Granite-Gabbro Relations in the Mineral Lake Intrusive Complex

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Abstract

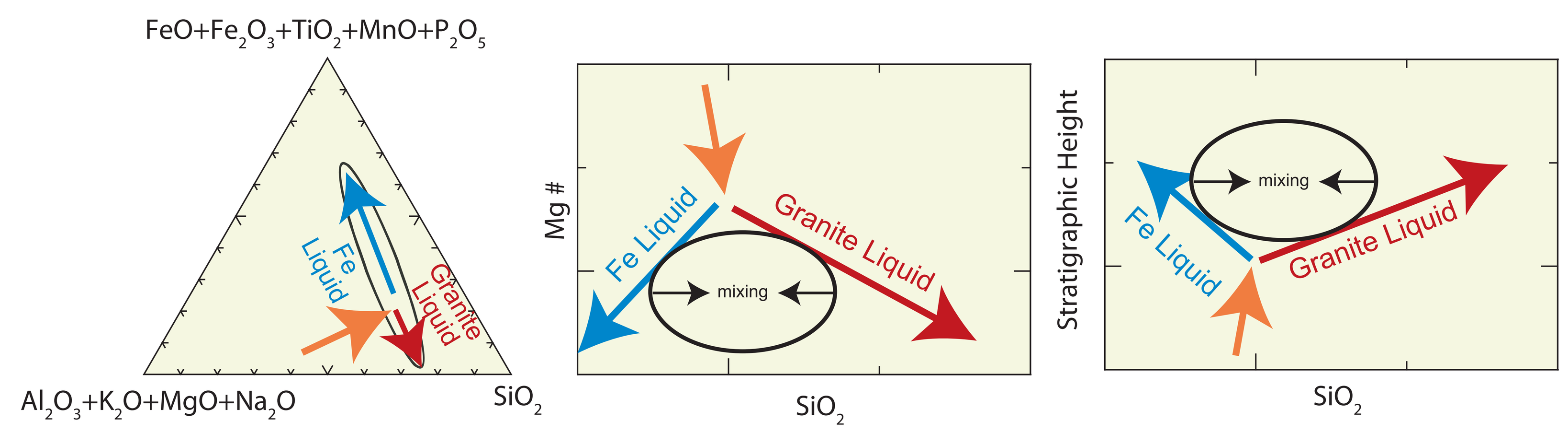
The Mineral Lake Intrusive Complex (MLIC) is a Layered Mafic Intrusion (LMI) located in northeastern Wisconsin. Granitic and gabbroic rocks are intimately associated in the MLIC, with each rock type often containing inclusions of the other. The relationship of these two magma types is the subject of some debate among geologists. Recently, we have developed an alternative model for the origin of granite in LMIs. The model holds that both the granitic and gabbroic rocks were derived from a common parent magma that experienced liquid immiscibility as crystallization proceeded. We suggest that as the parent magma cools, magma trapped within the crystalline framework evolves to Fe-rich compositions as Mg-rich minerals are removed. Eventually the evolved magma becomes saturated in a silica-poor, Fe-rich 'sludge' that quickly segregates from a residual silica-rich melt. The dense Fe-rich liquid sinks deeper into the crystal mush, whereas the buoyant granitic liquid migrates up through the overlying basaltic magma chamber. The granitic liquid either escapes to the surface to become rhyolite or is emplaced within overlying rocks as dikes, sills, and pods of granite. Here we examine the major and trace element variations of MLIC rocks to test this model for the origin of granite.

Introduction

An understanding of the evolution of layered mafic intrusions (LMIs) is useful for two very important reasons. First, these igneous bodies serve as the primary host for several resources (including Pt, Cr, V, and Ti) critical to our industrial society. Second, these fossilized magma chambers represent a complete record of the crystallization of basaltic magma, and therefore provide unique insights into the evolution of the material that makes up over 75% of the Earth's surface. Yet, the details of the evolution of LMIs remain obscure and controversial (Hunter & Sparks, 1987; McBirney & Naslund, 1990). For example, many studies of the well-exposed Skaergaard Intrusion in Greenland document a relatively simple, closed-system evolution in which a single vat of magma progressively crystallized from the outside in. However, the compositions of individual rock layers do not represent realistic magma compositions, and the average composition of the entire intrusion is significantly more mafic than the initial basaltic melt preserved on the chilled margins of the intrusion. The Mineral Lake Complex represents an ideal place to study compositional variations within an LMI, as tectonic rotation exposed a sub-vertical section across the body. Reconnaissance studies have investigated the mineralogical (Olmsted et al., 1982) and whole-rock compositional (Seifert et al., 1992) variation within the body, but a detailed study focused on stratigraphic variations of major and trace elements within the body has not been completed.

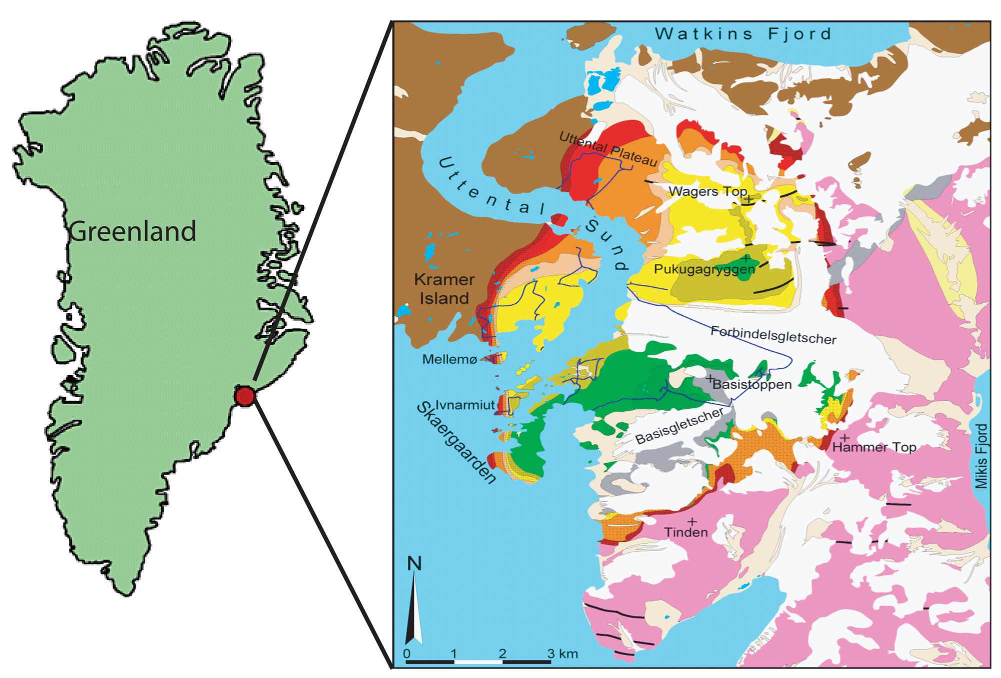
The Model

Over the last few years, we have been developing a new model for the origin of granitic magma that involves the sequential extraction of buoyant, felsic residual liquids generated within mafic magma chambers. It has long been recognized that removal of mafic minerals leads to more silica-rich (i.e, felsic) residual melts. This is the fundamental precept behind 'Bowen's Reaction Series', which is taught in every introductory geology class. Indeed, suites of magmas from around the world show the predicted silica enrichment observed by Bowen (and all subsequent researchers) in controlled experiments. However, LMIs do not show the expected changes in composition from margin to core. Our proposed model invokes the removal of evolved felsic liquids from within a crystal mush zone located behind the advancing crystallization front. The felsic liquids migrate up, first through the host crystal mush and subsequently through the overlying basaltic magma. Their evolved composition prevents them from mixing with the mafic liquid, and their enhanced buoyancy allows them to penetrate through the overlying roof and up into the overlying country rocks to eventually crystallize as granitic bodies or erupt as rhyolitic lavas. Our model is bolstered by the observation that every major LMI is associated with voluminous granitic and rhyolitic magmatism of equivalent age. A detailed geochemical study of an unaltered LMI is required to fully test this model.

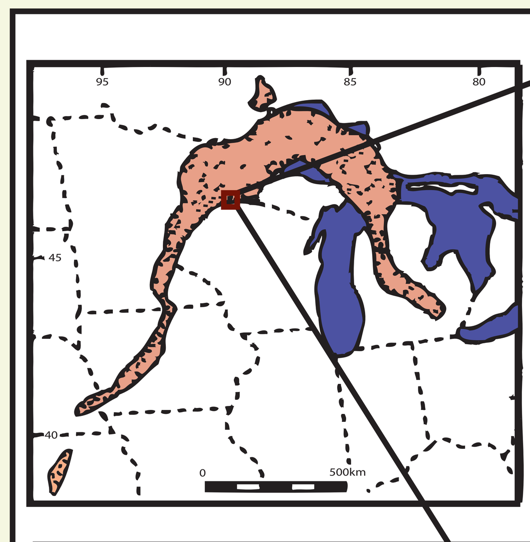


Immiscibility field from Philpotts, 1979

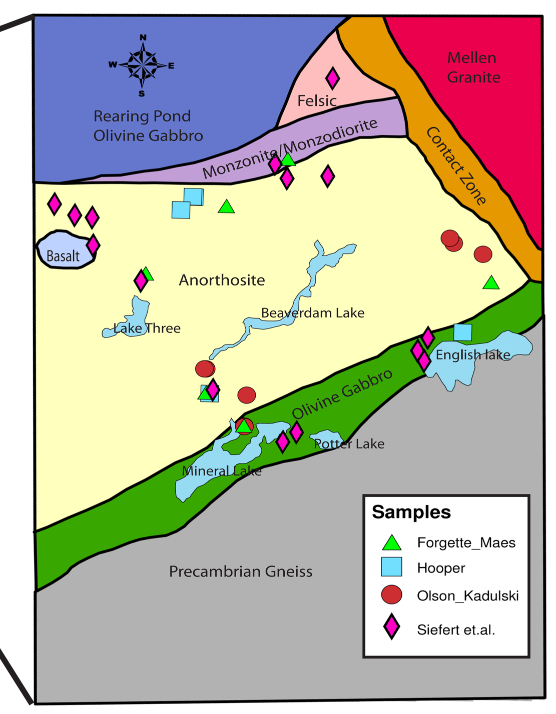
Comparing the Skaergaard and Mineral Lake Intrusions



Outcrop of the Skaergaard Intrusion is well exposed.

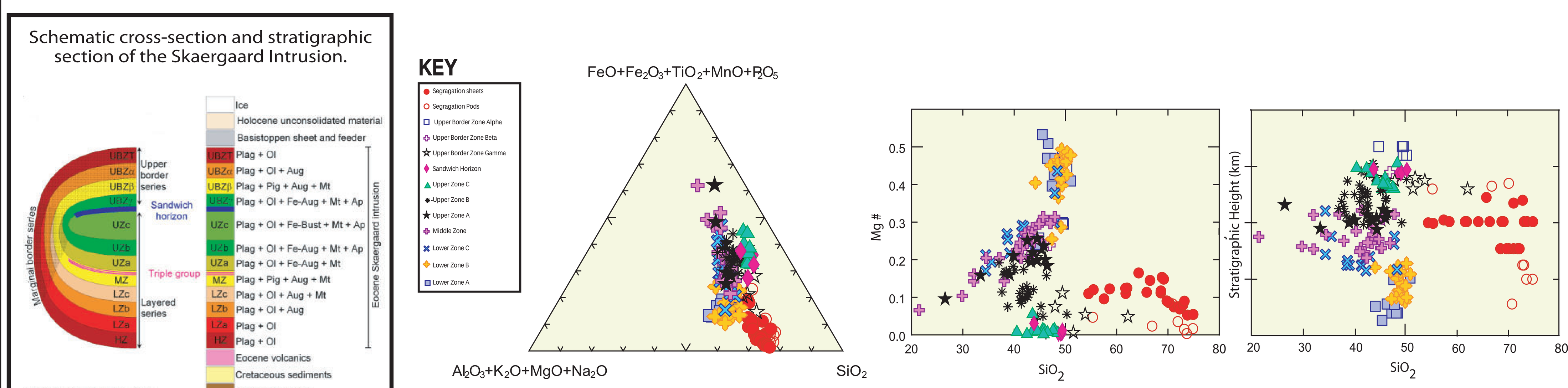


The Mineral Lake Intrusive Complex is a small component of the 1.1 Ga mid-continent rift, which stretches from Michigan, through Lake Superior, and down to Oklahoma.



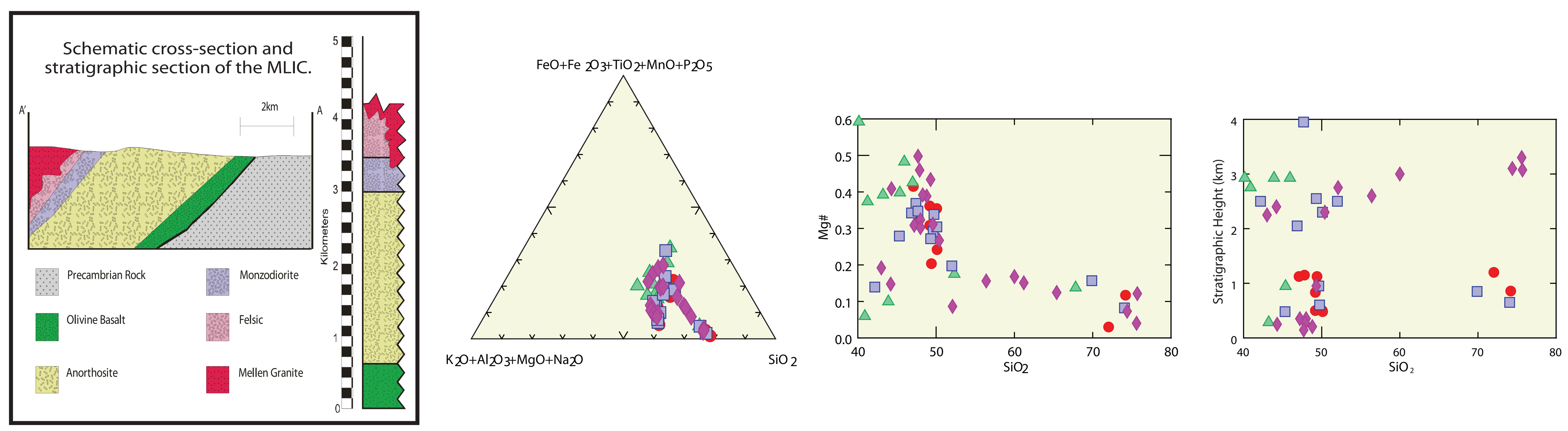
Unlike the Skaergaard, outcrop of the Mineral Lake Intrusive Complex is obscured by dense vegetation and covered by glacial overburden. Finding good rock exposure can be difficult.

Geochemical Variations in the Skaergaard Intrusion



(Data from McBirney, 1989; 1998; Jang et al., 2001; Hirschmann, 1992; Larson & Brooks, 1994)

Geochemical Variations in the Mineral Lake Intrusive Complex



Acknowledgements

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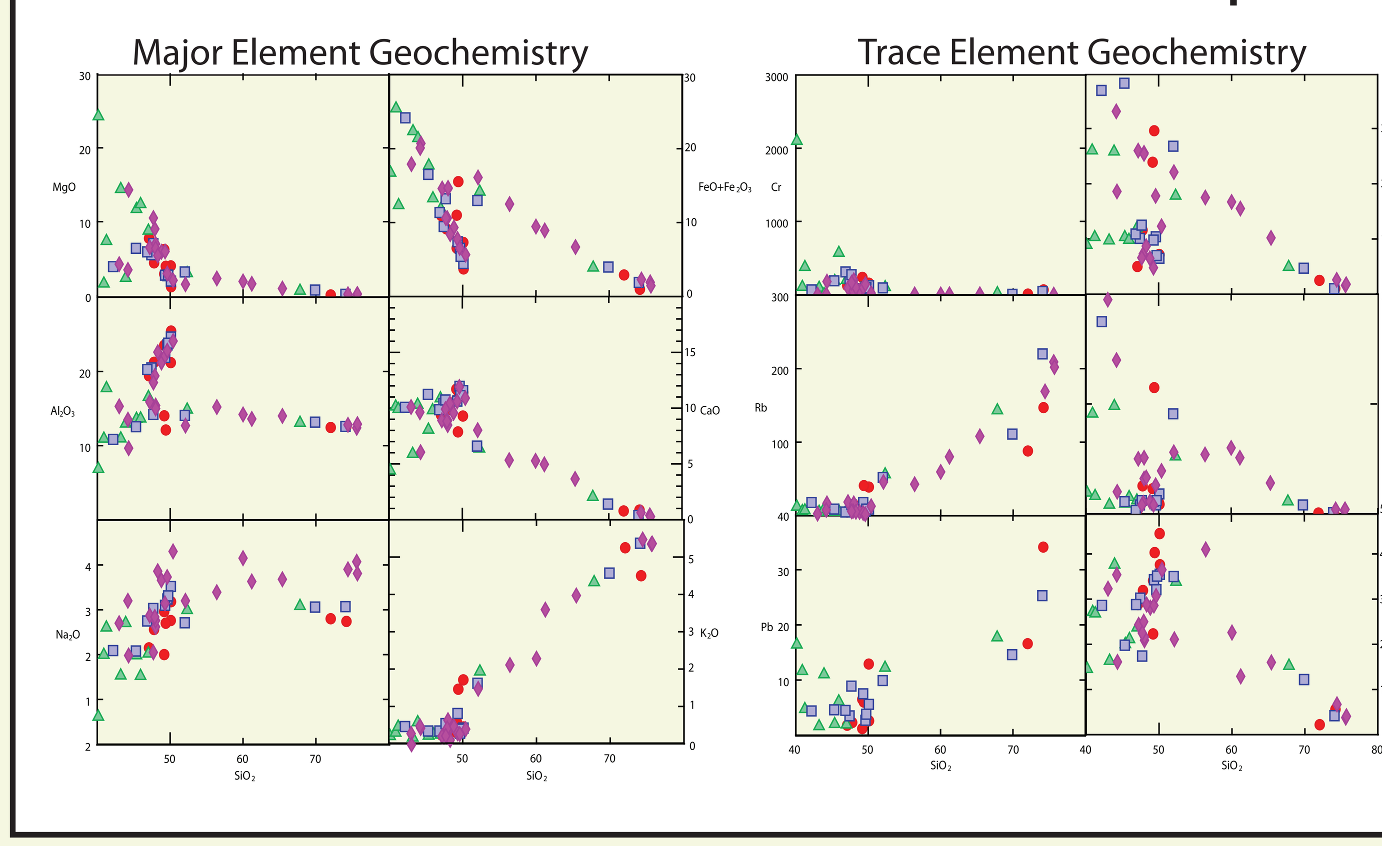
Conclusions

- Major and trace element geochemistry of MLIC samples show three distinct trends; one that describes the behavior of elements that partition into iron-rich liquid, a second that describes the behavior of elements that partition into SiO2-rich liquid, and a third that that describes the behavior of elements that partition into plagioclase feldspar of the crystalline framework.
- The whole-rock geochemical variations in the MLIC match the trends observed in the Skaergaard Intrusion.
- The whole-rock geochemical trends observed in the MLIC and the Skaergaard Intrusion are consistent with a new model for the formation of granite and the development of rhythmic layering in LMIs.

Major and Trace Element Geochemistry of the Mineral Lake Intrusive Complex

Major Element Geochemistry

Trace Element Geochemistry



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Future Research

We plan to continue our field mapping, sampling, and geochemical analysis to better understand the evolution of the MLIC magmatic system. We hope to expand our analysis to examine additional trace elements, such as the REEs, to better constrain the nature of liquid immiscibility in the system. Finally, we aim to simulate the geochemical evolution of the MLIC using known distribution coefficients in Rayleigh and Equilibrium Fractionation models that include segregation of silica- and iron-rich liquids.