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A comparison of detrital U–Pb zircon, $^{40}Ar/^{39}Ar$ hornblende, $^{40}Ar/^{39}Ar$ biotite ages in marine sediments off East Antarctica: Implications for the geology of subglacial terrains and provenance studies

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ABSTRACT

U–Pb ages of detrital zircon grains have provided an extraordinary tool for sedimentary provenance work, given that they are ubiquitous, resistant to damage and weathering, and that the U–Pb age records the crystallization age of the mineral. Although not as widely used, $^{40}Ar/^{39}Ar$ dating of detrital hornblende and biotite grains can also serve as powerful sedimentary provenance tools, particularly in situations where chemical weathering is minor (e.g., Antarctica). Certain natural biases exist among these mineral chronometers (e.g., abundance in different rock types, durability during abrasion, resistance to dissolution) that determine the extent to which they are found in sedimentary deposits. Additionally, the $^{40}Ar/^{39}Ar$ systems in hornblende and biotite have lower closure temperatures for thermally activated diffusion (~500 °C and ~300 °C, respectively). Thus, for areas that have experienced a polymetamorphic history, such as East Antarctica, combining these approaches can provide added detail to provenance studies.

In this study we provide a comparison of the detrital U–Pb zircon, $^{40}Ar/^{39}Ar$ hornblende and $^{40}Ar/^{39}Ar$ biotite age populations from 28 glacial-diamict and glacial-marine sediment core samples located around East Antarctica (55°W to 163°E). We present 3370 new detrital age measurements of U–Pb zircon, $^{40}Ar/^{39}Ar$ hornblende, and $^{40}Ar/^{39}Ar$ biotite, in conjunction with previously published data from some of the same core sites, as well as 78 U–Pb zircon ages measured on dispersed zircons from five ice-rafted debris (IRD) layers recovered at ODP Site 1165. Our data indicate that detrital U–Pb zircon, $^{40}Ar/^{39}Ar$ hornblende and $^{40}Ar/^{39}Ar$ biotite ages faithfully document the onshore geology of source areas within East Antarctica, as expressed in their respective age populations. In addition, a number of previously unknown age populations are recorded by the combined thermochronometers. Assuming an East Antarctic provenance, this approach helps to identify otherwise hidden geologic provinces. Previously unrecognized age populations include Archean $^{40}Ar/^{39}Ar$ hornblende and biotite ages in Dronning Maud Land; 1200–1300 Ma $^{40}Ar/^{39}Ar$ hornblende ages in the Weddell Sea; ~1560 Ma population of U–Pb zircons from the Wilkes Land margin; and Grenvillian (1000–1200 Ma) U–Pb zircon ages from the Adélie/George V Land margin.

Contents

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1. Introduction

The U–Pb system in detrital zircons is a widely used and powerful tool for conducting sedimentary provenance studies (e.g., Gaudette et al., 1981; Andersen, 2005; Gehrels et al., 2011a; Gehrels, 2012, see Fedo et al. (2003) for a discussion of detrital U–Pb zircon studies). $^{40}Ar/^{39}Ar$ ages measured in detrital hornblende and biotite are less exploited as a sedimentary provenance tool, but they are increasingly being used for studies of ice rafted debris (IRD) around Antarctica and other regions characterized by tidewater glaciers (e.g., Gwiazda et al., 1996; Hemming et al., 1998; Hemming et al., 2000; Hemming and Hajdas, 2003; Peck et al., 2007; Roy et al., 2007b; Williams et al., 2010; Pierce et al., 2011; Downing et al., 2013; Knutz et al., 2013). In this study, we compare U–Pb zircon, $^{40}Ar/^{39}Ar$ hornblende and $^{40}Ar/^{39}Ar$ biotite ages measured on detrital mineral grains from glacially-derived marine sediment samples taken from 28 marine sediment cores located around East Antarctica (Figs. 1, 2).

The first objective is to provide a direct comparison of detrital zircon U–Pb, hornblende $^{40}Ar/^{39}Ar$ and biotite $^{40}Ar/^{39}Ar$ age populations. Given the natural biases that exist for each system (see Section 2), we are interested in which of the minerals are present, which age populations are present, if the age populations are present across all mineral systems, and how these ages relate to one another from a thermochronology point of view. The findings have broad implications for evaluating each of these chronometers as a provenance tracer around East Antarctica, and they will particularly benefit the study IRD. The provenance of IRD provides key information on the ice sheet and ocean circulation dynamics that transport the mineral grains from their source to the ocean floor: flowing ice erodes and incorporates debris, and when the ice streams reach the ocean, they calve off icebergs that are carried by ocean currents, melting as they travel, and causing the entrained debris to sink and be deposited on the ocean floor.

The second objective of this study is to use this information to increase our understanding of East Antarctica's geology. Today more than 98% of East Antarctica is covered by the thick East Antarctic ice sheet, and relatively little outcrop is available for direct geologic study (Fig. 2). Despite these challenges, the general geological history of East Antarctica is known reasonably well. The bulk of East Antarctica was formed during the Precambrian; it comprises a number of Archean cratons, surrounded by orogenic belts and accreted terranes of Proterozoic and younger ages (e.g., Tingey, 1991; Boger, 2011). The amalgamation of the continents to form the supercontinent Rodinia at ~1100 Ma led to widespread occurrence of terranes with approximately Grenvillian (900–1300 Ma) ages. Though the Grenville orogeny itself is defined by Mesoproterozoic collisional activity along the Laurentian margin (e.g., Rivers, 1997), Fitzsimons (2000) compiled available U–Pb zircon outcrop data from East Antarctica and previous contiguous margins (see Fitzsimons (2000) for full description of data used), and defined three distinct Grenville-aged (or Grenvillian) zones in East Antarctica: Dronning Maud Land (1030–1090 Ma), Prydz Bay or Rayner Province (900–990 Ma), and Wilkes Land (1130–1330 Ma). In this paper we follow suit and refer to age populations within the bounds of 900 to 1330 Ma as Grenvillian or Grenville-aged. The timing of the subsequent break-up of Rodinia remains controversial (as does the existence of Rodinia itself), with different studies arguing for different ranges of ages that span ages from 520 to 1000 Ma, and for either continuous or multiphase rifting (Goodge et al., 2002; Cordani et al., 2003; Meert and Torsvik, 2003; Veevers, 2004).

A re-assembly of the continents occurred after rifting, with East Gondwana (India, Australia, and East Antarctica) colliding with West Gondwana (South America and Africa) to form Gondwanaland. During this time of continental amalgamation, two temporally close orogenies, the Pan-African and the Ross-Beardmore, affected the East Antarctic Craton (EAC).

The Pan-African orogeny (500–650 Ma) was the result of the Gondwana blocks colliding to form Gondwana, while the Ross orogeny (~480–590 Ma) was the result of subduction between Gondwana and what would become the Pacific plate (Tingey, 1991; Goodge, 2007; Boger, 2011). During these partly contemporaneous orogenies, the continued attachment of East Antarctica, India and Australia meant that parts of the craton – specifically Wilkes Land and part of Adélie Land – were buffered from the intense tectonothermal activity associated with these orogenies. The evidence for this buffering is the lack of a high-temperature overprint signatures in the ages of in-situ and detrital