

A 1.1 billion-year-old anisotropy experiment: a study of anorthosite xenoliths within the Beaver River diabase

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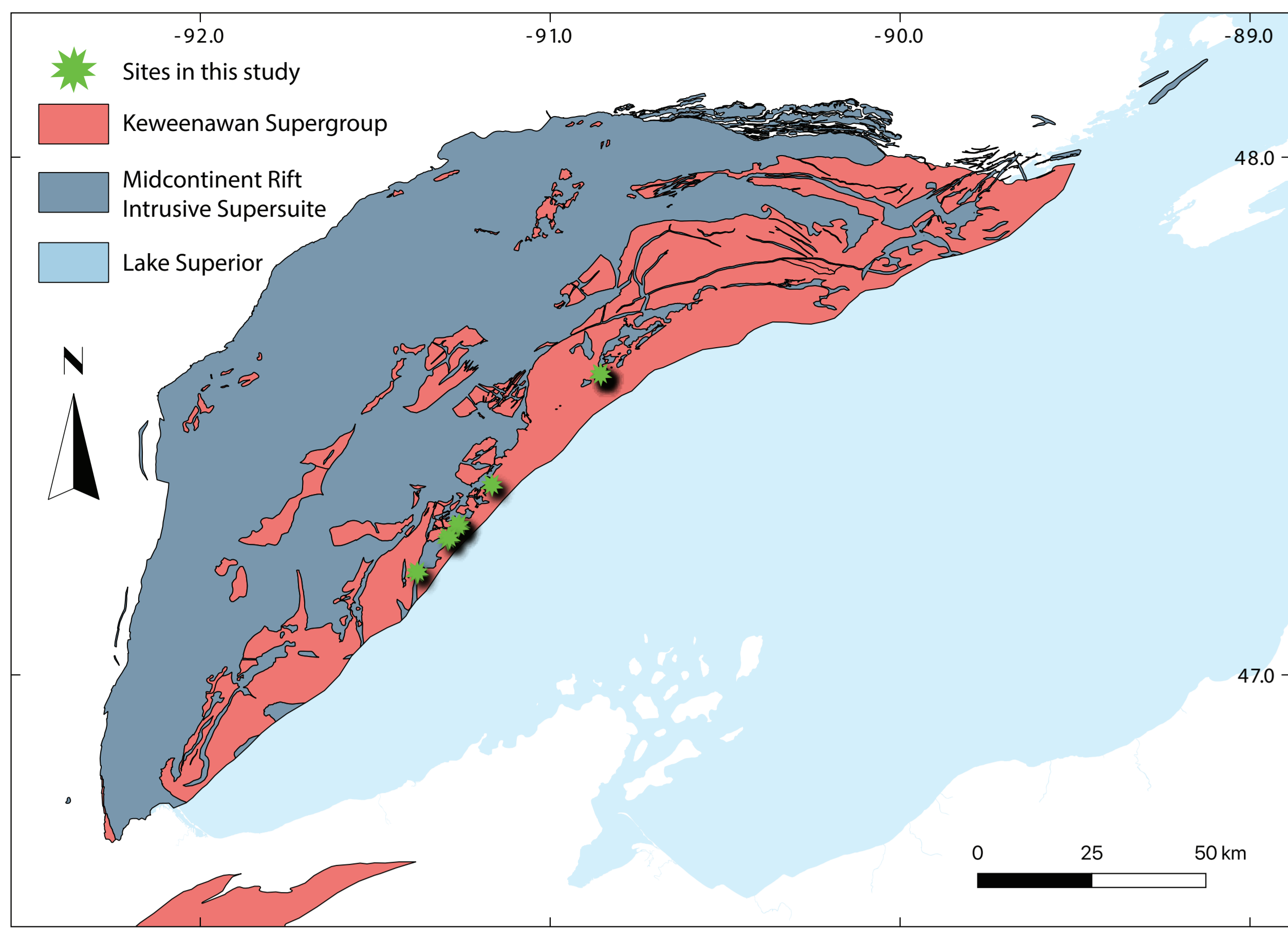
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Abstract

Anorthosites are attractive paleomagnetic recorders as silicate-hosted magnetite inclusions can be single-domain and be shielded from alteration. However, petrofabrics within anorthosites may result in magnetic remanence anisotropy that is potentially detrimental to recovering paleomagnetic direction and intensity. The Beaver River diabase of the North American Midcontinent Rift contains abundant nearly 100 percent plagioclase anorthosite xenoliths that are hypothesized to have been liberated from the lower crust by the magma enroute to becoming embedded in shallow crustal sills. In this study, we compare the remanent paleomagnetic directions recorded by anorthosite xenoliths to those of the Beaver River diabase host rocks. Given that both lithologies should record the same thermal remanent magnetization, this comparison provides a means to assess the effects of remanence anisotropy on the paleodirection recorded by the anorthosites. Thermal and anhysteretic remanence (TRM and ARM) anisotropy experiments, which are typically used to assess for anisotropy, can be compared to the natural remanence of the diabase and anorthosite in this geologic experiment that was conducted 1.1 billion years ago. Paleodirection data from the interior of the largest (>300 m) anorthosite xenoliths also have the potential to test their hypothetical lower crustal origin. An origin below the Curie depth would result in a full thermal remanence from the time of diabase emplacement, while a shallower origin from above the Curie depth could have resulted in a distinct remanence direction in the xenolith interior that predates the intrusion (with samples from the exterior having acquired a Beaver River diabase coeval thermal remanence in either scenario). Overall, this novel geological association between diabase and anorthosite provides a means to assess the effects of remanence anisotropy providing valuable context for efforts to use anorthosites to understand the ancient geomagnetic field.



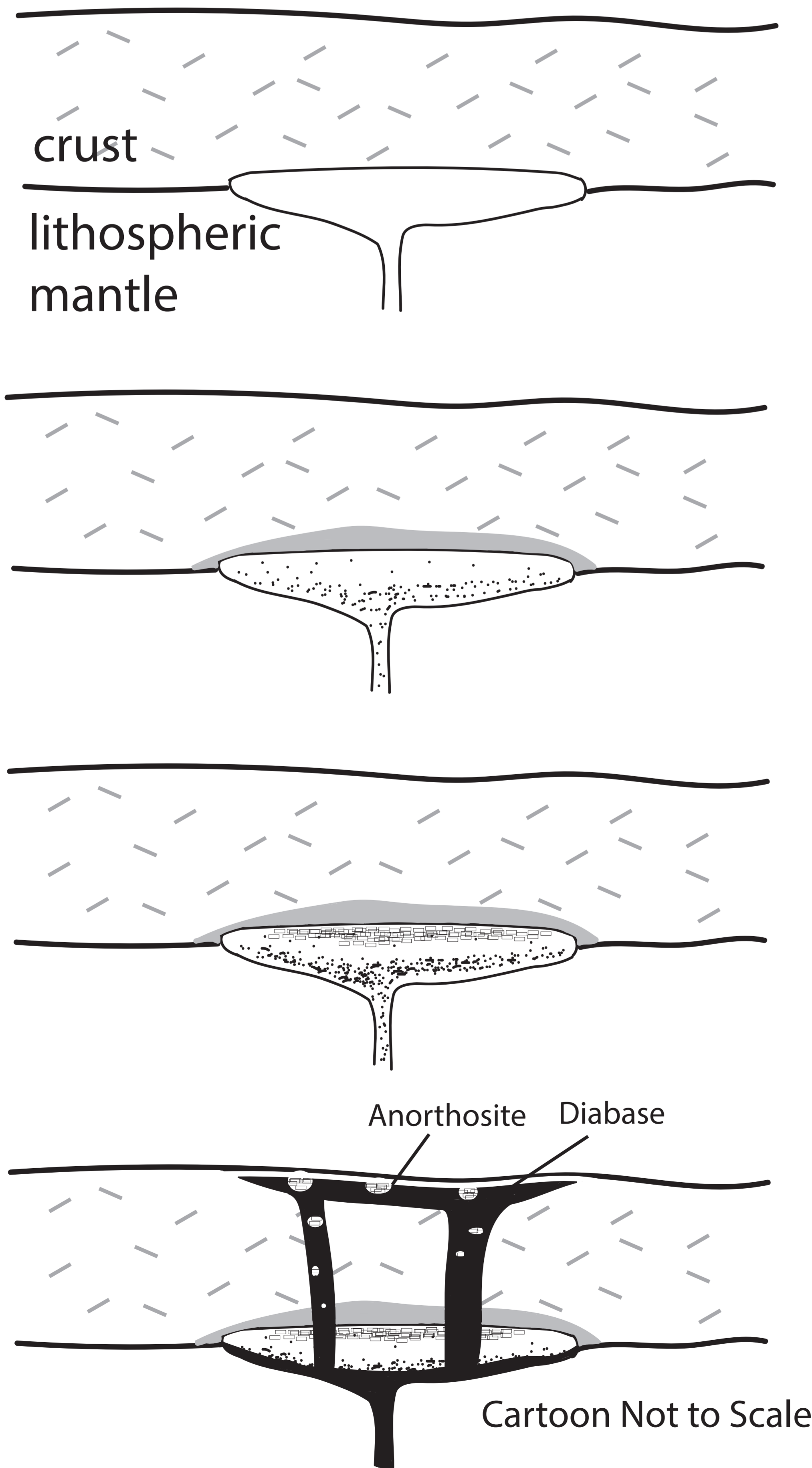
A 1.1 Billion-Year-Old Anisotropy Experiment: A Study of Anorthosite Xenoliths within the Beaver River Diabase

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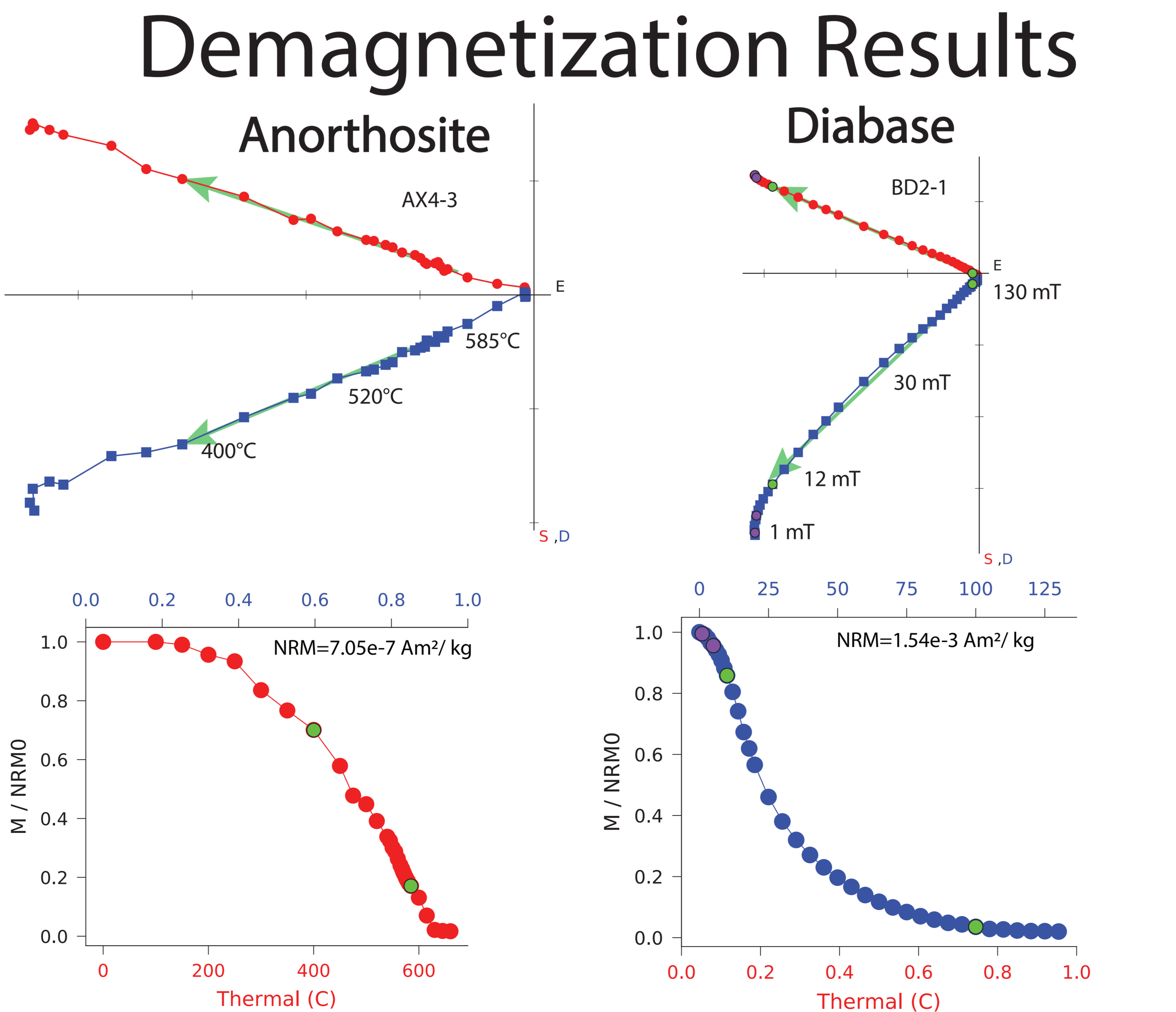
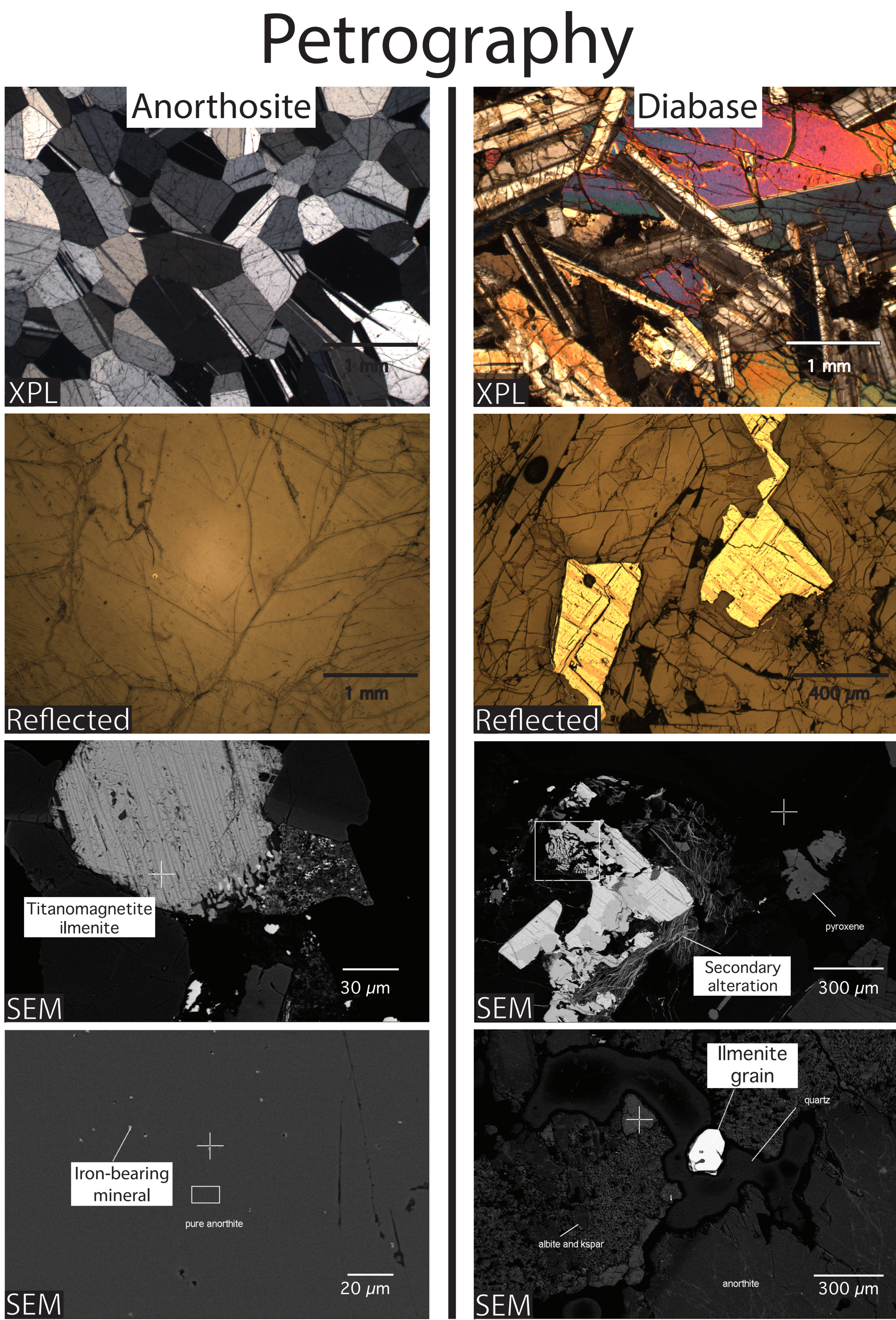
Introduction and Background

Anorthosites are attractive paleomagnetic recorders as silicate-hosted magnetite inclusions can be single-domain and be shielded from alteration. However, petrofabrics within anorthosites may result in magnetic remanence anisotropy that is potentially detrimental to recovering paleomagnetic direction and intensity. The ca. 1095 Ma Beaver River diabase of the North American Midcontinent Rift contains abundant nearly pure plagioclase anorthosite xenoliths that are hypothesized to have been liberated from the lower crust by the magma enroute to becoming embedded in shallow crustal sills. These xenoliths range in scale from centimeters to >100 meters. In this study, we compare the remanent paleomagnetic directions recorded by anorthosite xenoliths to those of the Beaver River diabase host rocks. Given that both lithologies should record the same thermal remanent magnetization, this comparison provides a means to assess the effects of remanence anisotropy on the paleodirection recorded by the anorthosites.

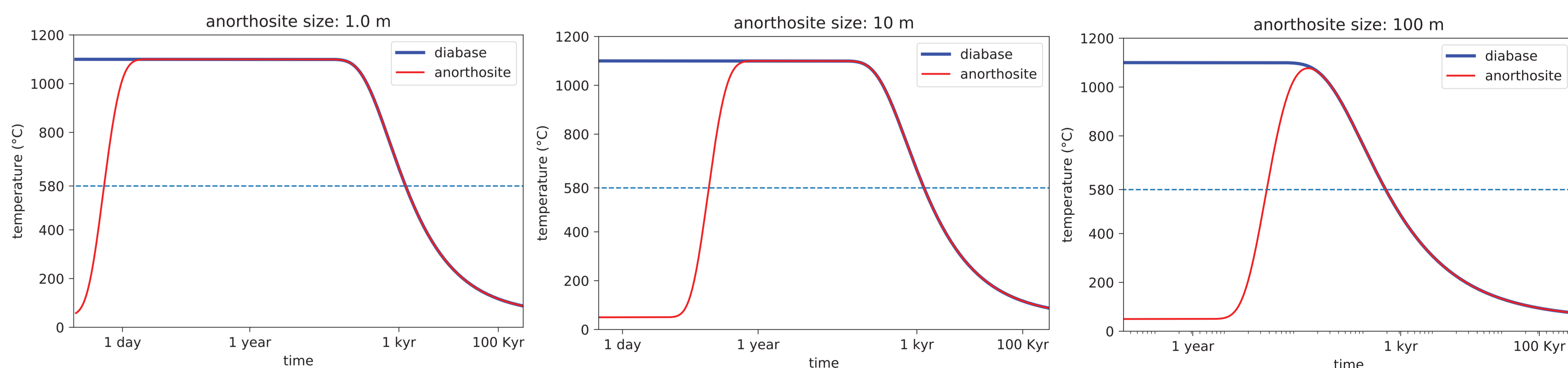
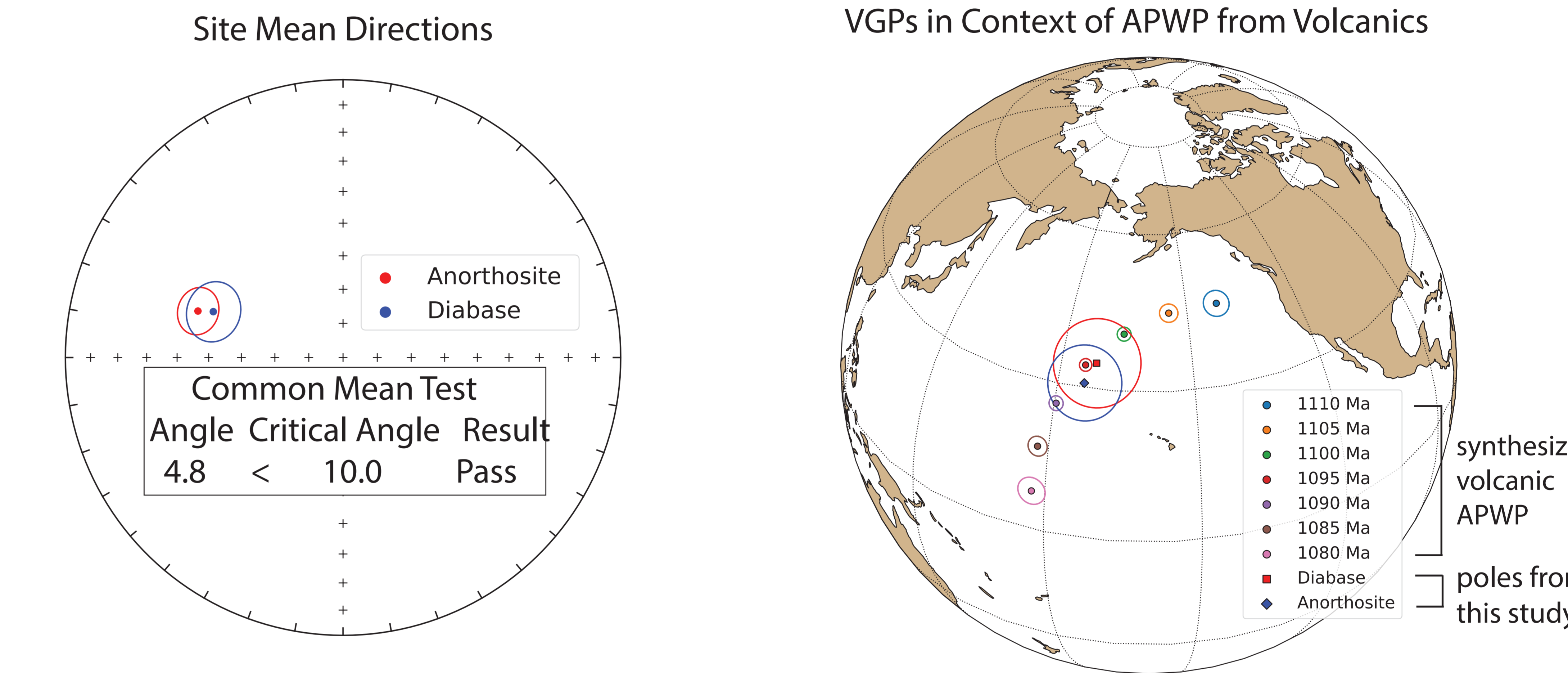
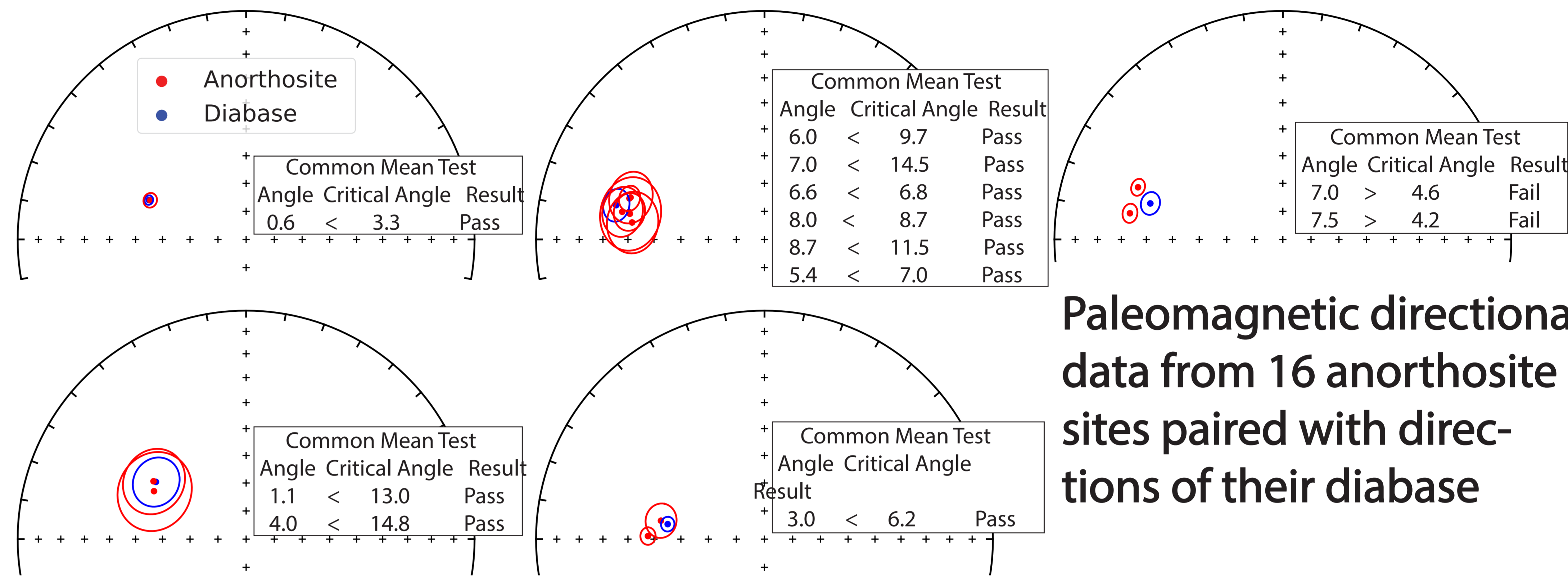
- Research Questions:**
1. Did the anorthosite xenoliths acquire a thermal remanence at the time of emplacement?
 2. Is the anorthosite remanence aligned with host diabase or skewed due to anisotropy?
 3. Do the plagioclase crystals contain magnetite ideal for paleointensity experiments?



Field photos of anorthosites and diabase, and schematic formation diagram for the Beaver Bay Complex modified from Ashwal (1993).



Paired Diabase-Anorthosite Sites



Cooling model for different sizes of anorthosite xenoliths embedded within the Beaver River diabase (modeled to be 200 meter thick. Anorthosites likely acquired full TRM within the diabase).

Conclusion and Future Research

1. The anorthosite xenoliths acquired a thermal remanent magnetization within the diabase as it cooled.
2. Common mean tests indicate minimal remanence anisotropy of anorthosite relative to diabase.
3. Determining the remanence carriers in the anorthosite requires additional rock magnetic experiments and electron microscopy.
4. Both whole rock anorthosite and single crystal plagioclase from the xenoliths are promising targets for

Reference

1. Ashwal, L. D. (1993). Anorthosites (Vol. 21). Springer Science & Business Media.
2. Delaney, P.T. (1987). Heat transfer during emplacement and cooling of mafic dykes. Mafic dyke swarms, 34, 31-46.
3. Miller, James D., Jr.; Green, J.C.; Severson, M.J.; Chandler, V.W.; Peterson, D.M.. (2001). M-119 Geologic map of the Duluth Complex and related rocks, northeastern Minnesota. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, <http://hdl.handle.net/11299/183>.
4. Swanson-Hysell, N. L., Ramezani, J., Fairchild, L. M., & Rose, I. R. (2019). Failed rifting and fast drifting: Midcontinent rift development, Laurentia's rapid motion and the driver of Grenvillian orogenesis. Bulletin, 131(5-6), 913-940.
4. Unsworth, J., & Duarte, F. J. (1979). Heat diffusion in a solid sphere and Fourier theory: an elementary practical example. American Journal of Physics, 47(11), 981-983.

Acknowledgement

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