et al. 2010); however, this age is not consistent with the Mount Mollie dike being normally polarized magnetically (Hollings et al. 2010). Normal magmatic polarity is an attribute of MCR rocks younger than 1102 Ma (Davis and Green 1997; Piispa, Smirnov and Pesonen 2011), which suggests that the age obtained by Hollings et al. (2010) may contain some inheritance.

Texturally and geochemically, the Mount Mollie dike can be broadly divided into an Upper Zone and a Main Zone, with additional subdivision of the Main Zone into an upper and lower sequence and a pegmatitic segregation subzone (Figure 2, left). The Upper Zone consists of ferrodiorite and likely represents the end product of extensive crystal fractionation. The Main Zone is characterized by troctolite, augite troctolite, olivine gabbro, and gabbro, with MgO, CaO, Al_2O_3, and Ni concentrations decreasing upward, and SiO_2, TiO_2, K_2O, Na_2O, P_2O_5, and incompatible trace element concentrations increasing upward, consistent with bottom-up fractional crystallization (Figures 3 and 4).

Strong differentiation of the Mount Mollie dike magma is indicated by the change in habit of clinopyroxene from ophitic (intercumulus) to granular (cumulus), which is the basis for the subdivision of the lower and upper sequences of the Main Zone. The lower sequence of the Main Zone also hosts a 24 m thick interval containing 1 to 2 m wide gabbroic pegmatite layers. These pegmatite layers are interpreted to be the result of localized enrichment of magmatic volatiles. The presence of an evolved core in the surface expression of the Mount Mollie dike, previously mapped by Geul (1973) and Smith and Sutcliffe (1989), suggests that there was some degree of lateral crystal fractionation in addition to bottom-up fractionation. The well-defined fractionation sequence, as well as an absence of abrupt geochemical changes, suggests that the Mount Mollie dike fractionally crystallized from a single pulse of magma.

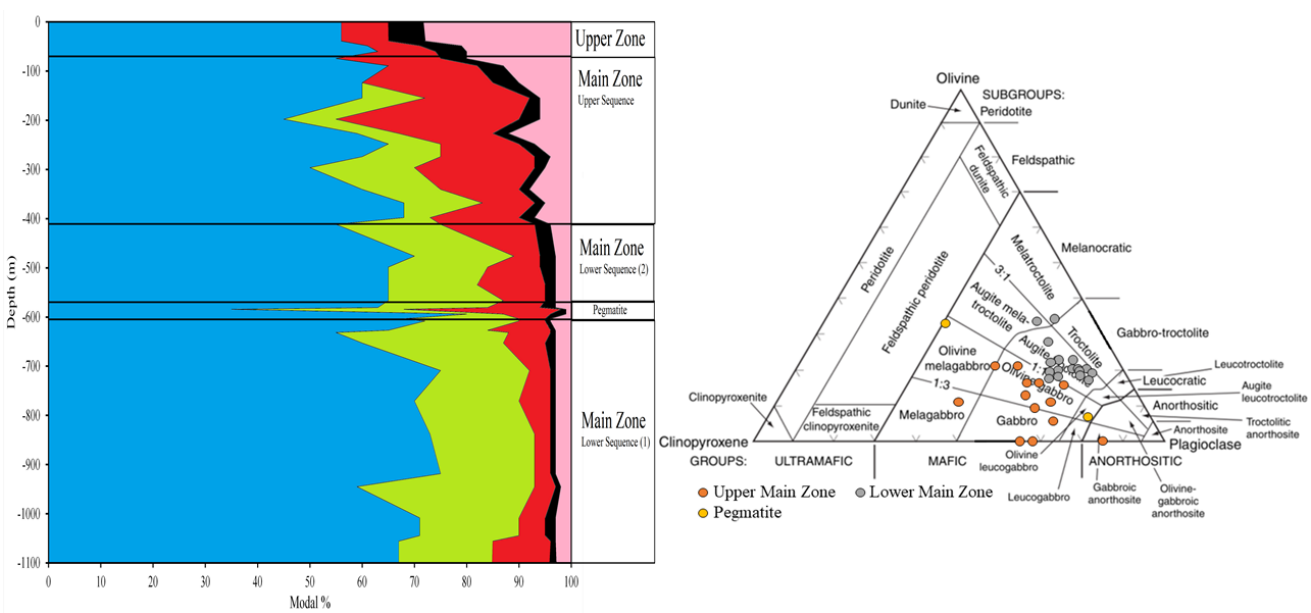

Figure 2. **Left.** Down-hole mineral modal abundance variations for the Mount Mollie dike (MMD) drill-core samples. Blue - plagioclase, green - olivine, red - clinopyroxene, black - Fe-Ti oxide, pink - accessory minerals. **Right.** Ternary diagram of normalized plagioclase, olivine and clinopyroxene modal abundances plotted for rock type for the MMD drill-core samples. Fields *after* Miller et al. (2002).

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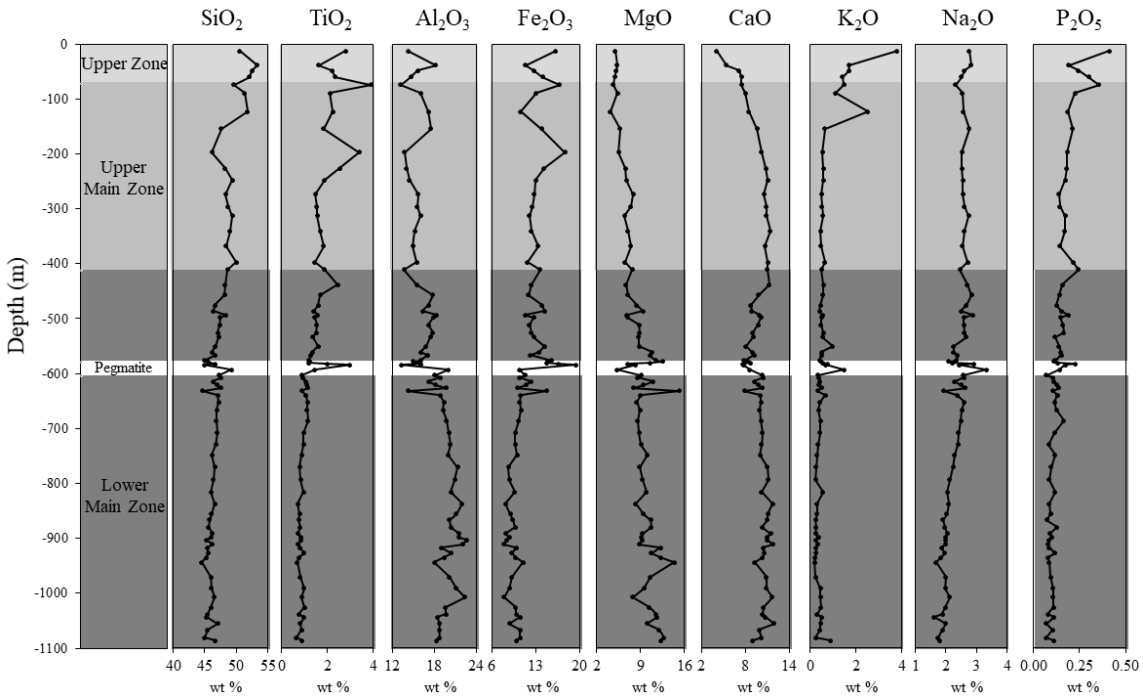

Figure 3. Down-hole variation diagram of major element oxides, in wt%, for the Mount Mollie dike.

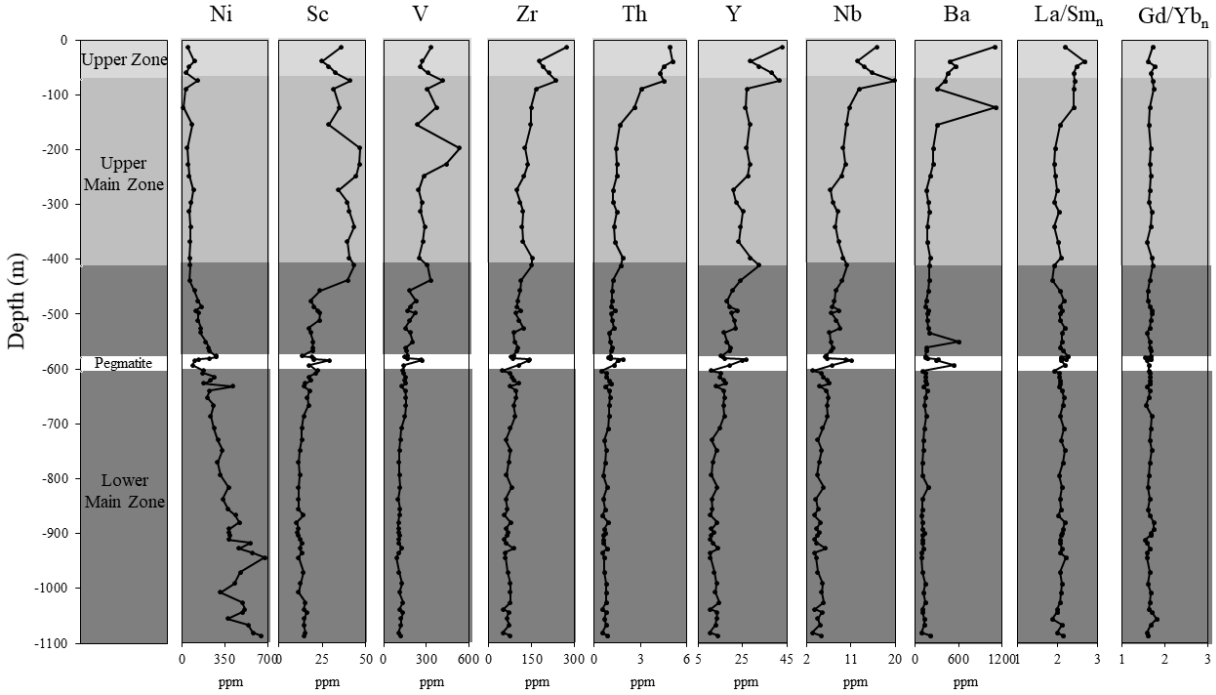

Figure 4. Down-hole variation diagram for select trace elements for the Mount Mollie dike.

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In an attempt to determine if the surface expression of the Mount Mollie dike is linked petrogenetically to the drill-core samples at depth, outcrop samples were also collected by this study. This was undertaken in part because the U/Pb age reported in Hollings et al. (2010) was from a surface sample. All the major element concentrations of the outcrop samples were within the range of the drill-core samples, and using MgO concentrations as a proxy for comparison and differentiation, the outcrop samples all fall in the range of drill-core samples from the Upper and Upper Main zones. Trace element concentrations of the outcrop samples are also broadly similar to those of the drill-hole samples, with an enrichment of the light rare earth elements (LREE) compared to the middle rare earth elements (MREE), as well as MREE enrichment over the heavy rare earth elements (HREE).

A plume model has generally been accepted as the cause for the Midcontinent Rift magmatism (e.g., Nicholson and Shirey 1990). During the ascent of the plume-derived magma that ultimately formed Mount Mollie dike, there was potential for contamination from Archean crust, Paleoprotozoic crust, and subcontinental lithospheric mantle (SCLM). Plots of normalized La/Sm (La/Sm_n) *versus* Th/Yb and Nb/Nb* from the Mount Mollie dike drill core and surface samples suggest that there was both localized and widespread crustal contamination of the magma (Figure 5). Localized contamination is suggested by the fact that only a few samples from the Mount Mollie dike have elevated La/Sm_n and Th/Yb values.

The consistent presence of a negative Nb anomaly in all of the samples was not expected for the rocks of the Mount Mollie dike. One explanation for the Nb anomaly is widespread crustal contamination of the Mount Mollie dike magma. As there are 3 possible sources of contamination, all of which have negative Nb anomalies (i.e., Paleoproterozoic crust, Archean crust, and SCLM), determining the precise cause of the Nb anomaly in the Mount Mollie dike rocks is a challenge.

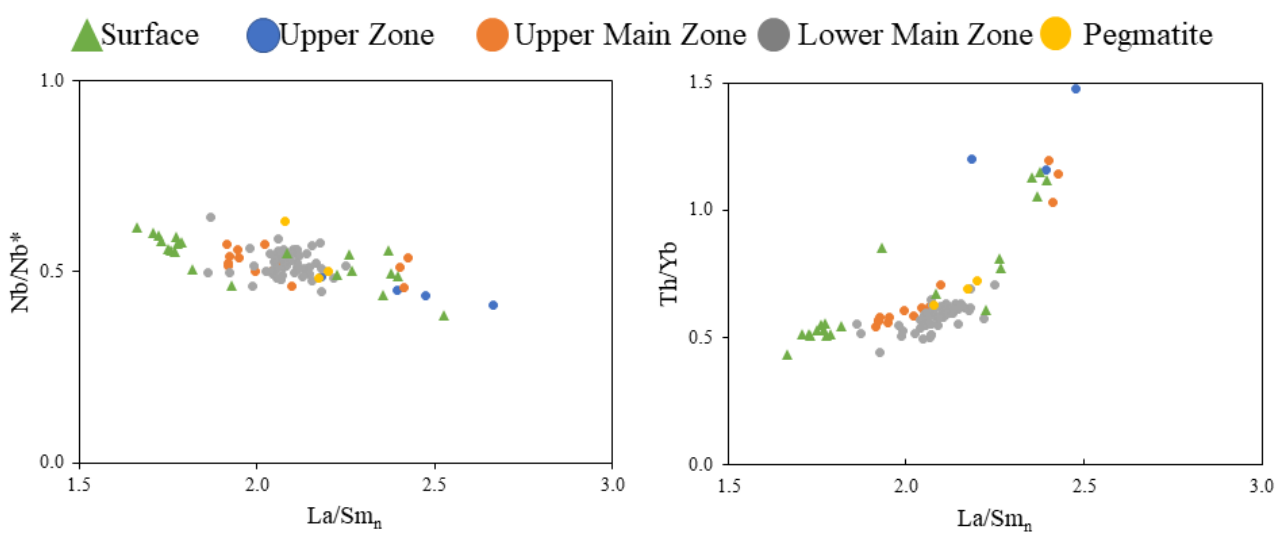

Figure 5. La/Sm_n values *versus* Nb/Nb* and Th/Yb for the Mount Mollie dike.

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