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An Inquiry-Based Approach to Learning Petrology Using Student-Generated Data

Karl R. Wirth, *Geology Department, Macalester College, St. Paul, MN 55105 (wirth@macalester.edu)*

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Introduction

An important objective of all science education is to help students develop an understanding of the fundamental methods of the scientific process. This goal can be difficult to accomplish in the absence of authentic scientific experiences. In essence, if students are to acquire the higher order skills necessary for posing questions, constructing explanations, collecting evidence, and testing hypotheses, they must do so in a learner-centered environment. Furthermore, the Learning-For-Use framework (Edelson, 2001) suggests that learning must be motivated by a perceived need for knowledge or skills on the part of the student, that understanding is constructed from experience and instruction, and that knowledge must be organized before it can be applied. Many of these learning stages are facilitated by inquiry-based projects that involve working with data.

School should be less about preparation for life and more like life itself
(John Dewey)

The Petrology course at Macalester College is designed around a semester-long activity, the Sonju Project. The course utilizes a studio format and meets for three two-hour sessions each week. This format helps blur the distinction between lecture and the laboratory making it possible to move between these two activities as needed. All laboratory and classroom activities within the Petrology course (Figure 1) are directed toward understanding and solving a real-world problem, the origin and evolution of the Sonju Lake Intrusion in northern Minnesota. In other words, all concepts and skills that are learned in the course are introduced and applied using specimens and data from the Sonju Lake Intrusion. Emphasis in the course is on using multidisciplinary approaches to a real-world problem, use of modern instrumentation, and hypothesis-testing using student-generated data.

Week	Segment	Topic	Sonju Project Activity
1	Tools & Methods	Classification & Petrography	Hand Specimens, Maps, Lithostratigraphy
2		Phase Diagrams	Petrography
3		Phase Diagrams	Petrography & Phase Relations
4		Chemistry	Petrography & Phase Relations
5		Mantle Comp., Structure, & Melting	Petrography & Phase Relations
6	Igneous Rocks	Layered Intrusions & Mid-Ocean Ridges	Mineral Chemistry - Scanning Electron Microscope
7		Ocean Islands and Continental Rifts	Mineral Chemistry - Scanning Electron Microscopy
8		Volcanic Arcs	Mineral Chemistry - Scanning Electron Microscopy
9		Granites & Alkaline Magmatism	Whole-Rock Chemistry - X-Ray Fluorescence
10	Sedimentary Rocks	Geochemistry of Sedimentary Rocks	Whole-Rock Chemistry - X-Ray Fluorescence
11	Metamorphic Rocks	Metamorphic Petrography	Geochemical Databases
12		Metamorphic Reactions	Geochemical Modeling & Metamorphic Petrography
13		Facies	Geochemical Modeling & Field Trip
14		Tectonics & Metamorphism	Writing
15		Thermobarometry	Final Reports and Presentations

Figure 1. Outline of Petrology Course and semester-long Sonju Project.

The Sonju Project

The Sonju Lake Intrusion is a small layered intrusion within the Midcontinent Rift System (1100 Ma) that is exposed along the North Shore of Lake Superior (Figure 2). The Sonju Lake Intrusion and associated Finland Granite are ideal for a semester-long student project because: (1) they are well exposed, (2) they are of relatively small size, (3) they have a relatively simple structure and stratigraphy that spans a variety or rock types and processes (Figure 3), (4) their origin can be examined using basic petrologic tools, and (5) data from the intrusion are relatively unambiguous. Students first visit the intrusion and study a specimen from the intrusion near the end of the Mineralogy course. Detailed study of the intrusion continues during the Petrology course. Exchange of data, images, and other information is accomplished via a project web page (Figure 4).

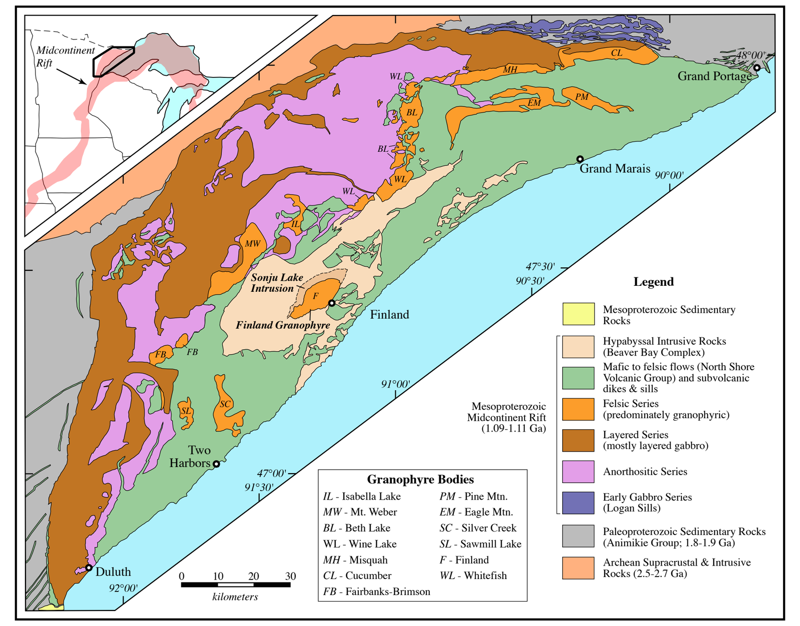

Figure 2. Generalized geologic map of the north shore of Lake Superior. Modified from Miller et al. (2001)

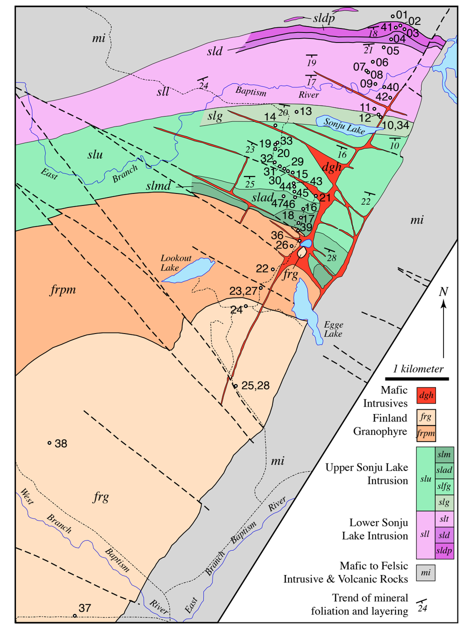

Figure 3. Map of the Sonju Lake Intrusion and Finland Granite. Modified from Miller et al. (2001)

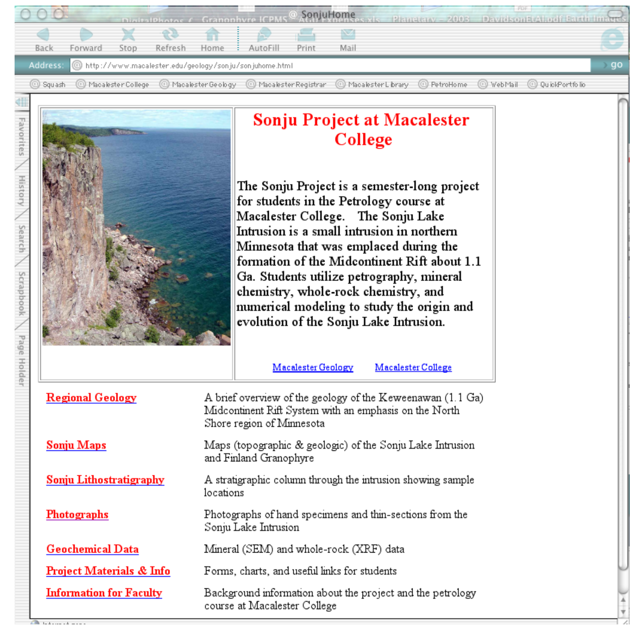

Figure 4. Data and images are shared among students via a project web page.

Field & Petrographic Data

Students are provided a suite of rocks, a map, and a lithostratigraphic column from the Sonju Lake Intrusion at the beginning of the semester. The specimens are part of an evolving suite that has been collected by students in the Mineralogy and Petrology courses over the past 5 years. Students work as a group to describe and classify the rocks using hand specimens and thin sections. This is followed by detailed petrographic analysis, which provides data about mineral textures, mineral compositions, and mineral modes. The petrographic data are used to establish unit names and descriptions (Figure 5). At this stage students also begin to formulate models of the origin and evolution of the rocks, including: (1) crystallization sequence from textures, (2) changes in mineral composition and mode with stratigraphic height, (3) relative proportions of rock types, (4) changes in cooling rate from grain size, (5) a comparison with phase diagrams, and (6) mantle source composition and melting.

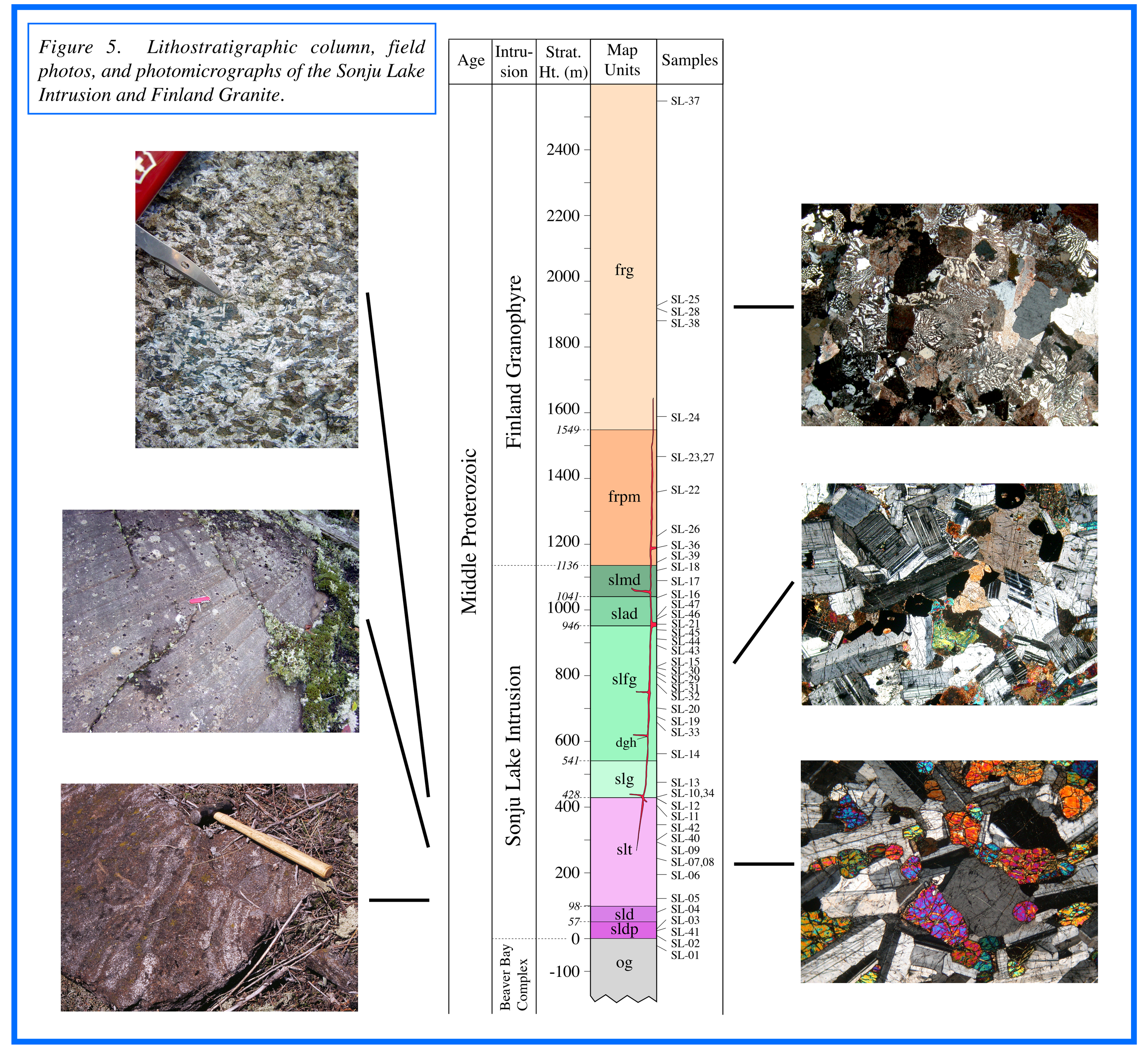

Figure 5. Lithostratigraphic column, field photos, and photomicrographs of the Sonju Lake Intrusion and Finland Granite.

Geochemical Data

Data from the petrographic studies are used to construct explanations of the origin and evolution of the intrusion. These hypotheses are then tested by collecting mineral (SEM-EDS) and whole-rock (XRF) chemical data. Students prepare and analyze samples (Figure 6 & 7) that were collected during the previous field season. The new geochemical data are added to an evolving student-generated petrologic database on the intrusion. Students then use petrologic database software (e.g., MinPet®) to manage and interpret the geochemical, petrographic, and field data (Figures 8 & 9). There are currently more and 360 analyses of 60 samples in the database.

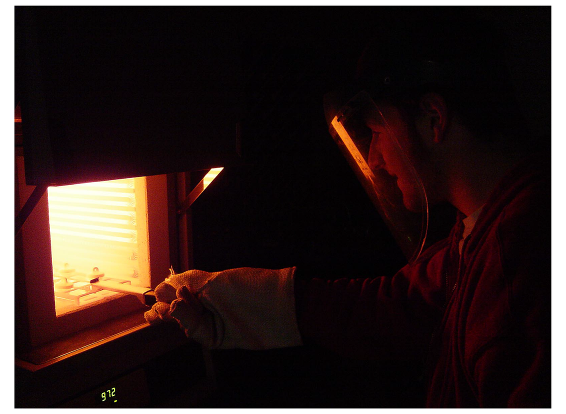

Figure 6. Petrology student preparing glass beads for whole-rock major element analyses by XRF.

Figure 7. Petrology student conducting mineral analyses by SEM-EDS.

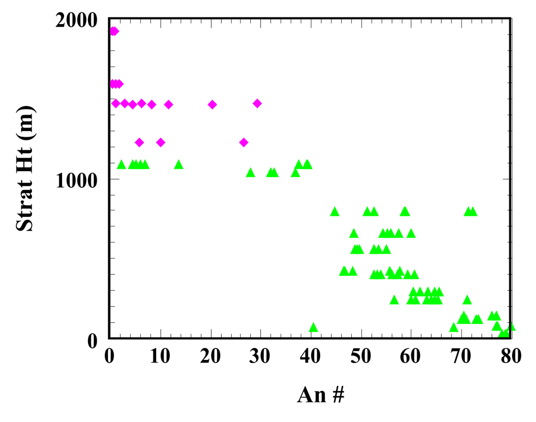

Figure 8. Plot of plagioclase An content versus stratigraphic height in the Sonju Lake Intrusion.

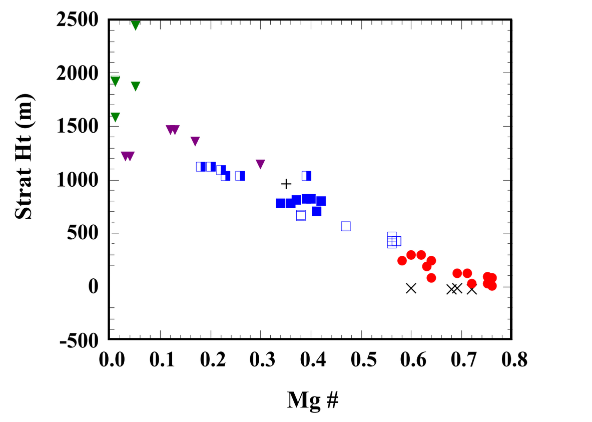

Figure 9. Plot of Mg# versus stratigraphic height in the Sonju Lake Intrusion.

Numerical Modeling & Conclusions

After completing the analytical phase of the project, students further test their hypotheses of the origin and evolution of the intrusion using numerical models (MELTS and trace element models). Until this point of the project the students primarily work together as a group. During the modeling phase of the project each student chooses one aspect of the petrogenesis of the intrusion that is of interest to them and then specializes in modeling that aspect (Figure 10, 11, & 12). At the end of the semester, students submit written reports and present their findings to the class orally in the *Annual Conference on the Origin and Evolution of the Sonju Lake Intrusion*.

Although it is more labor intensive, both for students and faculty, to complete a project such as this, there are many benefits. Since incorporating the project into the Petrology course, students: (1) exhibit improved quantitative and problem-solving skills, (2) they think like petrologists and have a much deeper understanding of fundamental petrologic processes and methods, (3) demonstrate greater facility working with large datasets, (4) are able to synthesize diverse observations, and (5) understand the relationships between data, rocks, and geologic processes.

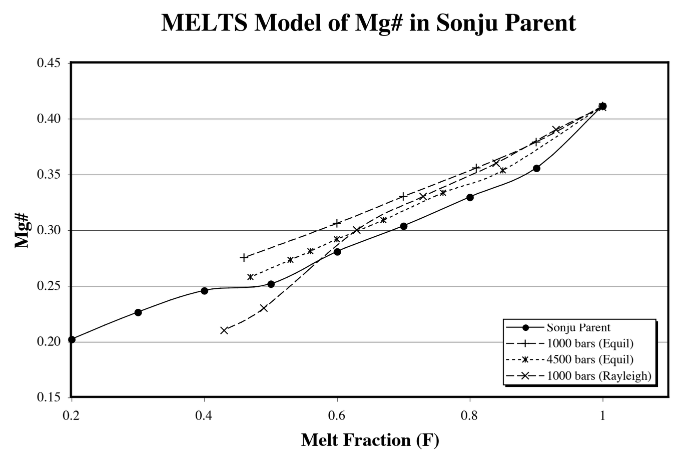

Figure 10. Plot of Melt Fraction (f) versus Mg# in Sonju liquids and MELTS models (Figure 10). Sonju liquids are estimated using mass balance models of the different layers in the intrusion.

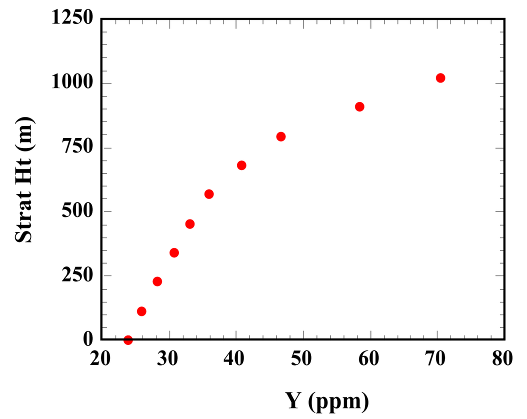

Figure 11. Plot of Y (ppm) versus stratigraphic height in Sonju mass-balance liquids.

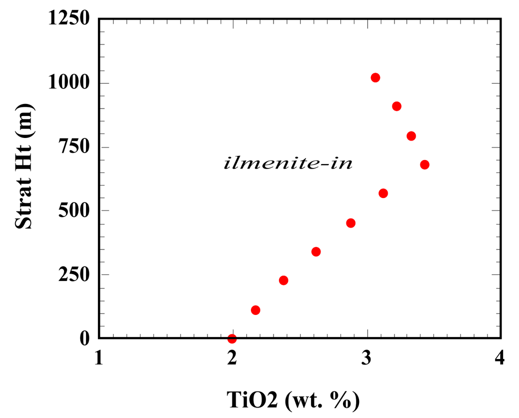

Figure 12. Plot of TiO_2 (wt %) versus stratigraphic height in Sonju mass-balance liquids. The inflection in the TiO_2 curve corresponds with the appearance of ilmenite in thin-section.

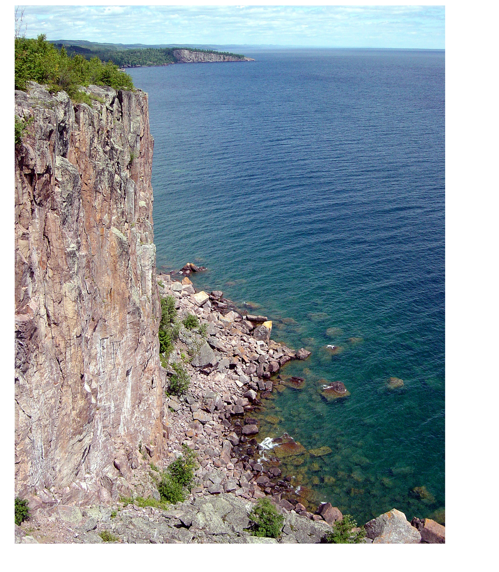

Figure 13. Exposures of rhyolite at Palisade Head (foreground) and Shovel Point (background) along the north shore of Lake Superior.

Additional Project Information at:
http://www.macalester.edu/geology/sonju/sonjuhome.html