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Generation and fate of glacial sediments in the central Transantarctic Mountains based on radiogenic isotopes and implications for reconstructing past ice dynamics

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ABSTRACT

The Nd, Sr and Pb isotopic compositions of glacial tills from the Byrd and Nimrod Glaciers in the central Transantarctic Mountains (TAM) in East Antarctica were obtained to assess the sources of detritus transported by these ice masses. Tills from lateral moraines along the entire extent of both glaciers have isotopic compositions consistent with their derivation predominately from erosion of adjacent bedrock. Fine- (<63μ) and coarser-grained (0.5 mm–2 mm) sediment from these tills have identical isotopic characteristics, indicating that fine-grained detritus is the product of further comminution of coarser sediments. Comparison of present-day till isotopic data to existing data from fine-grained LGM tills in the central Ross Sea confirm that these were deposited from East Antarctic ice that expanded through the TAM and indicates that the LGM sediments are mixtures of detritus eroded along the entire path of ice transiting the TAM. If specific lithologies were preferentially eroded as ice passed through the TAM, it is not clearly evident in the Ross Sea till isotopic compositions. Our data do demonstrate, however, that glacial tills generated from erosion of inboard regions of the mountain belt yield sediment with a larger component of 560 Ma to 600 Ma detrital zircons and lower average $\varepsilon_{Nd}(0)$ values (<−5) than that produced further downstream. As a result, past retreat of ice grounding-lines up the narrow valleys of the TAM resulting in active erosion of inboard region should recognizable in glacial sediments deposited in the Ross Sea and so provide a means to identify times when the East Antarctic ice sheet was smaller than today. This study highlights both the value and necessity of utilizing multiple provenance methods in evaluating glacial erosion and transport when reconstructing past ice sheet dynamics.

1. Introduction

Assessing potential instabilities in the East Antarctica Ice Sheet (EAIS) during warming climatic conditions is critical given the role that the degradation of the EAIS plays in raising global sea level (Dolan, 2011). One approach is to investigate past instabilities in the EAIS, particularly during earlier warm periods such as the Mid-Pliocene (Austermann et al., 2015; Sugden, 1996; Winnick and Caves, 2015; Yokoyama et al., 2016). For this purpose, radiogenic isotope analyses (Nd, Sr, Pb) of glaciomarine sediments deposited on the continental shelf provide important insights into the behavior of the EAIS, an approach that has been successful in identifying EAIS expansion into Ross Embayment during the LGM (Farmer et al., 2006; Licht et al., 2005) and ice margin retreat along the Adélie Land coast during the Mid-Pliocene Warm Period (Cook et al., 2013). A full assessment of the potential of radiogenic isotope data in reconstructing past dynamics of the EAIS, however, is lacking and will require a better understanding of the factors that control the sources of glacial sediment delivered to and deposited at any given portion of the ice margin during both ice expansion and retreat. Is the locus of erosion and sediment production concentrated at the ice margin (Alley et al., 1997; Jamieson et al., 2010)? Do the sources of glacial sediments vary during ice expansion and retreat when the ice margin overrides a region of high underlying basement relief and focused ice flow (Creyts et al., 2014)? Even if the locus of bedrock erosion shifts as a regular function of ice extent, does the detritus produced inherit a radiogenic isotope that could be unambiguously used to assess the sediment provenance along a given portion of the EAIS margin?

In this study, we address some of the above issues through the

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use of radiogenic isotope data obtained principally from the <63μ size fraction of tills deposited by the Byrd and Nimrod Glaciers to help determine the sources of sedimentary material generated and transported by ice currently traversing the Transantarctic Mountains (TAM). These data are used to assess the locus of erosion that produced subglacial sediments deposited in the central and western Ross Sea during the LGM, and to assess the likelihood that major retreat or expansion of the EAIS would produce changes in the primary sources of EAIS-derived sediment deposited in the Ross Sea that would be identifiable from radiogenic isotopic data.

The new and existing isotopic data from modern tills in the central TAM indicate that these sediments represent the products of erosion and communition of adjacent bedrocks, with downstream isotopic compositions of <63μ tills reflecting changes in the age and/or lithology of local bedrocks. Tills inboard of where the Byrd and Nimrod Glaciers enter the TAM, in contrast, contain detritus that most likely derived from otherwise unexposed Precambrian basement sources underlying adjacent portions of the EAIS. When combined with existing chemical, isotopic, and zircon U-Pb age data from central-western Ross Sea LGM tills, our data confirm that the LGM tills are complex mixtures of detritus derived largely from glaciers traversing across the entire width of the central TAM. Although the relative contributions of specific TAM bedrock contributions to LGM tills cannot be unambiguously determined, our data do suggest that grounding line retreat through the TAM in the past should be recognizable in both the radiogenic isotopic compositions of fine-grained glaciomarine sediments and in the U-Pb ages of detrital zircons delivered to the Ross Embayment during such events.

2. Geologic setting/previous studies

This study targets tills associated with the Byrd and Nimrod Glaciers in the central TAM, the latter representing the two dominant sources of ice contributed by the EAIS to the Ross Ice Shelf today (Humbert et al., 2005). The central TAM is well-suited for an assessment of the production and transport of glacial till because the bedrock geology varies regularly across the strike of the mountain belt, parallel to the direction of ice flow of the main outlet glaciers (Fig. 1) (Elliot, 2013). Both the Byrd and Nimrod Glaciers channelize EAIS ice that overrode Proterozoic basement rocks prior to entering the central TAM (Goodge et al., 2001, 2008) and that traversed a set of Phanerozoic sedimentary and igneous rocks before spilling into the Ross Ice Shelf. The Byrd Glacier is distinct, however, because it overlies a post 40 Ma fault zone that produced ~1 km of relative uplift of the southern and northern boundaries of the glacial valley (Foley et al., 2013). The north side of the glacial valley is comprised of Cambro-Ordovician Granite Harbour Intrusive Suite rocks that intruded high grade metamorphic rocks of the Horney Unit (Fig. 1) (Borg et al., 1990). Detrital zircons in moraines along these outcrops are dominated by ages ~530 Ma (Licht and Palmer, 2013), consistent with bedrock ages of 531.0 ± 7.5 Ma on a diorite and 545.7 ± 6.8 Ma on a foliated granite (Stump et al., 2006). On the south side of Byrd Glacier, the bedrock is Lower Cambrian to Ordovician Shackleton Limestone, Douglas Conglomerate, Madison Marble and Contortion Schist; the latter were named the Selborne Group and subsequently determined to be equivalent to formations in the Byrd Group (Myrow et al., 2002; Stump et al., 2004). At the head of the Byrd Glacier, nunataks are composed of Devonian Beacon Supergroup siliciclastic rocks and Ferrar Supergroup dolerites (Anderson, 1979; Grindley and Laird, 1969) (Fig. 1). The age and composition of East Antarctic Precambrian basement rocks further inland within the catchment are known from allochthonous clasts recovered at Lonewolf Nunataks and include a variety of Cambrian, Proterozoic and Archean intermediate to silicic composition igneous and metamorphic rocks (Goodge and Fanning, 2010; Palmer, 2008; Palmer et al., 2012).

At Nimrod Glacier, the bedrock geology also varies along the valley. At the head of the Nimrod Glacier, outcrops at nunataks and in the Miller Range are Beacon/Ferrar Supergroup rocks and

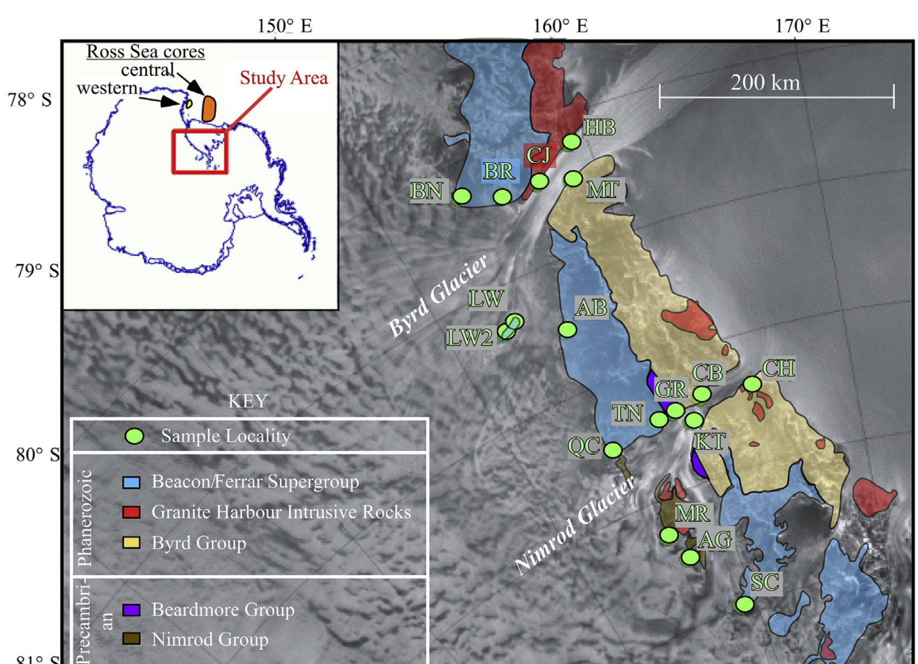

Fig. 1. Till sample locations shown on Radarsat basemap. Schematic bedrock geology after Grindley and Laird (1969) and Myrow et al. (2002). Inset map shows general location of Ross Sea cores for which LGM glacial sediment isotopic analyses are available (Farmer et al., 2006). BN = Bates Nunatak, BR = Brittania Ridge, CJ = Crazy Jim, HB = Horney Bluff, MT = Mt. Tuatara, LW/LW2 = Lonewolf Nunataks, AB = All Blacks Nunatak, QC = Quest Cliffs, TN = Turret Nunatak, GR = Gargoyle Ridge, CB = Cambrian Bluff, CH = Campbell Hills, KT = Kon Tiki Nunatak, MR = Milan Ridge, AG = Argo Glacier, SC = Sanford Cliffs.