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Burial and exhumation during Archean sagduction in the East Pilbara Granite-Greenstone Terrane

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ABSTRACT

Archean granitic domes and intervening volcano-sedimentary basins are commonly interpreted as the product of "sagduction", a process involving the gravitational sinking of surficial greenstone cover sequences into narrow belts and the coeval exhumation of deeper granitic crust into broad domes. Alternatives to the sagduction model that can account for the regional dome and basin pattern include fold interferences and extensional metamorphic core complexes. In order to provide quantitative constraints on the pressure–temperature–time (P–T–t) evolution experienced by greenstone–granite pairs we investigate the Warrawoona greenstone belt and adjacent Mount Edgar granitoid dome the East Pilbara craton (Western Australia). We adopt a multidisciplinary approach that includes structural, metamorphic, geochronological and numerical investigation of the 3.5–3.2 Ga Mount Edgar high-grade metamorphic rocks. Garnet-bearing metasediments and metabasalts collected along the SW and SE rims of the Mount Edgar Dome show higher pressure but lower temperature of equilibration (9–11 kbar and 450–550 °C) than enclaves collected in the core of the dome (6–7 kbar and 650–750 °C). In situ oxygen isotope analysis and U–Pb dating of zircons from the enclave indicate a metasedimentary origin ($\partial^{18}O \sim +13‰$) for the protoliths and a metamorphic age of 3311.9 ± 4.9 Ma. In addition, monazites included in garnet from the SW dome margin yield an age of 3443.4 ± 4.5 Ma. These monazites suggest the existence of an older metamorphic cycle and imply a polymetamorphic evolution of the unit. The P–T–t data support fast, gravity-driven tectonics, wherein sedimentary rocks were buried to lower crustal conditions, metamorphosed and exhumed back to the surface during a cycle lasting only a few million years. Forward thermo-mechanical modeling confirms the P–T–t evolutions deduced from thermobarometry and geochronology. Our model shows a large range of possible apparent geothermal gradients during sagduction, including low apparent geothermal gradients that are similar to those proposed for Archean and modern subduction.

1. Introduction

Archean continents have many attributes that set them apart from post-Archean counterparts. The relative abundance of komatiites in the Archean reflects hotter mantle than today (Arndt and Nisbet, 1982; Hoffman, 1988; Abbott et al., 1994; Jaupart et al., 2007; Coltice et al., 2009) and possibly widespread mantle plume activity (Condie and Benn, 2006). One of the most striking characteristics of Archean terranes is the systematic presence of thick, denser, continental flood basalts (greenstone covers) on felsic and therefore less dense crusts (Abbott and Hoffman, 1984; Taylor and McLennan, 1985; Bickle, 1986; Hoffman and Ranalli, 1988; Smithies et al., 2003). The combination of density inversion and hotter Archean crustal geotherm due to higher U–Th–K content conspired to make this stratigraphy mechanically unstable (e.g. Macgregor, 1951; Ramberg, 1967; Anhaeusser, 1973; Mareschal and West, 1980; Dixon and Summers, 1983; Chardon et al., 1996; Chardon et al., 1998; Collins et al., 1998). The coupled foundering of greenstone covers into narrow basins and exhumation of the deeper felsic crust into granitic domes has been named sagduction (Macgregor, 1951) and is, at least in part, responsible for the dome-and-basin pattern in many Archean cratons. This process corresponds to a partial convective overturn (Collins et al., 1998;

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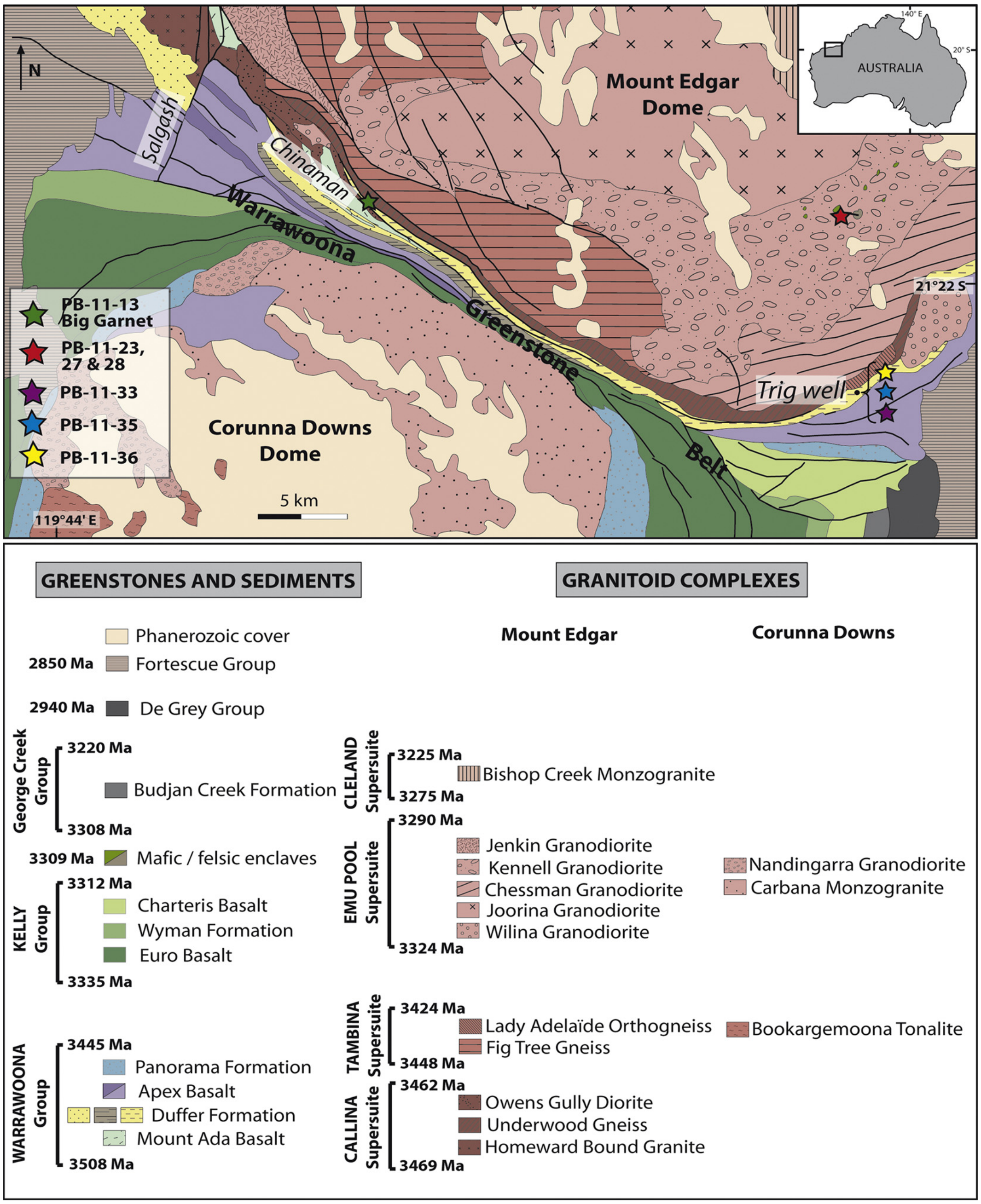

Fig. 1. Geological map of the southern part of Mount Edgar granitoid, the Warrawoona Greenstone Belt and the northern part of Corunna Downs granitoid. See location in Fig. S1 in supplementary data. Colored stars show sample locations. Age data from Williams and Collins (1990), Thorpe et al. (1992), McNaughton et al. (1993), Buick et al. (1995), Barley and Pickard (1999), and Nelson (1999, 2001a). Map after Williams and Bagas (2007), Mount Edgar, WA Sheet 2955: Geological Survey of Western Australia, 1:100 000 Geological Series and Hickman and Van Kranendonk (2008), Marble Bar, WA Sheet 2855: Geological Survey of Western Australia, 1:100 000 Geological Series. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Van Kranendonk et al., 2004), which tends to create the density inversion and promote the cooling of the geotherm via the concentration of U–Th–K in the upper part of the crust (West and Mareschal, 1979). In the Archean, sagduction was a process able to drive crustal scale deformation, involving deep burial and exhumation, far away from plate margins where plate tectonic processes tend to focus. Sagduction has been the focus of structural studies (e.g. Bouhallier et al., 1993; Percival et al., 1994; Bouhallier et al., 1995; Chardon et al., 1996; Chardon et al., 1998; Collins et al., 1998; Bédard et al., 2003; Peschler et al., 2004; Van Kranendonk et al., 2004) as well as physical (e.g. Dixon and Summers, 1983; Chardon et al., 1996) and numerical modeling (e.g. West and Mareschal, 1979; Mareschal and West, 1980; de Bremond d'Ars et al., 1999; Cagnard et al., 2006; Robin and Bailey, 2009; Thébaud and Rey, 2013). However, this important process, which is perhaps unique to the Archean, lack of studies integrating detailed metamorphic petrology and geochronology.

In order to better document the pressure–temperature–time (P–T–t) signatures of Archean domes we conducted a multidisciplinary study (structural, petrological, geochemical, geochronological and numerical) of the 3.5–3.2 Ga old Mount Edgar high-grade rocks of the East Pilbara Granite–Greenstone Terrane (EPGGT, Western Australia). This terrane displays narrow belts of strongly deformed greenstones (mafic to ultramafic volcanic rocks and metasediments), in association with broad TTG (Tonalite–Trondhjemite–Granodiorite) granitoids (Fig. S1). The Mount Edgar and