Provenance of glacially transported material near Nimrod Glacier, East Antarctica: Implications for the ice-covered East Antarctic shield

D. M. Brecke and J. W. Goodge

Department of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812, USA (brec0058@d.umn.edu, and jgoodge@d.umn.edu)

Summary Study of glacial-clast petrography, igneous whole-rock geochemistry, metamorphic mineral composition, and magnetic susceptibility of glacially eroded, transported, and deposited material near Nimrod Glacier, East Antarctica provides information on the composition of the ice-covered East Antarctic shield. Over 100 igneous and metamorphic rocks collected from moraines near Nimrod Glacier show both local and transported material. Most metamorphic rocks collected show intense deformation fabrics, high-grade mineral assemblages, and high-grade P-T conditions, which are similar to the Archean and Paleoproterozoic Nimrod Group. Many igneous rocks may originate from either the Nimrod Group or from the syn-tectonic and post-tectonic Cambrian-Ordovician Granite Harbour Intrusive series, and some come from nearby Ferrar dolerite (Jurassic). Although many of the clasts can be explained by local derivation, others appear exotic and may represent more distal origins in the shield interior. Future geochronology will help to refine the relative contributions of local and distal sources to test these conclusions.

Citation: Brecke, D.M., and J.W. Goodge (2007), Provenance of glacially transported material near Nimrod Glacier, East Antarctica: Evidence of the ice-covered East Antarctic shield, in Antarctica: A Keystone in a Changing World — Online Proceedings of the 10th ISAES X, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 125, 4 p.

Introduction

The sub-ice geology of East Antarctica can be examined through analysis of glacially-transported rock material collected near the ice cap margin. Limited exposures of basement rock units near Nimrod Glacier in the Transantarctic Mountains (TAM) represent the Pacific margin of the Archean to Neoproterozoic East Antarctic shield (Goodge et al., 2001). Here, well-mapped basement outcrops represent the only known exposure of Archean rocks in the TAM. This study focuses on ice-margin moraine clasts collected from the Nimrod Glacier region that are potentially Precambrian basement and/or unique to the adjacent outcrops. Description of petrography, igneous whole-rock geochemistry, metamorphic mineral compositions, and magnetic susceptibility data from over 100 large rock clasts provides a foundation with which to compare moraine clasts to mapped rock units.

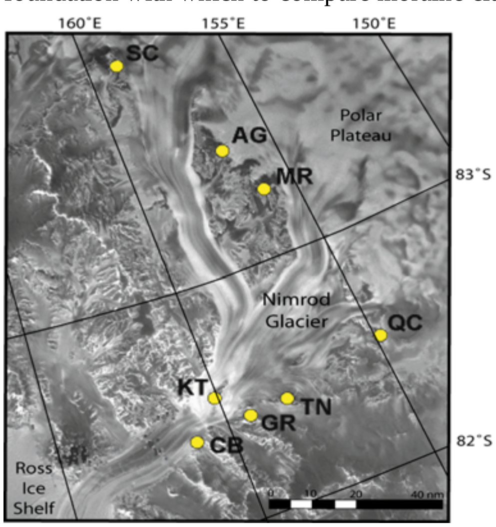
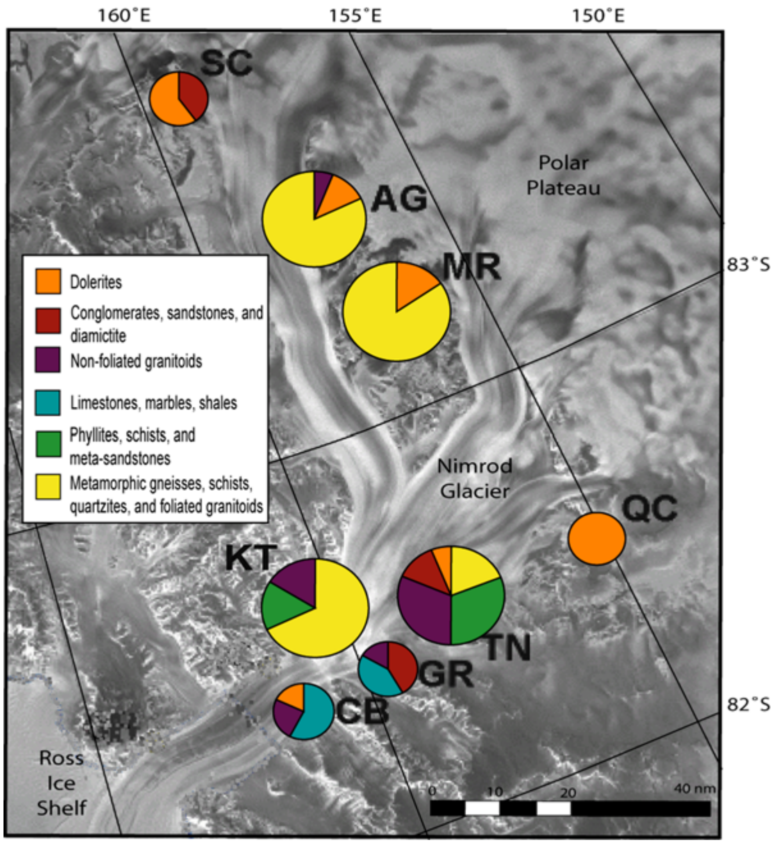


Figure 1. Study area near Nimrod Glacier. Primary moraines: Argo Glacier (AG), Milan Ridge (MR), Turret Nunatak (TN), and Kon-Tiki Nunatak (KT). Secondary moraines: Sanford Cliffs (SC), Quest Cliffs (QC), Gargoyle Ridge (GR), and Cambrian Bluff (CB). Radar base from Canadian Space Agency.

Discussion

Sampling from eight moraine locations near Nimrod Glacier (Figure 1) provided 156 large clasts that show evidence for both glacial transport and local rock fall. Physical characteristics of local rock fall include angular edges, whereas distantly transported material exhibits rounded edges, glacial striations, or rock types only seen upstream. A variety of shapes and degrees of roundness are found at primary moraine sites, different from secondary moraine sites that show primarily local angular rock fall. In general, primary moraine sites reflect both erratic rock types and local geology, while secondary moraine sites only show contributions of local geology. At primary site locations, not only did we focus on Precambrian rock types likely to represent basement material of the East Antarctic shield, but we generally excluded rock types Devonian or younger in age (Beacon or Ferrar). Rock types collected at each site location are shown in Figure 2; these were selected for petrologic interest and are not representative of the moraines. The majority of collected moraine clasts at primary site locations show some evidence for glacial transport such as rounded edges. Glacially-transported rocks collected from primary sites nearest the Polar Plateau (Argo Glacier, Milan Ridge, and Turret Nunatak) are likely to be derived from somewhere under the EAIS. The lack of sub-aerial sources upstream of these moraines, and the presence of rounded edges, eliminates the possibility of a local rock fall origin. The extent of glacial transport is unknown but is restricted to the catchment area of Nimrod Glacier (Hughes, 1998).



Metamorphic rocks are the most abundant rock type collected. The majority of these are pelitic gneisses and schists, similar to lithologies in the Nimrod Group. Several of these rocks contain an aluminum-silicate polymorph, commonly sillimanite, which indicates high temperatures and/or pressures. Garnet and biotite are commonly present in the mineral assemblage. Additional metamorphic rock types include phyllite, amphibolite, quartzite, marble, and eclogite. A sample of sillimanite-muscovite-biotite quartzite is unique to the collected suite because it is a high-grade aluminous quartzite that shows mica-pinning microstructures reflecting high-T recrystallization.

Granites and dolerites comprise the most abundant igneous rock types collected. Granites are subdivided by the presence or absence of macroscopic foliation seen in hand-sample. However, intrusion of the Granite Harbour rocks occurred both during (540-520 Ma, Goodge et al, 1993) and after the Ross Orogeny (500-475 Ma, Gunner and Mattinson, 1975), leading to deformation fabrics in Granite Harbour rock types. Because the age of the foliated rock types cannot be distinguished in hand-sample, all foliated rocks are spatially associated with exposures of the Nimrod Group. In general, foliated rock types are pinkish in color, whereas the non-foliated rock types are light gray and contain a mineral assemblage of muscovite + biotite ± tourmaline, as is common in the Granite Harbour suite. Granodiorite and monzodiorite are non-foliated granitoids that may also be associated with the Granite Harbour suite.

A common rock type collected at both primary and secondary site locations is dolerite. These rocks are generally fine-grained dark mafic rocks with a sub-ophitic texture of plagioclase and clinopyroxene. They are compositionally and texturally similar to Ferrar Group dolerite occurring in numerous sills in the area.

Leucodiorite and quartz monzodiorite are distinctly different mineralogically and texturally from all other samples. Biotite leucodiorite has a unique blotchy texture formed by black (biotite) and white (quartz and feldspar) mineral domains. Biotite-hornblende quartz monzodiorite contains large feldspar phenocrysts surrounded by a black fine-grained matrix showing internal foliation. Both clasts have well-rounded edges, suggesting glacial transport.

Selected rock types chosen on the basis of petrographic observations were analyzed for igneous whole-rock geochemistry (31 samples) and metamorphic mineral composition (11 samples). Igneous whole-rock data from collected rock types are compared with known sample suites of granitoids in the TAM to help identify samples derived from the ~500 Ma Granite Harbour Intrusive series and Jurassic Ferrar dolerites. Samples with compositions outside of these two main groups may therefore represent older igneous lithologies of the East Antarctic shield that would be good targets for further study and geochronological analysis. Based on geochemical data, the origin of many samples can be associated local outcrops. Petrography and geochemical data, with the exception of elevated values in a few mobile elements (Sr and Rb), suggest many samples are from the Granite Harbour Intrusive series. These samples share many characteristics with Ross-age granites in southern Victoria Land.

Ten samples in the collected moraine suite are likely to originate from a source other than the Granite Harbour suite. These samples show unique characteristics in both petrography and geochemistry when compared with published Granite Harbour data. Some of these samples form distinct sub-groups whereas others are individually unique. For example, two biotite-hornblende gneisses are similar to each other in mineralogy, deformation fabric, geochemistry, and magnetic susceptibility, but unique to the whole group. Hornblende-biotite granite and biotite-hornblende quartz monzodiorite show similar trace element patterns and magnitudes when compared with patterns obtained from the previously described biotite-hornblende gneisses. In general, these four samples show major-element trends different from published data yet they show similar trace element patterns. All contain large poikilitic feldspar, but otherwise they show distinct differences in overall appearance. Thus, these rocks may be magmatically related as a group but they are unique compared to known granitoid data and may represent rocks derived from under the ice sheet.

Six samples are unique petrographically and geochemically from published data and the remainder of the collected moraine suite. These samples include two muscovite-biotite granites, biotite-hornblende granite, biotite leucodiorite, muscovite-biotite monzodiorite, and sillimanite-muscovite-garnet-biotite gneiss. The low silica contents in biotite leucodiorite and muscovite-biotite monzodiorite are unusual for the Granite Harbour suite and these samples rarely plot within the published data. The remaining samples show high values in immobile elements Y, Cr, and Zr.

Analysis of eleven garnet-bearing samples by electron microprobe generated elemental oxide data for garnet, plagioclase, biotite, muscovite, amphibole, pyroxene, and staurolite. This study analyzed 11 moraine clasts for mineral compositions including seven gneisses, two phyllites, one amphibolite, and one eclogite. Geothermobarometry on these samples yielded a wide range of conditions, clearly showing different rock type origins. Most correlate with conditions from known outcrops, while some remain unique with uncertain origins. In general, the moraine clasts show retrogression patterns similar to rocks found in the Nimrod Group and the Beardmore Group. In particular, several gneissic rocks have zoned garnets that yield cooling and decompression paths that are similar to changes inferred from Nimrod Group gneisses. Other samples (phyllites) show low-T prograde heating paths similar to those inferred for Beardmore Group rocks near granitic plutons. Yet other samples (eclogite and gneisses) show decompression paths with a near-isothermal trajectory that is similar to that inferred from Paleoproterozoic eclogitic relics in the Nimrod Group (Goodge et al., 2001); of particular interest is kyanite-garnet-biotite gneiss, which is a high-P gneiss not previously known from the Nimrod Group and may be exotic.

Aeromagnetic data collected near Nimrod Glacier show a Ross Orogen trend which extends ~100 km underneath the ice sheet from the exposed rock units. Farther inland, this trend is followed by very high-amplitude magnetic anomalies (Finn et al, 2006; Anderson et al., 2006, Goodge et al., 2004c; Goodge et al., 2004d). Although magnetic susceptibilities from collected moraine clasts are not high enough to explain the sub-ice magnetic anomalies, they are consistent with values seen in the Miller and Geologists ranges (J.W. Goodge, unpublished data). Either the collected moraine clasts have only traveled on order of 100 kilometers distance or the collected sample suite simply contains none of these highly-magnetic rocks. There is no evidence to rule out either possibility and based on the small number of randomly collected rocks it is more likely that high-magnetic samples are present in the moraines and were just not found.

Summary

Petrography, igneous whole-rock geochemistry, metamorphic mineral composition, and magnetic susceptibility are used to describe 156 large rock clasts collected from glacial moraines near Nimrod Glacier, East Antarctica. Sample data are compared with known outcrops in order to identify possible origins for the moraine clasts and predict sub-ice contributions from the East Antarctic shield.

Igneous whole-rock geochemistry and geothermobarometry indicate that many samples were likely derived from known and exposed rock types. A few show unexplained anomalies, such as elevated immobile trace element concentrations, when compared to published Granite Harbour suite data or other samples within the moraine suite, or very high-grade metamorphism. Extreme P-T conditions seen in a few samples are not consistent with exposed rock types. Perhaps these rock types only exist in a sub-ice setting, where the glaciers have eroded deep into the TAM.

Most of the moraine suite is likely to originate from a nearby source in the central TAM. This larger group thus indicates that much of the glacial debris captured at the head of a major outlet glacier, such as Nimrod Glacier, may have a provenance within the broadly define Ross Orogen. A few samples unique in petrography, geochemistry, and/or P-T conditions may be from a source unseen in the Nimrod Glacier region. These rocks have the greatest potential for providing information on the lithologic character of the sub-ice region and, even if in lower abundance, may yield important insight into the character and age of the adjacent East Antarctic shield. They therefore represent the best targets for future geochronology.

Based on the results of this study, 20 rocks were selected for geochronology, which will provide information to aid in refining sample history and origin. Such an understanding will help refine our understanding of the nature and age of the adjacent East Antarctic shield, and it may lead to further clarification of the Rodinia supercontinent assemblage. Additional questions remain because of limited information about the glacial flow characteristics of Nimrod Glacier. Ultimately, it is unclear how far samples were carried and their origin. Further investigation on glacial processes in the Nimrod Glacier region can place restrictions on the origin of clasts used in this study.

Acknowledgments. This project is supported by the National Science Foundation, Geological Society of America, University of Minnesota-Duluth Department of Geological Sciences, and the University of Minnesota-Duluth College of Science and Engineering.

References

Anderson E.D., C. A. Finn, D. Damaske, J. D. Abraham, F. Goldmann, J. W. Goodge, and P. Braddock (2006), Aeromagnetic and Gravity Data Over the Central Transantarctic Mountains (CTAM), Antarctica: A Website for the Distribution of Data and Maps, United States Geologic Survey, Open-File Report 2006-1255, http://pubs.usgs.gov/of/2006/1255/.

Finn, C. A., J. W. Goodge, D. Damaske, and C. M. Fanning (2006), Scouting Craton's Edge in Paleo-Pacific Gondwana: Contributions to global earth sciences, Springer-Verlag, Berlin Heidelberg, New York, 165-174.

Goodge, J. W., C. M. Fanning, and V. C. Bennett (2001), U-Pb evidence of ~1.7 Ga crustal tectonism during the Nimrod Orogeny in the Transantarctic Mountains, Antarctica: implications for Proterozoic plate reconstructions. Precambrian Research, 112, 261-288.

Goodge, J. W., N. W. Walker, V. L. Hansen (1993), Neoproterozoic-Cambrian basement-involved orogenesis within the Antarctic margin of Gondwana, Geology, 21, 37-40.

Goodge, J., C. Finn, D. Damaske, J. Abraham, H. D. Moeller, E. Anderson, N. Roland, F. Goldmann, P. Braddock, and M. Rieser (2004a), Aeromagnetic and gravity data reveal crustal structure and tectonic history of the central Transantarctic Mountains region, Eos, Transactions of the American Geophysical Union, 85, T11A-1237.

Goodge, J., C. Finn, D. Damaske, J. Abraham, H. D. Moeller, E. Anderson, N. Roland, F. Goldmann, P. Braddock, and M. Rieser (2004b), Crustal structure of Ross Orogen revealed by aeromagnetics and gravity, Geological Society of America Abstracts with Programs, 36, 495.

Gunner, J., and J. M. Mattinson (1975), Rb-Sr and U-Pb isotopic ages of granites in the central Transantarctic Mountains, Geological Magazine, 112, 25-31.

Hughes, T. J. (1998), Ice Sheets, Oxford University Press, New York.