PETROGENESIS OF A GRANITE XENOLITH IN THE 1.1 GA MIDCONTINENT RIFT AT SILVER BAY, MN

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INTRODUCTION

Much of the study of the North American 1.1 Ga Keweenawan Midcontinent Rift System (MRS) has focused on the large mafic and felsic flows and mafic intrusions (Miller and Chandler, 1997) which make up a significant proportion of the exposed rock. This study focuses on felsic plutonic rocks, particularly a single, large, diabase-hosted granite xenolith with a cross-cutting mafic dike.

The focus of the study is a granite xenolith, 5 meters wide, found within the hypabyssal Beaver Bay Complex of the Midcontinent Rift System (MRS), along the shore of Lake Superior at Silver Bay, MN (Miller and Chandler, 1997). This pluton and complex was emplaced into the extrusive sequences of the North Shore Volcanic Group. Most of the Beaver Bay intrusions are gabbroic or dioritic, however, one is granophyric, the Finland granophyre. The granite xenolith might have been derived from the Finland granophyre or a related rock. Alternatively, the granite could possibly have been part of the Giants Range Batholith of Archean age, and plucked from the walls of the country rock by the diabase when the MRS intrusions occurred. However, it also could be a result of the fractionation of MRS related magma at depth. Comparison of the xenolith to well-studied granophyres in the area (Kennedy, Vervoort, Wirth, 2000) allows the origin of the granite xenolith to be constrained further and have implications for the evolution of the MRS.

The study utilized geochronology, geochemistry and the anisotropy of magnetic susceptibility of the granite xenolith and cross-cutting dike as a means to understand the petrogenesis of the granite. Specifically, determining the age of the granite was of supreme importance, as the granite may have originated from anyone of several sources.

METHODS

Anisotropy of Magnetic Susceptibility (AMS)

To determine the magmatic flow of the granite and dike, four oriented samples were collected from the granite and dike. The three samples from the granite were chosen from the south, middle and north of the xenolith to examine flow at the edges of a xenolith versus the middle of the xenolith. The AMS fabric of the rocks was determined using a “Roly Poly” Magnetic Anisotropy Bridge built and located at the Institute of Rock Magnetism (IRM) at the University of Minnesota, Minneapolis.

Geochemistry (X-Ray Fluorescence)

Five samples were collected from the granite, the dike, and the diabase to determine their geochemistry. Three of the samples were of the granite (from the northern end, the middle, and the southern end). One sample each was collected from the dike and the underlying diabase. Fused glass beads and pressed pellets were prepared and analyzed using a Philips PW-2400 XRF with Rh-anode, at Macalester College. The method of X-Ray Fluorescence used did not distinguish FeO from Fe_2O_3, and total Fe concentration was reported as Fe_2O_3.

Geochronology

In addition to AMS and XRF analyses, the age of the granite was investigated using U-Pb zircon methods. Twenty zircon grains were analyzed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at Washington State University.

RESULTS

Geochronology

U-Pb data for the granite are plotted on a Concordia diagram and weighted age plot for interpretation and analysis. In a Concordia diagram (Fig. 1a), the discordia line intersects the Concordia curve at the crystallization age (1094±11 Ma) and at the age when lead loss occurred (-86±240 Ma). Weighted averages of the 207 Pb/206 Pb concordant points are also taken and plotted. The plot of weighted average of the 207 Pb/206 Pb ages is 1093.5±6 Ma (Fig. 1b). This age is younger than the youngest age (1095±4 Ma) of granophyres associated with the Keweenawan Mid-continent Rift (Vervoort, Wirth, 2004), but is within analytical error. The nearest exposed large granophyre complex is the Finland granophyre which has an age of approximately 1098.5±1.3 Ma (Green, Davis, Schmitz, 2001). However, the xenolith is found 10 km south of the Finland Granophyre.

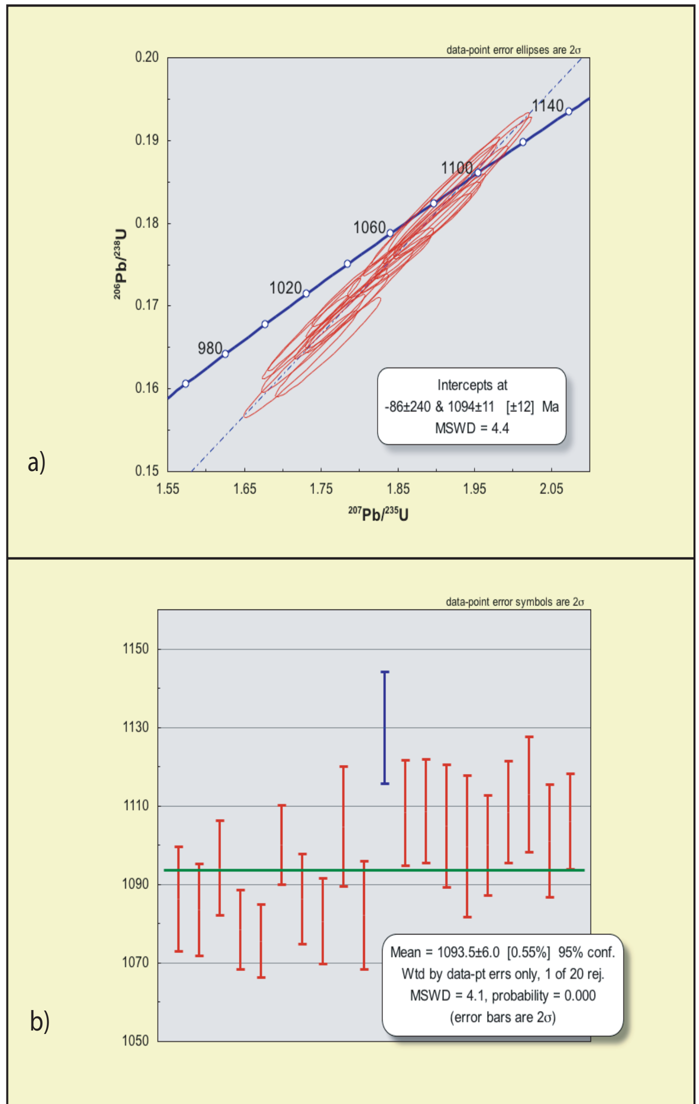

Figure 1. (a) The Concordia curve of data collected using U-Pb zircon geochronology which determines the age of formation as well as the age at which a lead loss event occurred. (b) An additional graphical method of analyzing the data through a weighted average plot of the 207 Pb/206 Pb analyses.

Petrography

The granite is composed of quartz (35-50 vol. %), plagioclase (30-40 vol. %), orthoclase (35-45 vol. %), and interstitial pyroxene and amphibole (~1 vol. %). There are numerous sites that exhibit intergrowths of quartz and alkali feldspar with a texture that can be termed granophyric. The few pyroxenes and amphiboles have undergone extensive alteration. In addition, several accessory minerals are found in minute concentrations, including spene and apatite. The color of the granite in hand sample and thin section is much lighter in color than the Finland Granophyre. The xenolith is also much less altered than the Finland, as only the pyroxenes show signs of significant alteration. The Finland granophyre, however, shows signs of much greater deformation in

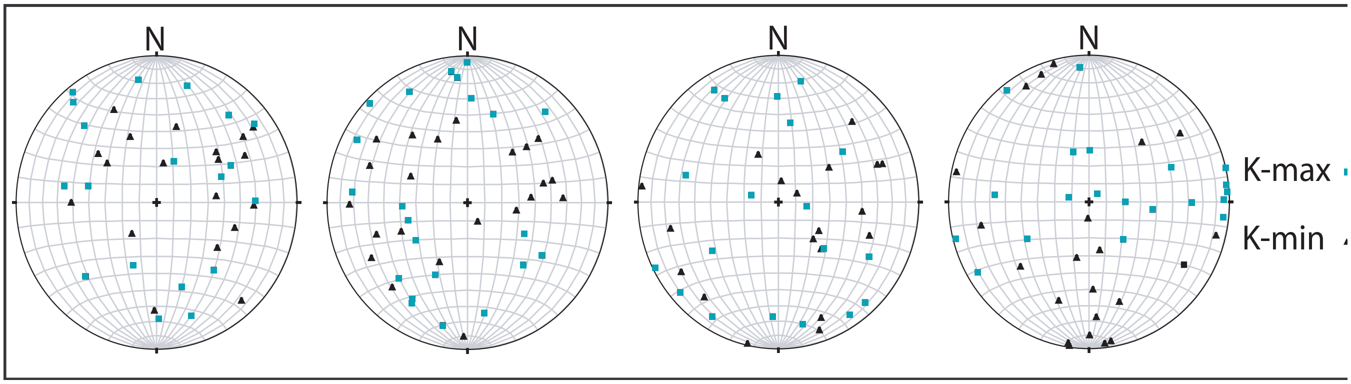

Figure 2. Lower hemisphere projections of four samples analyzed for anisotropy of magnetic susceptibility. K-max (direction of extention) and K-min (direction of compression) values are plotted. From left to right: KP05-45B (northern part of the xenolith), KP05-45D (middle of xenolith), KP05-45F (southern end of xenolith), and KP05-45I (dike).

hand sample and a larger proportion of the grains in thin sections are indistinguishable due to alteration.

AMS

Anisotropy of Magnetic Susceptibility (AMS) was used to try to determine a flow fabric within the granite and dike. Three different areas of the granite (north, south, and middle) as well as the dike cutting the granite were analyzed. Data for both the granite and the dike show no identifiable magnetic fabric (Fig. 2). Thus, it is assumed that the granite did not flow enough to preserve a fabric during its formation. The dike, on the other hand, would be expected to manifest some flow fabric, as it must have flowed through the granite to form.

Geochemistry

The results of major element analysis using the XRF are plotted on Harker diagrams. The SiO_2 is used as a measure of crystal fractionation, and different magmatic processes can be inferred from the character of variation in the oxide-containing major elements. The major element analyses of the granite are compared to the previous analyses of MRS granites (Kennedy, Vervoort, Wirth, 2000). The granite xenolith has an average SiO_2 content (78.28 wt. %), higher than the highest SiO_2 content of the granophyres studied (~76 wt %). Therefore, when the major elements are plotted on Harker diagrams, the xenolith data is almost always at the end of a linear or curvilinear set of data from the granophyre complexes. The only two chemical components which did not seem to fall into line with the other granophyres were K_2O and Na_2O (Fig. 3). The xenolith has much higher concentrations of Na_2O (6.52 wt. % > 2-4 wt. %) and much lower concentrations of K_2O (0.17 wt. % < 3-6 wt. %). However, when Na_2O+K_2O are plotted versus SiO_2, the xenolith plots further along the same curve as the data from the granophyre complexes. In addition, the amount of aluminum is greater than the amounts of sodium and potassium added together, so the xenolith is classified as metaluminous.

The trace element analyses were also compared with those of the larger granophyre complexes. These, in contrast to the major element plots, do not correlate as well with the data from the granophyre complexes. The xenolith has similar values of the trace elements Th, Y, Cr, Ni, V, Sc and Nb to the granophyre complexes. However, the concentrations of La, Ce, Ga, Rb, Zr, Ba U, and Co are lower than those of the complexes and the concentration of Sr is higher than those of the complexes.

The geochemistry of the diabase was also compared to the known geochemistry of the intrusions of the Beaver Bay Complex (Miller

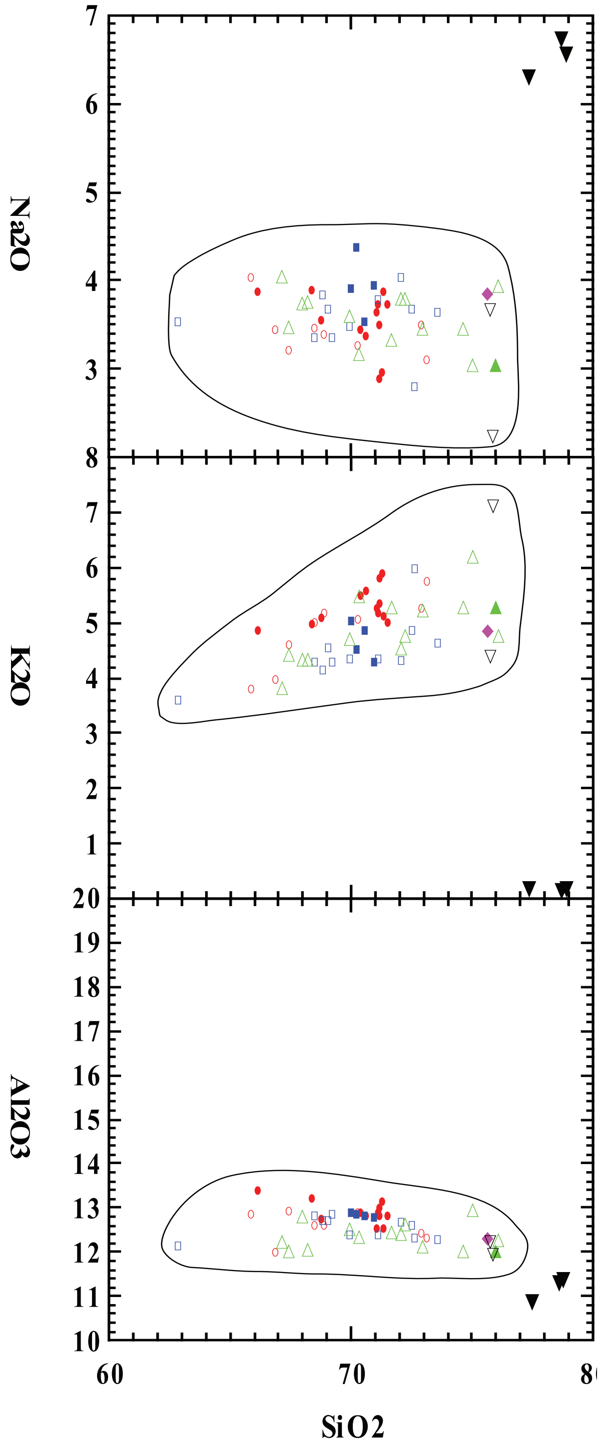

Figure 3. Harker Diagrams are plotted with the oxides Na20, K20, and Al2O3, versus SiO2. The K20 plot shows the very low concentrations of K20 in the granite xenolith relative to the concentrations found in the other MRS granophyres. The Na20 plot indicates the higher concentrations in the granite xenolith relative to those in the granophyres. The Al2O3 plot shows a general trend of the granophyres including the xenolith studied, though the xenolith still plots a bit off the main line.

and Chandler, 1997). It is expected that the diabase surrounding the xenolith is the Beaver River Diabase (Miller, 1987; Miller, 1989; Miller, Chandler, 1997). The major element data collected differs somewhat, but not significantly from the data on the Beaver River Diabase, as all the values are within 3 wt. % (Fig. 4). A few values differ only a few percent relative to the other (such as SiO_2, Al_2O_3, and MgO), though others vary by almost 50 % (including K_2O, P_2O_5, and Na_2O). The trace element data differs with higher Cr, Rb, Sr, Ba, Y, La, Ce, and Zr values, while Co and Ni values were lower for the diabase measured from Silver Bay.

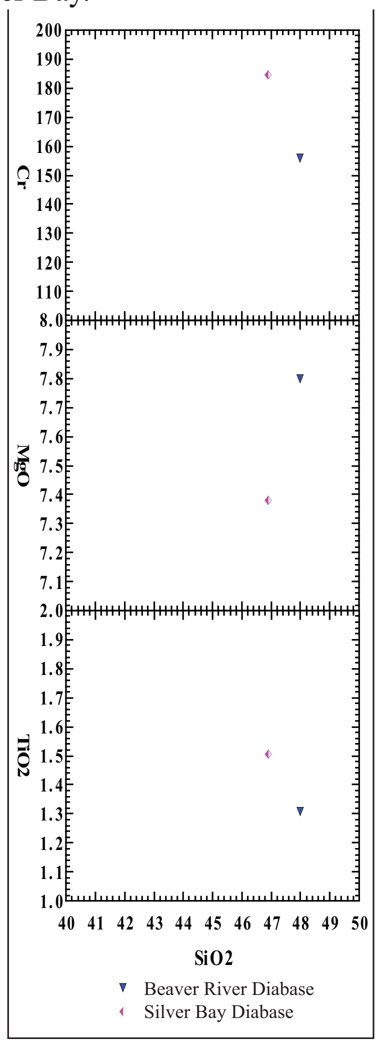

Figure 4. Plots of Cr, MgO, and TiO2 versus SiO2 give an example of the magnitude of difference between the geochemistry of the measured diabase and the previously studied Beaver River Diabase. The graphs exhibit the range of divergence between the two, which theoretically ought to be similar.

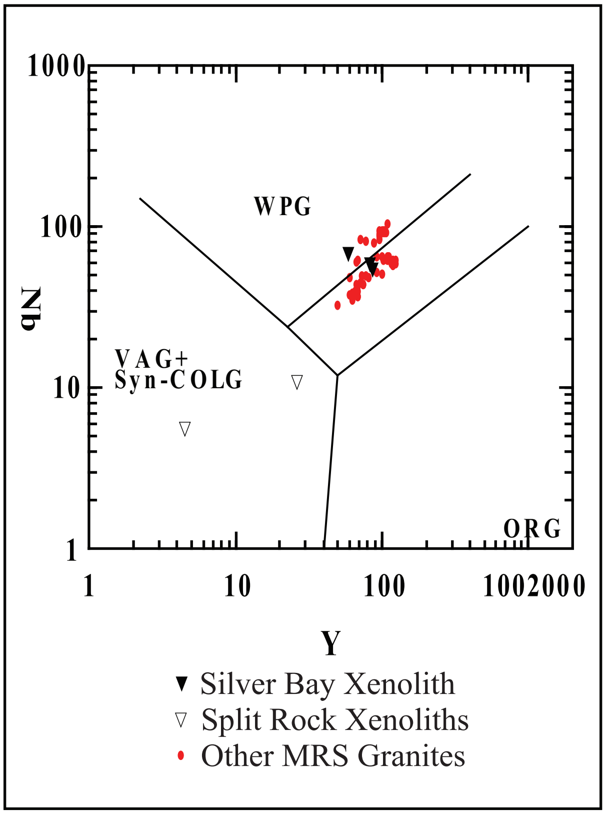

Figure 5. This discrimination diagram used by Pearce (1984), compares concentrations of the trace elements Nb and Y to determine tectonic setting of granite formation. The granite xenolith data plots in the WPG area (within plate) along with the data from other MRS granophyres. Sets of data from two granite xenoliths at Split Rock, MN, collected during this study but not analyzed in this paper, plot in the VAG (volcanic arc) + Syn-COLG (syn-collisional) area.

DISCUSSION

Through U-Pb zircon geochronology, this study confirms that the granite xenolith was not part of the Archean crust broken off and carried toward the surface by the intruding mafic flows, as the zircons did not exhibit any age data older than the Rift. The age is also lower (though within the analytical error) than that of other MRS granophyres, which may suggest a later crystallization. The confirmation that the granite xenolith was formed within the MRS is evidence for a greater amount of granite formed within the MRS than previously believed. Already before this study, more granite was accounted for in the MRS than would be expected in such a system. This suggests that the melt source of this MRS must be different from the assumed MRS melt source so as to produce so much alkalic material.

The geochemistry of the granite is indicative of the type of setting in which the granite formed. When plotted on a discrimination diagram based on combinations of trace elements that do not exhibit anomalous behavior, the xenolith plots within the WPG (within plate) area (Fig. 5). The trace element geochemistry affirms this, as the concentrations of Nb, Y, and Zr are higher than most I-type granites, as is common in A-type granites.

The granite xenolith exhibits such low concentrations of potassium that are usually associated only with a particular type of granites called plagiogranites. If the age of the granite had not been known, the low potassium levels could have suggested an Archean age, as most Archean granites have lost much of their alkali minerals over time. However, other chemical characteristics of the granite, such as its high silica content, suggest otherwise and are more consistent with the theory supported by the measured age of the rock (that the granite xenolith was formed within a plate, in an active rift zone almost 1100 Ma years ago). The anomalously low alkali concentrations may be explained due to the mobility of those elements (K, Ba, Rb). Some fluid may have infiltrated the granite during late-stage cooling at some point in time and drawn out the K and associated LIL elements (Rb, Ba).

The diabase from Silver Bay exhibits higher concentrations of more incompatible elements (Rb, Sr, Ce, Ba) and lower concentrations of compatible elements (Ni, Co) though Cr concentration is also high and it is highly compatible. This is consistent with models of silicic magmas, rather than mafic magmas, as one would expect from a diabase. This may be indicative of the source of the magma from which the diabase crystallized.

CONCLUSIONS

The resulting age from U-Pb zircon geochronology puts the granite squarely within the magmatism of the MRS. This data refutes the previous hypothesis that the granite xenolith was a part of the Archean crust brought up with the mafic intrusions of the MRS. This study confirms that the amount of granite in the MRS is greater than previously thought. Already, previous studies concluded there is a large amount of granite in the system. The data from this study suggests that the amount is even greater.

In addition, the geochemistry of the granite xenolith suggests a resemblance to other MRS granophyres, though it is low in potassium and associated elements. However, this lack may be explained by the solubility of these elements and the possibility of fluid infiltration of this granite during late-stage cooling.

Without isotopic data, the method of formation of the granite is hard to determine, as the granite could have formed through fractional crystallization of a melt or as the result of partial melting of crustal material. The understanding of the granite's formation is further hampered by the lack of a recognizable flow fabric. However, the data collected in this study has furthered the understanding of the generation of granites in the MRS, and with further study the method of granite formation may become more conclusive.

ACKNOWLEDGEMENTS

Financial support was provided by the Keck Consortium. Additional support, including housing was provided by Macalester College. I would like to thank the project leaders, John Craddock, Cam Davidson, and Karl Wirth, as well as the other students participating in the program for their contribution to the collection and analysis of data for this project. In addition, I would like to thank Jeff Vervoort at Washington State University who aided in the use of the LA-ICP-MS, and Michael Jackson at the Institute of Rock Magnetism for his aid in using the Roly Poly.

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