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Low-temperature thermochronology of the northern Thomson Orogen: Implications for exhumation of basement rocks in NE Australia

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ABSTRACT

The Tasmanides of eastern Australia record much of the Phanerozoic tectonic development of the retreating Pacific-Australia plate boundary and are an oft-cited example of an orogen that has undergone “tectonic mode switching.” To begin to constrain the timing of exhumation of basement rocks that are now exposed in portions of the NE Tasmanides, we measured apatite and zircon (U–Th)/He ages from the Thomson Orogen and overlying Paleozoic strata in the back-arc of the New England Orogen in NE Australia. Zircon (U–Th)/He ages from basement samples (including those recovered from boreholes at depths of up to 1.1 km) are characterized by large inter- and intra-sample variability and range from approximately 180 Ma (Early Jurassic) to 375 Ma (Late Devonian). (U–Th)/He zircon ages from several individual samples are negatively correlated with effective uranium (eU), a pattern that is also true of the dataset as a whole, suggesting that variations in U and Th zoning and radiation damage are partially responsible for the age variability. The oldest zircon (U–Th)/He cooling ages coincide with the formation of regionally extensive Late Devonian–early Carboniferous back-arc basins, suggesting that Late Devonian extension played a significant role in exhumation of parts of the northern Thomson Orogen. Apatite (U–Th)/He ages from a basement sample and a late Permian sandstone in the overlying Bowen Basin, which are also marked by intra-sample variability and age–eU correlations, span from the Early Cretaceous through Oligocene, in general agreement with previous apatite fission track data. In conjunction with observations of key geologic relationships and prior K–Ar and $^{40}Ar/^{39}Ar$ data, our results suggest four overall phases in the thermal history of the northern Thomson Orogen: (1) Cambrian–early Silurian metamorphism during the Delamerian and Benambran Orogenies; (2) protracted cooling during the Late Devonian through mid-Permian that likely resulted from extensional exhumation; (3) Permian–Triassic reheating during burial beneath thick sedimentary basins; and (4) Cretaceous and Paleogene cooling during uplift and erosion.

1. Introduction

Exhumation of basement rocks in the cratonward regions of continental arcs is frequently attributed to one of two processes: back-arc extension (e.g., Foster and John, 1999; Jolivet et al., 1994; Stockli et al., 2000) or retro-arc thrusting (e.g., Davis, 1979; Fosdick et al., 2013; Pearson et al., 2012). In some areas it may be relatively straightforward to determine which of these processes was most relevant to tectonic exhumation, though in the case of orogenic systems that have experienced multiple transitions from extension to contraction (in other words, regions characterized by “tectonic mode switching,” e.g., Lister et al., 2001; Collins, 2002a; Beltrando et al., 2008) deformation style in the back-arc may be more difficult to unravel. Indeed, these transitions are being increasingly recognized, even in regions that have been extensively studied in the past (e.g., Beltrando et al., 2008; Wells et al., 2012). Estimates for the timing of basement exhumation in these multiply deformed orogens are particularly critical because they may link deformation in the interiors of orogenic systems with regional tectonic events that are more clearly manifest in regions closer to the plate boundary. However, tectonic mode switches also tend to result in complicated thermochronological datasets (e.g., Guenthner et al., 2014a), necessitating nuanced interpretations of these data and integration with key field observations.

The Tasmanides of eastern Australia, an enormous tectonic province encompassing most of the Australian continent east of approximately Adelaide (Fig. 1), is a prominent example of an orogenic system that has undergone multiple phases of extension and contraction (e.g., Cawood, 2005; Collins, 2002a,2002b; Coney et al., 1990; Fergusson, 1991; Glen, 2005; Harrington, 1974; Jenkins et al., 2002; Purdy et al., 2013). The youngest component of the Tasmanides is the New England Orogen (Fig. 1), a relatively narrow belt along the eastern margin of Queensland and New South Wales that is closely associated with late Paleozoic–Mesozoic deformation that also affected back-arc

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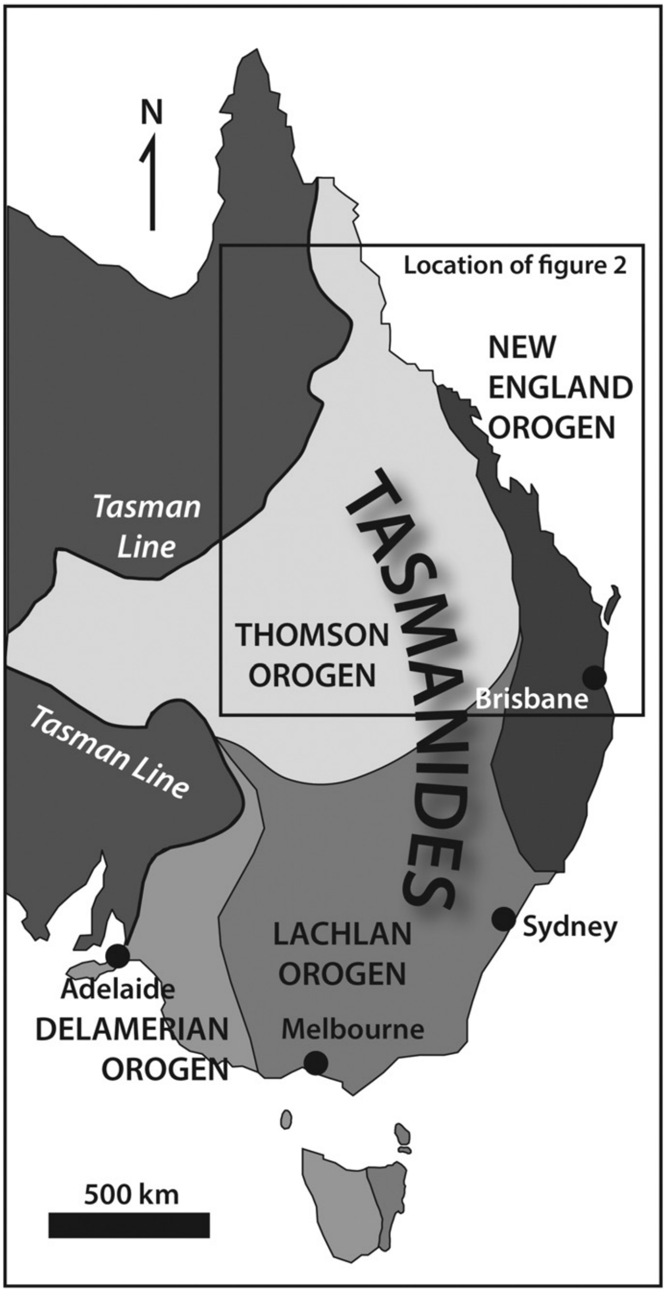

Fig. 1. Major tectonic elements of eastern Australia. After Foster and Gray (2008).

regions within the interior of eastern Australia (e.g., Day et al., 1978; Fergusson, 1991; Holcombe et al., 1997a,1997b; Li et al., 2012; Murray et al., 1987; Roberts and Engel, 1987; Shaanan et al., 2015). The New England Orogen includes most of the important elements of a convergent margin, including ophiolites, an accretionary complex, fore-arc basin sediments, and remnants of a volcanic arc (e.g., Korsch, 1977; Fergusson, 1984; Roberts and Engel, 1987; Li et al., 2012; Rosenbaum et al., 2012).

Basement rocks of NE Australia in the "back-arc" of the New England Orogen largely consist of Proterozoic–early Paleozoic metamorphic and igneous rocks that make up the Thomson Orogen (Fig. 1; e.g., Kirkegaard, 1974; Murray and Kirkegaard, 1978; Fergusson and Henderson, 2013). These basement rocks are poorly exposed but underlie large and economically important sedimentary and volcanic basins. Because of poor exposure, basic characteristics of the Thomson Orogen such as lithology and age are still largely unknown (e.g., Glen et al., 2013), but in one of the largest basement exposures (the Anakie Inlier of east-central Queensland, Fig. 2), paleobarometry suggests that some late Proterozoic–Cambrian metasedimentary rocks of the Thomson Orogen experienced pressures of 0.6–0.8 GPa (Offler et al., 2011). The timing and mechanisms by which these rocks were buried to depths of up to 20 km and subsequently exhumed are largely unknown, as are the thermal histories of the basins that overlie them. Given the complex and protracted tectonic history of the Tasmanides, as well as evidence for tectonic mode switching in other parts of eastern Australia (e.g., Collins, 2002a,2002b; Glen et al., 1998), improved understanding of the thermal history of the Thomson Orogen is likely to refine models of the geologic evolution of the Tasmanides as a whole, which, in turn, informs the overall tectonic history of Gondwana.

To place constraints on the low-T exhumation history of the central Queensland portion of the Thomson Orogen, we measured apatite and zircon (U–Th)/He ages from surface and subsurface samples of the northern Thomson Orogen, Devonian granitoids that intrude Thomson Orogen rocks, and Permian sandstone from an overlying basin. Combined with the results of previous K–Ar, $^{40}Ar/^{39}Ar$, and apatite fission track investigations, our new results allow us to assemble a first-order framework for the medium- and low-temperature thermal history of the Thomson Orogen.

2. Tectonic background

2.1. New England Orogen

The Paleozoic New England Orogen extends 1500 km along-strike across the eastern margin of Australia (Fig. 1). Several phases in the development of the New England Orogen are particularly relevant to our study of the northern New England back-arc, and these phases also constitute evidence for tectonic mode switching in the northern Tasmanides. The first is a widespread period of Late Devonian–early Carboniferous back-arc extension and volcanism in the Drummond Basin and correlative basins of eastern Queensland (Fig. 2; Davis and Henderson, 1996; Henderson et al., 1998; Bryan et al., 2004; Van Heeswijck, 2006; Blake et al., 2012). The second is a phase of late Carboniferous–midPermian extension and related basin initiation, magmatism, and metamorphic core complex formation that affected much of eastern Australia (Holcombe et al., 1997b and Korsch et al., 2009a; Little et al., 1992, 1993; Shaanan et al., 2014). The third is a late Permian–Middle Triassic period of contractile deformation known as the Hunter–Bowen Orogeny (e.g., Holcombe et al., 1997a; Korsch et al., 2009b), which is manifest in the northern New England Orogen as thin-skinned thrusting (Fergusson et al., 2001) and which transitioned extensional back-arc basins formed during the late Carboniferous–midPermian extensional phase into retro-arc foreland basins. The final relevant tectonic events were periods of Cretaceous (e.g., Gurnis et al., 1998; Raza et al., 2009) and Paleogene (e.g., Kohn et al., 2002) uplift and erosion.

2.2. Thomson Orogen, cover sequences, and back-arc counterparts of New England Orogen deformation

The Thomson Orogen comprises latest Proterozoic–early Paleozoic continental and oceanic rocks that underlie many of the Phanerozoic basins of eastern Australia (e.g., Fergusson et al., 2001; Glen et al., 2013; Kirkegaard, 1974). In the Anakie Inlier of east-central Queensland (Figs. 2 and 3), Thomson Orogen rocks are intruded by Devonian granitoids such as the mid-Devonian Retreat Granite (Bryan et al., 2004; Withnall et al., 1995).

On the western flank of the Anakie Inlier, metasedimentary and metavolcanic rocks of the Thomson Orogen, as well as the Devonian granitoids, are overlain by up to 12 km of Late Devonian–early Carboniferous volcanic and sedimentary rocks within the Drummond Basin (Fig. 2; e.g., Olgers, 1972; Johnson and Henderson, 1991; Davis and Henderson, 1996; Henderson et al., 1998; Bryan et al., 2004; Blake