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Invited review

Analysis of Antarctic glacigenic sediment provenance through geochemical and petrologic applications

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ABSTRACT

The number of provenance studies of glacigenic sediments in Antarctica has increased dramatically over the past decade, providing an enhanced understanding of ice sheet history and dynamics, along with the broader geologic history. Such data have been used to assess glacial erosion patterns at the catchment scale, flow path reconstructions over a wide range of scales, and ice sheet fluctuations indicated by iceberg rafted debris in circumantarctic glacial marine sediments. It is notable that even though most of the bedrock of the continent is ice covered and inaccessible, provenance data can provide such valuable information about Antarctic ice and can even be used to infer buried rock types along with their geo- and thermochronologic history. Glacigenic sediments provide a broader array of provenance analysis opportunities than any other sediment type because of their wide range of grain sizes, and in this paper we review methods and examples from all size fractions that have been applied to the Antarctic glacigenic sedimentary record. Interpretations of these records must take careful consideration of the choice of analytical methods, uneven patterns of erosion, and spatial variability in sediment transport and rock types, which all may lead to a preferential identification of different elements of sources in the provenance analyses. Because of this, we advocate a multi-proxy approach and highlight studies that demonstrate the value of selecting complementary provenance methods.

1. Introduction

The persistence of the Antarctic ice sheet through warm interglacial periods sets it apart from most continental-scale northern hemisphere ice sheets. While Antarctica provides important opportunities to directly study modern ice dynamics and geomorphic processes, we cannot rely as readily on the glacial geomorphology to reconstruct its past configuration as pioneering naturalists Schimper, Charpentier, Agassiz, Chamberlain and others used in the 1800's to begin to understand the history and influence of glacier ice on the landscape. Although tremendous progress has been made in understanding Antarctic ice with multibeam swath bathymetric data that provided paradigm-shifting images of the continental shelf geomorphology (e.g., Shipp et al., 1999), targeted sampling of glacial landforms, comparable to terrestrial glacial studies, has been difficult to achieve. . Glacial geologists working in the Antarctic also lack the 'luxury' of having direct access to the bedrock geology. Bedrock geology influences erosion rates and ice flow (e.g., Jamieson et al., 2010; Golledge et al., 2013), and the lithological and geochemical/geochronological expressions of the geologic history of sediment sources provide important tools for tracing the transport pathways of sediment (e.g., Licht and Palmer, 2013; Pierce et al., 2014) and for probing erosion rates and thus inferring landform evolution of hidden sources (e.g., Thomson et al., 2013).

On glacial-interglacial timescales, changes in Antarctic ice sheet volume have resulted in eustatic sea level changes causing major changes locally to the geomorphology and deposition on continental shelves around Antarctica, but also, globally as coastlines shifted, altering ocean currents and fluvial gradients. This link to global sea level changes strongly motivates ongoing study of Antarctica ice sheets to inform models that can more reliably estimate the potential for future sea level rise, an area of substantial uncertainty (Church et al., 2013). Many of the first-order questions of Antarctic ice sheet history (i.e., ice sheet extent), particularly for the last glacial maximum (LGM), have been addressed (e.g., RAISED consortium, 2014) and data-driven numerical models have been developed that attempt to optimize model outputs with existing

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geologic data on ice extent and flow pathways (e.g., Golledge et al., 2013) (Fig. 1). However, many fundamental questions about ice sheet extent and configuration remain even for the last deglaciation, and there is a particularly sparse record for pre-LGM times. The limited exposure of pre-LGM deposits onshore, and limited access to offshore deposits means that relatively few samples have been analyzed. Thus reconstructions mainly rely on indirect geophysical datasets such as marine seismics and airborne radar. However, physical samples provide information essential to ice sheet reconstructions, including analysis of sediment provenance (origin and transport).

In this review we use the term "sediment provenance" or "provenance analysis" in the most general sense: it is the reconstruction of the origin of sediment, that is the sources and processes on the landscape from which the sediment was derived. Provenance analysis has been widely used in glaciated areas of the northern hemisphere for both academic studies of ice sheet history and applied science such as mineral exploration, but has only begun to be widely used in Antarctica in the past decade. Early work in the Ross Sea by Stetson and Upson (1937), using cores

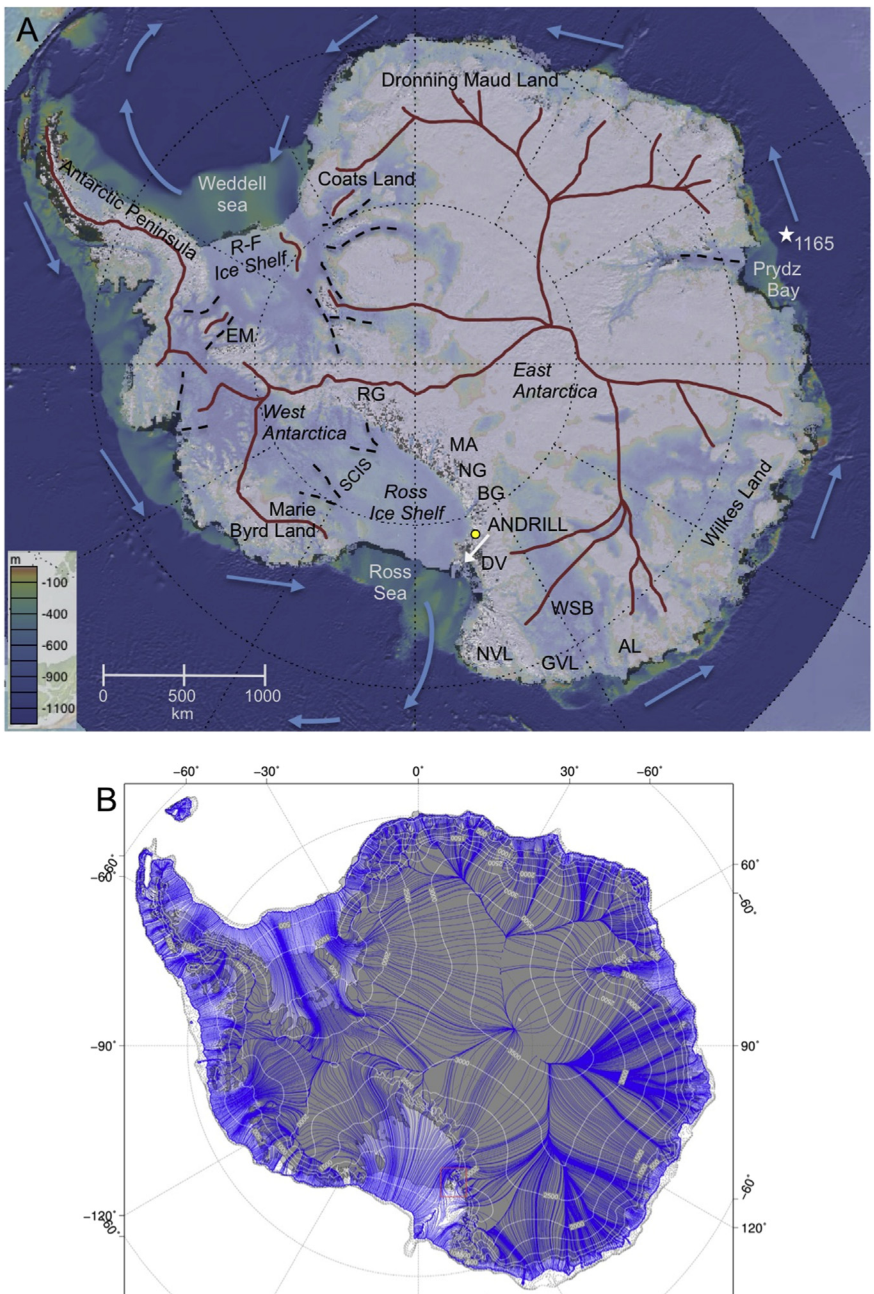

Fig. 1. (A) Locations named in text shown on the BEDMAP 2 subglacial topography from Fretwell et al. (2013) with a semi-transparent overlay of the Landsat Image Mosaic created with GeoMapApp. Red lines show ice divides, black dashed lines are ice streams, blue arrow show generalized surface currents. AL = Adélie Land, BG=Byrd Glacier, DV = Dry Valleys, EM = Ellsworth Mountains, GVL = George V Land, MA = Mt. Achernar and Law Glacier, NG=Nimrod Glacier, NVL = north Victoria Land, R-F = Ronne-Filchner, and RG = Reedy Glacier, SCIS=Siple Coast ice streams, yellow dot marks Skelton-Mulock Glaciers. (B) Model reconstruction of Antarctic ice flow lines for the Last Glacial Maximum (Golledge et al., 2013) compared to modern grounded ice extent shown on base image (grey shading).