PETROLOGY OF A SYSTEM OF GRANOPHYRE DIKES IN THE BEAVER BAY COMPLEX IN BEAVER BAY, MINNESOTA

MATT ANDRING
Whitman College
Sponsor: John Winter

INTRODUCTION

The Beaver Bay Complex is an intrusive igneous complex composed of six major intrusive events of Keeweenaw age (1.1-1.06 Ga) and part of the failed mid-continent rift system (Miller et al., 1994). The best exposure of the Beaver River diabase border phase is on the north shore of Lake Superior from the mouth of the Beaver River for approximately 2km NE along the shore of Beaver Bay. The border phase is the edge of the intrusion and is characterized by numerous igneous zenoliths including granite, anorthosite, amygdaloidal basalt, basalt, rhyolite, and aplite among others. The border phase also contains a series of red granophyre dikes which cut both the matrix and the inclusions. In many places the dikes seem to delineate the contact between the country rock and xenoliths, where in others they cuts across both (Gehman, 1957). This project attempts to characterize these dikes and establish their tectonic and magmatic origin.

SAMPLING

Oriented samples of the granophyre were taken at several locations in a continuous dike for which the surface contact showed it surrounding one of the basalt inclusions (samples 44b-44d). Another granite sample was taken from a dike with a linear surface contact and not visibly connected to the other sampled dike (sample 44a). For geochemical comparison, a sample was taken from a granite xenolith in the diabase (sample 44e). A sample was also taken from the Beaver River Diabase near the northeast part of the bay (sample 44f), and a seventh sample was taken from the basalt inclusion (sample 44g).

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

This study uses AMS (anisotropy of magnetic susceptibility) to determine magnetic fabric as a proxy for magmatic flow. It has been successfully used in the past to determine magmatic flow direction in a dike swarm by Ernst and Batagar (1992). The “Roly-Poly”, at the Institute for Rock Magnetism at the University of Minnesota, was used to extract information about the magnetic fabric of the rocks. It is an AC susceptibility bridge with an automated sample handler for determining anisotropy of low-field magnetic susceptibility at room temperature. An alternating current “drive” coils produces an alternating magnetic field in the sample space. The induced magnetization of a sample is detected by a pair of “pickup” coils. A sample is rotated about three orthogonal axes, and susceptibility is measured at 1.8° intervals in each of the three measurement planes resulting in 600 directional measurements. The precision of this method is very high, and in most cases principal axis orientations are reproducible to within two degrees, and axial ratios to within about 1 percent. For each cube, a resultant Kmax, K int and Kmin axis is determined that resolves the magnetic ellipsoid. Kmax and Kmin are plotted stereographically , with ~20 cubes/sample.

The AMS data (Fig. 1) do not indicate flow direction in the granitic dikes and only a weak flow direction in the basalt encircled by the granitic dykes. These results suggest three possibilities. 1) The granites traveled a very short distance and thus were not able to develop a strong magnetic or magmatic fabric. 2) The magmatic flow was very turbulent until the magma crystallized inhibiting the formation of a magnetic fabric. 3) The magma traveled as a crystal mush with a large percentage of crystals inhibiting the crystals' free rotation in the magma. None of these situations are mutually exclusive, but any one of them could explain the lack of magnetic fabric as a proxy for magmatic flow during intrusion.

GEOCHEMISTRY

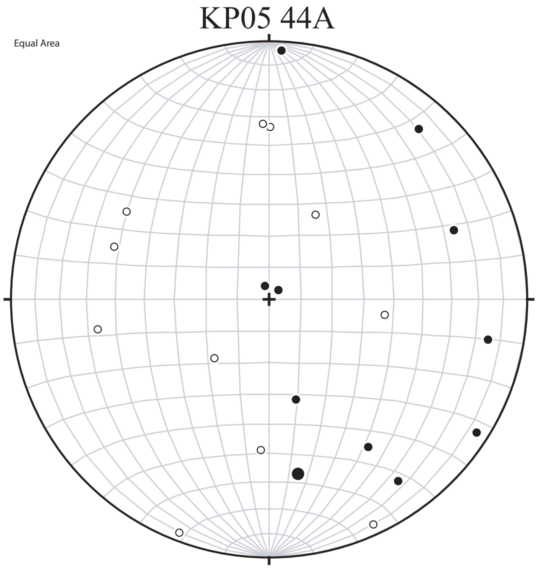
X-ray fluorescence spectrometry was used to determine major and minor elemental composition of the granophyre dikes, one of the included basalt zenoliths, and the Beaver River host diabase. A CIPW norm was used to calculate mineral composition of the rocks because thin sections were not available to determine modes. Based on the norm percentages the dikes were determined to be true granites plotting near the center of a QAP diagram (Fig. 2). On a plot of silica versus total alkalis the basalt inclusion is a basaltic andesite and the diabase is a basalt.

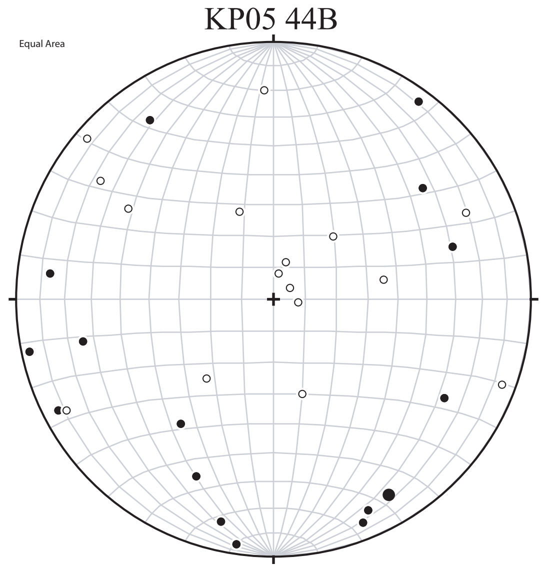
Four granite discrimination diagrams were used in an attempt to constrain the original tectonic setting of the granophyre dikes (Fig. 3). Pearce et al. (1984) showed that graphs based upon Nb-Y-Rb could reliably demonstrate a tectonic origin for granites. On a graph of Y+Nb versus Rb the granites plot in the "within plate granite" field. On a plot of Y versus Nb the granites lie only slightly less precisely in the field above the lower limit of the within-plate granite but below the upper limit of anomalous ocean ridge granites. This is not totally unsurprising as the granites are part of the failed continental rift system, so it is appropriate that the granite is similar to some mid ocean spreading ridge granites. Also Whalen (1987) showed that plots of 10^4Ga/Al versus both major and minor elements could be used to discriminate between A-type granites and I&S-type granites. The plot of 10^4Ga/Al versus Zr shows the granite falling within the A-type classification. Finally Shand's index (1943) shows the granites to be metaluminous, a possible indicator for A-type granites (Pearce, 1984). In addition they fall within the rift-related and aborted rift/hotspot related fields on Shand's index as designated by Maniar and Piccoli (1989). Discrimination between rift and aborted rift/hotspot granites can be further defined through the use of elemental ratios, and the Na_2O/K_2O and Na_2O/CaO weight percent ratios support the aborted rift/hotspot granite classification.

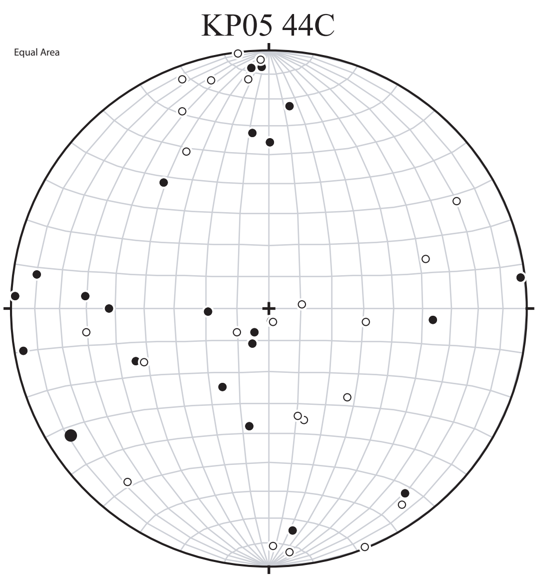
DISCUSSION AND CONCLUSIONS

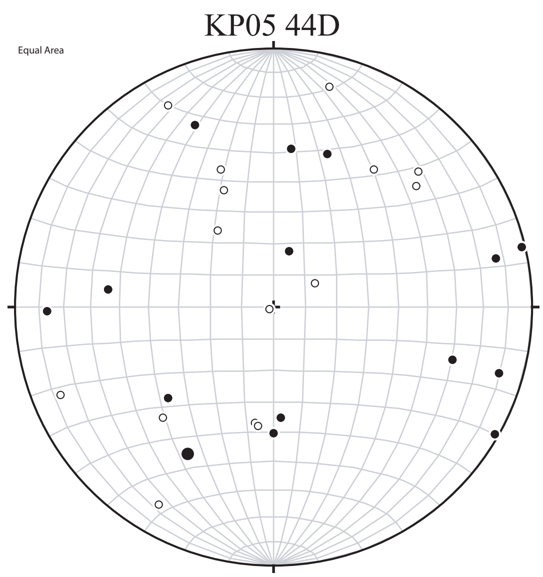
It is important to note that weight percentage norms were used in lieu of a mineralogical mode due to the availability of the latter. This probably skewed the numbers for some of the mineral phases. Much of the geochemical analysis though is based directly on oxide analysis rather than mineralogical traits, so the conclusions drawn should maintain validity even with a lack of modes for the rocks investigated.

The geochemistry of the granites points firmly to an A-type granite with a rift or failed rift-related tectonic origin. Knowing that the rocks lay directly in the midst of the Keeweenaw age failed mid-continent rift system the granites can be confidently labeled as being a direct result of that rift system. The granites show cross-cutting relationships to the local Beaver River Diabase and its inclusions, so they are a post-diabase emplacement magmatic event. Their granophyric texture points to the alkali feldspar and quartz co-crystallizing and a quick cooling









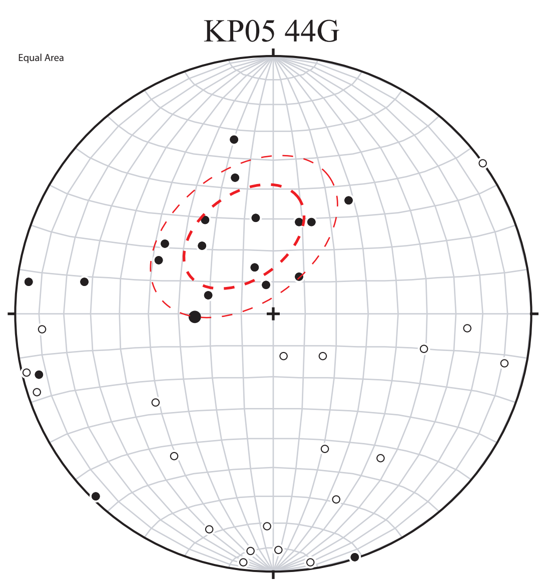


Figure 1. The four granophyre dike AMS signatures (KP05 44A-D) show no discernable pattern. The basalt zenolith (KP05 44G) which is bordered by the dikes in the field displays a weak anisotropic magnetic fabric shown in red.

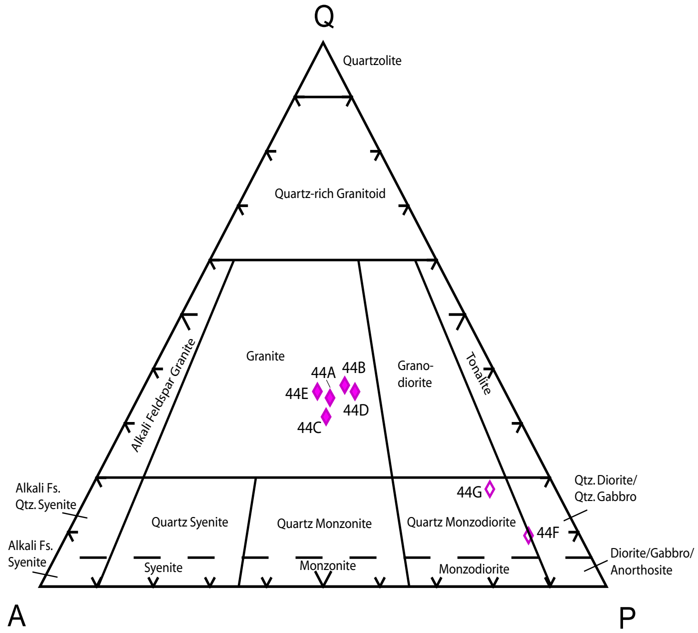


Figure 2. CIPW norms plotted on the IUGCS classification of rocks based on quartz, plagioclase and alkali feldspar content. All granophyres plot in the granite range of the diagram, and the basalt and diabase plot in the quartz monzodiorite region of the diagram.

process (Winter, 2001) and they are chemically and geochronologically related to granophyres studied by Kennedy et al (2000) and Juda (2006, this volume).

The textural evidence best supports the third possibility posed by the AMS data. The granite traveled as a crystal mush which kept it from forming a strong magnetic fabric alignment. The geochemistry does not rule out the other two possibilities however, and rare earth element analysis combined with a larger range of sampling could possibly support a local magmatic evolution from the diabase (Gehman, 1957).

REFERENCES CITED

Ernst R.E. and Baragar, W.R. A., 1992. Evidence from the magnetic fabric for the flow of magma in the Mackenzie giant radiating dyke swarm. Nature 356, p. 511.

Gehman, H.M., Jr., 1957, The petrology of the Beaver Bay Complex, Lake County, Minnesota: Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis, 92p.

Juda, Natalie. 2006. Petrogenesis of a granite xenolith in the 1.1 Ga midcontinent rift at Silverbay, MN. 19th annual Keck Research Symp;osium in Geology Proceedings, pp. 136-141.

Kennedy, B.C., Sandland, T.O., Wirth, K.R., Vervoort, J.D., 2000. Petrogenesis of midcontinent rift granophyres in northern Minnesota; geochemical evidence. Geological Society of America, 2000 Annual meeting Abstracts with Programs, Geological Society of America 32, p.398-399

Maniar, P.D. and Piccoli, P.M., 1989, Tectonic discrimination of granitoids. Geological Society of America Bulletin, 101: 635-643.

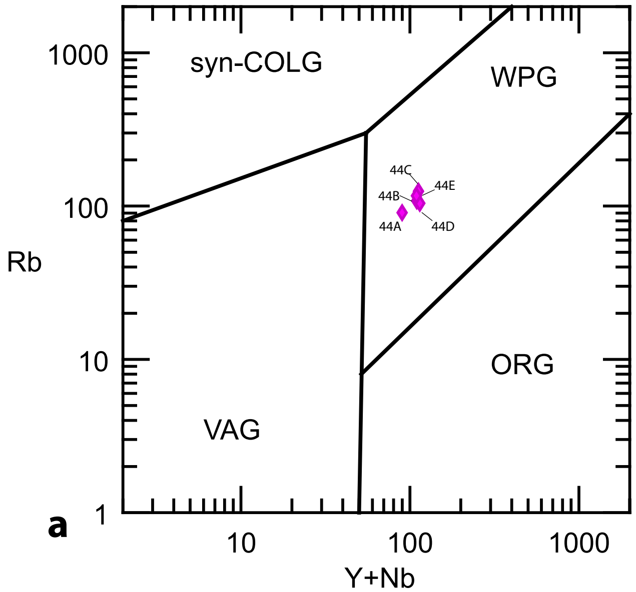
Miller, J.D., Jr., Boerboom, T.J., Chandler, V.W., Green, J.C., 1994, Geology of the “greater” Beaver Bay complex, northeastern Minnesota. Institute on Lake Superior Geology, 40th annual meeting, proceedings; Part 1, Program and abstracts Proceedings and Abstracts - Institute on Lake Superior Geology, 40: 42-43.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol., 25: 956-983.

Shand S.J., 1943. Eruptive Rocks; Their Genesis, Composition, Classification, and their Relation to Ore Deposits, with a chapter on Meteorites (revised second edition): Hafner Publishing Co., New York, 444p.

Whalen, J.B., Currie, K.L. and Chapell, B.W., 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis. Contrib. Mineral. Petrol., 95: 407-419.

Winter, J.D., 2001. An Introduction to Igneous and Metamorphic Petrology: Prentice Hall, Upper Saddle River, New Jersey, 697p.



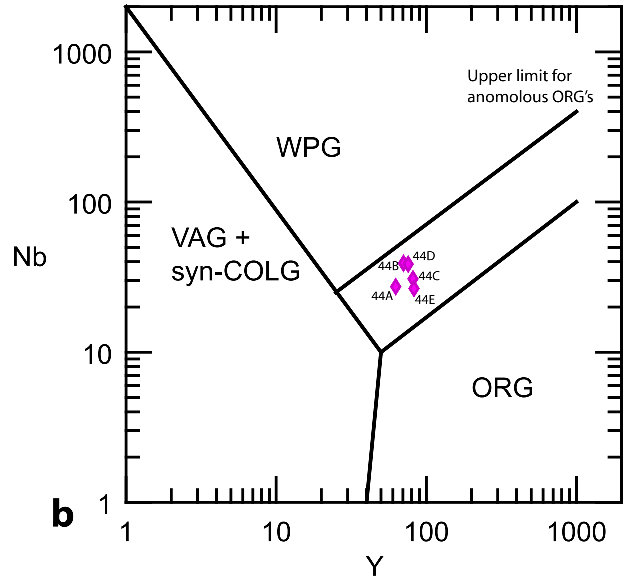
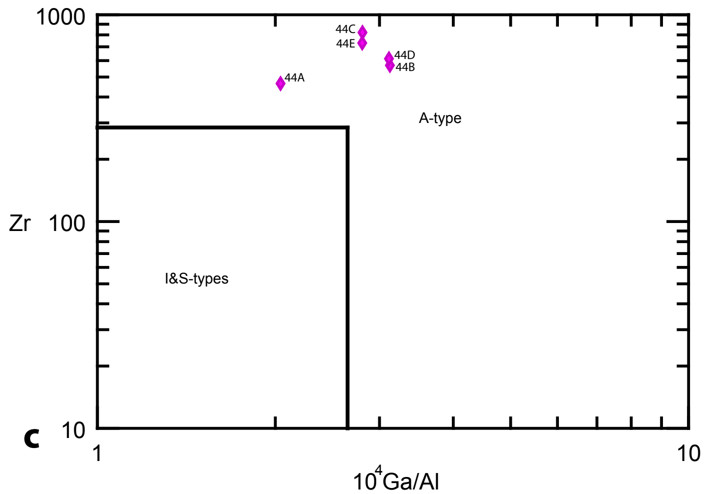


Figure 3a. (VAG) = volcanic arc granite, (syn-COLG) = syn-collisional granite, (ORG) = ocean ridge granite, (WPG) = within plate granite. All granite samples taken at the site are WPGs. (Pearce et al., 1984)

Figure 3b. All granites fall in the WPG field, but below the upper limit for anomolous ORGs. This is possibly due to the similar nature of mid-ocean rifting to continental rifting. (Pearce et al., 1984)



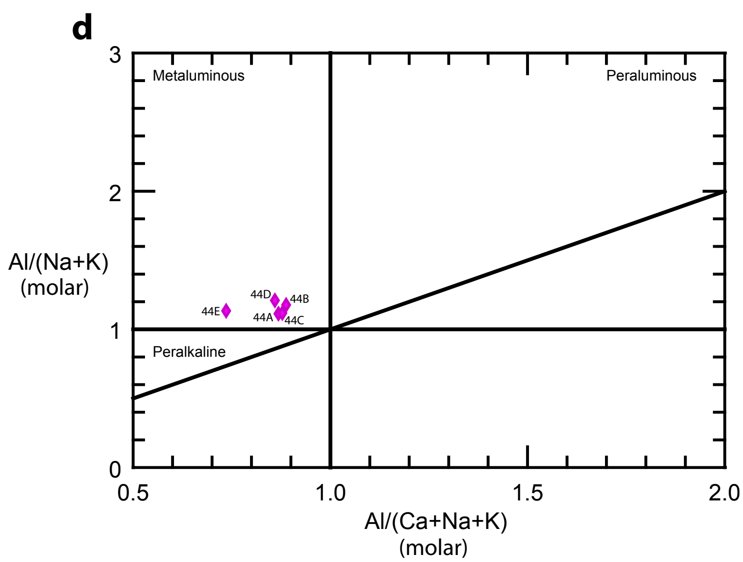


Figure 3c. The granite samples are all A-type granites according to Whalen, 1987.

Figure 3d. Shand's luminosity plot showing all of the granites to be metaluminous. Metaluminosity is normal for some sub-classes of A-type granites. (Pearce et al., 1984, Shand, 1943)