Geochemistry of the Mafic and Felsic Norite: Implications for the Crystallization History of the Sudbury Igneous Complex, Sudbury Ontario

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Introduction

The 1.85 Ga Sudbury Igneous Complex (SIC) is a 60 x 30 km layered igneous body occupying the floor of a crater in northern Ontario. The SIC comprises, from base to top: a discontinuous unit of sulfide-rich, inclusion-bearing norite (Contact Sublayer), mafic norite, felsic norite, gabbro transition zones, and granophyre (Main Mass). Concentric and radial Quartz Diorite Offset Dykes extend into the footwall rocks.

The distributions of the Sublayer and associated Ni-Cu-PGE ores are controlled by the morphology of the footwall: the Sublayer and contact ores are thickest within km-sized radial depressions in the footwall referred to as embayments (e.g., Whistle Embayment) and thinnest (or often absent) outside embayments (Figure 1.).

Although the geometry of the ore environments is well known, the petrogenetic relationships between the ores, the Sublayer, and the Main Mass remain controversial. The purpose of this study has been to study mafic and felsic norite in the Whistle Embayment to aid in the understanding of the crystallization and metallogenetic history of the SIC.

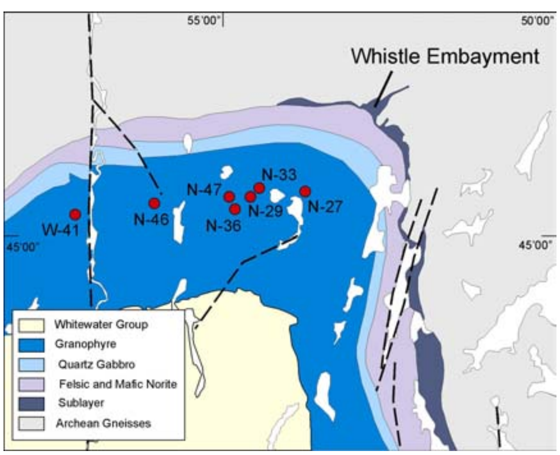

Figure 1. *The northeastern portion of the Sudbury Igneous Complex, showing the Whistle Embayment extending NE into the footwall and the locations of drill holes sampled in this study.*

Whistle Embayment Geology

The Whistle Embayment occurs along the NE margin of the basin under the Main Mass of the SIC and extends into the footwall as an Offset dyke (Whistle/Parkin Offset). Pattison (1979) and Lightfoot et al. (1997) provide detailed descriptions of the embayment environment at Whistle. The embayment contains up to ~300m of inclusion-rich, sulfide-bearing Sublayer in a well-zoned funnel extending away from the base of the SIC. Poikilitic, hypersthene-rich Mafic Norite occurs in and along the flanks of the embayment as discontinuous lenses between the Sublayer and the Felsic Norite. The Felsic Norite in the Whistle area ranges from ~450m thick adjacent to the embayment to >600m thick directly over the embayment. The Felsic Norite has a hypidiomorphic granular to sub-poikolitic texture with a low cumulus orthopyroxene content. Directly above the embayment the most basal norite occasionally contains 1-5 % sulfides with a sub-poikolitic texture.

Main Mass Geochemistry

A database has been compiled of 1153 representative analyses from each of the units of the SIC, including previous analyses from Lightfoot et al. (1997), Binney (1994), and samples collected for this study from the Mafic and Felsic Norite in the Whistle Embayment. The database of Main Mass samples was divided into 1) Granophyre (GRAN), 2) Transition zone Quartz Gabbro (TRZN), 3) Felsic Norite (FNOR), 4) Mafic Norite (MNOR), and 5) South Range Norite (SRNOR).

The Main Mass of the SIC shows a continuous range of Mg# from a minimum of ~0.5 to <0.1. The Granophyre has the lowest Mg# (0.07-0.2) followed by the Quartz Gabbro (0.07-0.3), Felsic Norite (0.3-0.5), South Range Norite (0.4-0.5), and Mafic Norite (0.47-0.56). When plotted against Mg#, most elements tend to show one of four trends and therefore can be divided into four groups based on the behavior of these elements.

Group 1 elements include Si, K, Na, Y, Nb, Zr, Hf, Zr, Rb, Ba, Th, and the REEs. The Mafic Norite generally has relatively low concentrations of Group 1 elements and the highest

Mg#. With the exception of the Quartz Gabbro these elements generally increase in abundance with decreasing Mg# stratigraphically upwards through the Main Mass of the SIC. In the Quartz Gabbro above the Felsic Norite the concentrations of these elements decrease abruptly with decreasing Mg# to a minimum value at a Mg# of 0.2. As Mg# decreases further, Group 1 elements tend to increase steadily stratigraphically upwards through the Quartz Gabbro. The Granophyre has the highest concentrations of Group 1 elements.

Group 2 elements include Fe, Ti, P, V, and Sc. This group contains elements that are generally incompatible in plagioclase and pyroxene, but compatible in accessory Fe-Ti-oxides and apatite. These elements are generally low in the Mafic Norite (with the exception of Fe, which may be the result of sulfide accumulation in the Mafic Norite) and tend to increase slightly with decreasing Mg# stratigraphically upwards through the Main Mass. These elements increase in abundance to a maximum value in the Quartz Gabbro at a Mg# of approximately 0.2 before they begin to decrease with decreasing Mg#. This peak corresponds to the peak minimum values of Group 1 elements. These elements are typically low in the Granophyre.

Group 3 elements are chalcophile elements including Ni, Cu, Co, Zn and S. The Mafic Norite has the highest concentrations of these elements. The Felsic Norite tends to have moderately high and variable abundances of these elements, and decrease with decreasing Mg#. The Quartz Gabbro and Granophyre have the lowest concentrations of these elements.

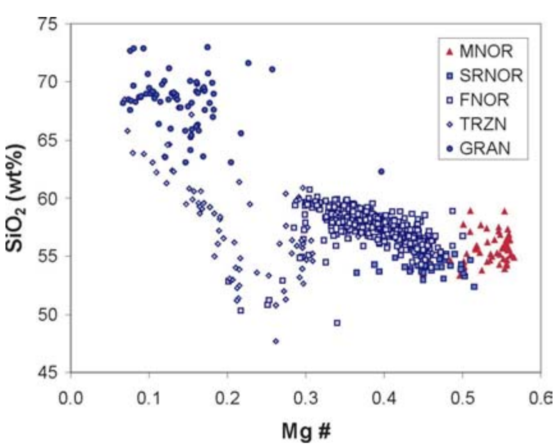

Figure 2. *Typical trend produced when Group 1 elements are plotted against Mg#.*

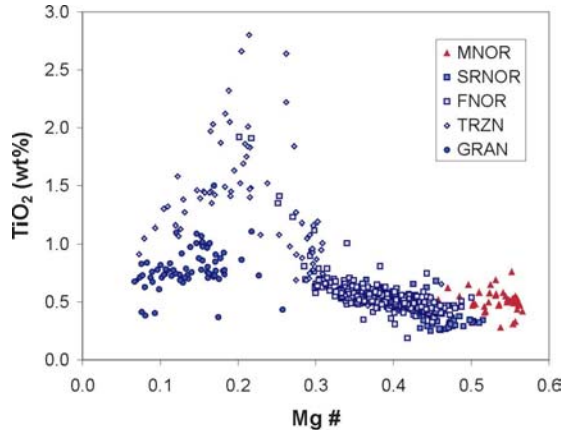

Figure 3. *Typical trend produced when Group 2 elements are plotted against Mg#.*

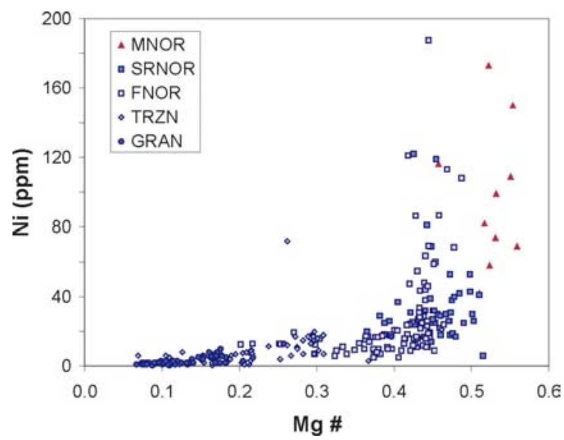

Figure 4. *Typical trend produced when Group 3 elements are plotted against Mg#.*

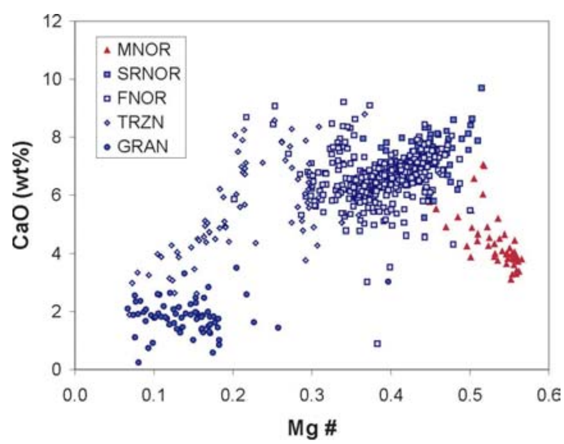

Figure 5. *Typical trend produced when Group 4 elements are plotted against Mg#.*

Group 4 elements include Al, Ca, and Sr. These elements tend to decrease steadily with decreasing Mg# stratigraphically upwards through the Main Mass of the SIC. Ca, however, is generally enriched in the Quartz Gabbro, showing a trend similar to Group 2 elements. This increase in Ca corresponds to an increase in P, Fe, and Ti in the Quartz Gabbro and is likely the result of apatite and Fe-Ti oxide accumulation in this unit.

These groups and trends can best be explained by the fractionation and/or accumulation of one or more of the following minerals during the crystallization history of the SIC: orthopyroxene, plagioclase, clinopyroxene, apatite, Fe-Ti-oxides, and sulfides.

Geochemistry of the Felsic and Mafic Norite of the Whistle Embayment

Seven drill holes intersect the embayment, including (from west to east): W-41, N-46, N-47, N-36, N-29, N-33, and N-27. Drill hole N-36 overlies the thickest Sublayer (~270m) in the center of the embayment, whereas W-41 and N-27 are outside the embayment.

Figure 7 shows the chemostratigraphy of selected elements within the Felsic Norite and where present the Mafic Norite in the Whistle Embayment. In the cores sampled outside the embayment, Mg increases stratigraphically downward (W-41, N-27). Directly over the embayment, however, the Mg begins to increase downward, but remains constant or decreases stratigrap-hically downward near the bottom of the Felsic Norite. Ti typically decreases stratigraphically downward outside the embayment, but within the embayment Ti increases stratigraphically downward. This “reverse” trend exists only in the lower norite above the embayment and therefore it can be used to vector in on potentially mineralized embayments.

Conclusions

The geochemistry of the Mafic and Felsic Norite vary with proximity to the Whistle embayment. A zone of lower norite that appears to be present only above the embayment shows different trends in Mg and Ti. These differences suggest a process other than simple crystal fractionation and gravity settling occurred in the embayment environment, and can be used to vector in on other potentially mineralized embayments. Trace element geochemical data are being used to better define the process involved in forming the Felsic Norite above embayments.

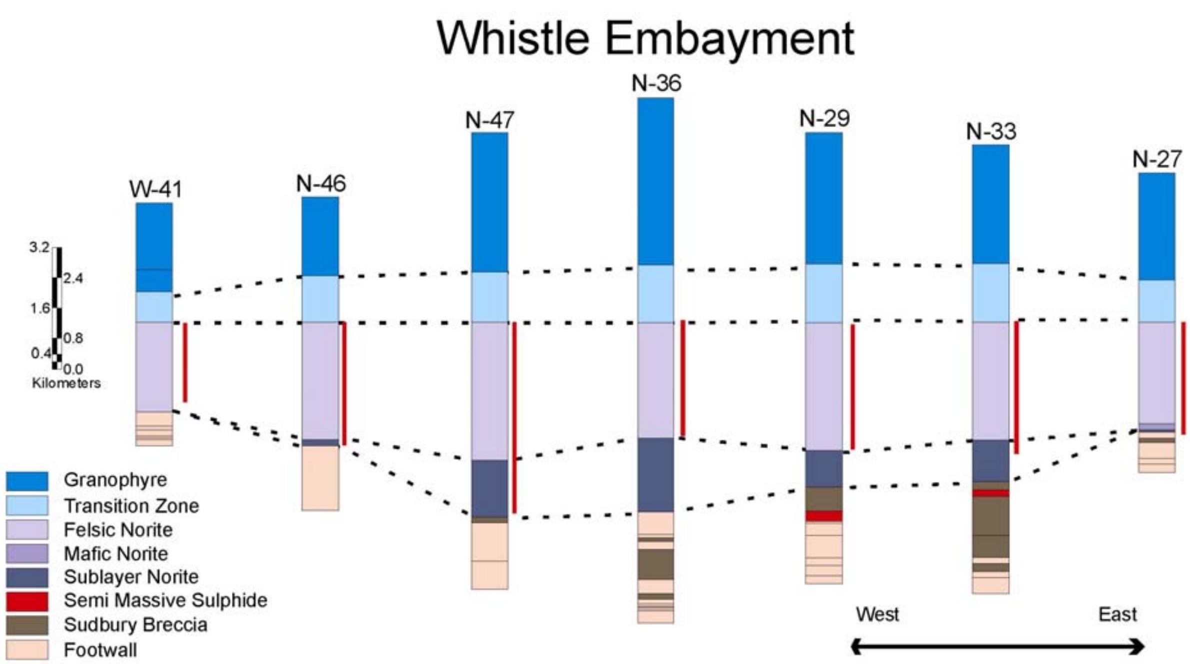

Figure 6. *Stratigraphy of the Whistle Embayment. The red bars indicate the intervals where the core was sampled approximately every 10m. Selected geochemical stratigraphy of the sampled zones is given in Figure 7.*

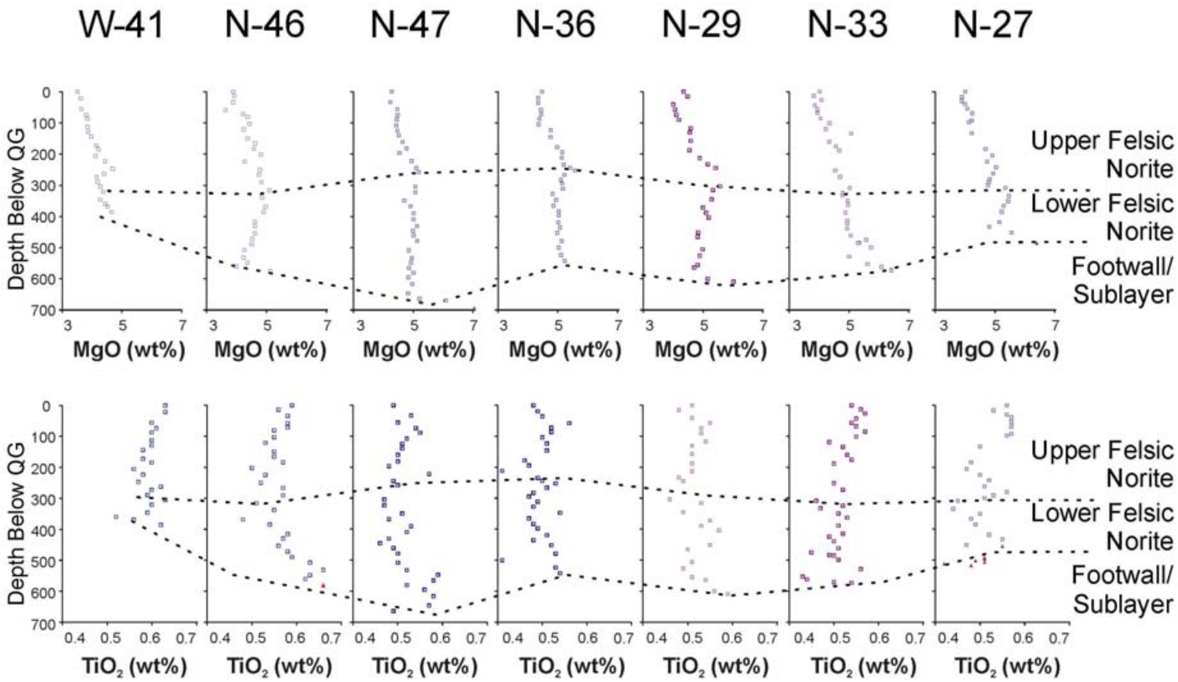

Figure 7. *Variations in MgO and TiO_2 with stratigraphic height in the Felsic and (where present) Mafic Norite above the Whistle Embayment.*

References

Binney, P.W., 1994. Whole Rock Geochemistry Sudbury Igneous Complex - some initial results - Falconbridge Internal Report B000002, 1-18p.

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