Gondwana Research 28 (2015) 1310–1328

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Hot orogens and supercontinent amalgamation: A Gondwanan example from southern India

Chris Clark [a,*], David Healy [b], Tim Johnson [a], Alan S. Collins [c], Richard J. Taylor [a], M. Santosh [d], Nicholas E. Timms [a]

[a] Department of Applied Geology, Curtin University, Perth WA 6845, Australia
[b] School of Geosciences, King's College, University of Aberdeen, AB24 3UE United Kingdom
[c] Department of Earth Sciences, The University of Adelaide SA 5005, Australia
[d] School of Earth Science & Resources, Chinese University of Geosciences, Beijing, China

ARTICLE INFO

Article history:
Received 1 October 2014
Received in revised form 31 October 2014
Accepted 2 November 2014
Available online 28 November 2014

Handling Editor: S.J. Liu

Keywords:
Phase equilibria modelling
U–Pb geochronology
High temperature metamorphism
Gondwana supercontinent
Southern India

ABSTRACT

The Southern Granulite Terrane in southern India preserves evidence for regional-scale high to ultrahigh temperature metamorphism related to the amalgamation of the supercontinent Gondwana. Here we present accessory mineral (zircon and monazite) geochronological and geochemical datasets linked to the petrological evolution of the rocks as determined by phase equilibria modelling. The results constrain the duration of high to ultrahigh temperature (>900 °C) metamorphism in the Madurai Block to be c. 40 Ma with peak conditions achieved c. 60 Ma after the formation of an orogenic plateau related to the collision of the microcontinent Azania with East Africa at c. 610 Ma. A 1D numerical model demonstrates that the attainment of temperatures >900 °C requires that the crust be moderately enriched in heat producing elements and that the duration of the orogenic event is sufficiently long to allow conductive heating through radioactive decay. Both of these conditions are met by the available data for the Madurai Block. Our results constrain the length of time it takes for the crust to evolve from collision to peak *P–T* (i.e. the prograde heating phase) then back to the solidus during retrogression. This evolution illustrates that not all metamorphic ages date sutures.

1. Introduction

The Southern Granulite Terrane (SGT) in peninsular India is characterised by the occurrence of high to ultrahigh temperature (>900 °C) metamorphic assemblages over a length scale of ~500 km, in which elevated temperatures persisted for up to 100 Ma (Santosh et al., 2003, 2006; Cawood and Buchan, 2007; Collins et al., 2008, 2014). The lack of any strong evidence for an input of heat from mantle-derived magmas requires an alternative heat source that was long-lived.

There are currently two competing hypotheses to account for the source of heat needed to generate UHT metamorphic conditions on a regional scale. Brown (2007) has suggested that UHT metamorphism may record closure and thickening of continental back arc basins, which are characterised by regions of thinned lithosphere. In this scenario, the extreme metamorphic temperatures are due to high mantle heat flow prior to orogenesis, which are enhanced by thickening of the hot crustal column during orogenesis. The most likely tectonic setting for inversion of a back-arc basin is continental accretion and collision at a magmatic arc, which is consistent with the observation that UHT metamorphism is generated during periods of continental assembly (Brown, 2007; Clark et al., 2014). Another plausible, but less well understood, mechanism suggests that the crust can be heated to UHT conditions by the radioactive decay of heat producing elements (HPE) (Chamberlain and Sonder, 1990; Huerta et al., 1998; Goffe et al., 2003; McKenzie and Priestley, 2008; Clark et al., 2011). In this scenario, high temperatures are the result of heat generated within the thickened crustal column during collisional orogenesis. The numerical models of McKenzie and Priestley (2008) suggest that the attainment of UHT conditions requires crust with higher than average concentrations of HPE (>2 μW m^{-3}) (Vila et al., 2010) that is subsequently thickened (a thickening factor of three times in their model) during orogenesis and requires an incubation time on the order of 60 My (their Fig. 8). A current natural example of this scenario might be the Himalayan collision system, in which metamorphosed crustal xenoliths sourced from the deep crust of the Tibetan Plateau underwent UHT metamorphism at mid crustal depths (Hacker et al., 2000). The metamorphism associated with large scale collisional systems has previously been investigated through the application of 2D numerical models (Beaumont et al., 2001, 2004; Faccenda et al., 2008b; Beaumont et al., 2010; Jamieson et al., 2010; Gerya and Meilick, 2011; Jamieson and Beaumont, 2011; Lexa et al., 2011). The results of these studies suggest that elevated temperatures can be achieved in the orogenic core, where crustal material remains buried for extended periods of time.

* Corresponding author. Tel.: +61 8 9266 2446; fax: +61 8 9266 3153.
E-mail address: c.clark@curtin.edu.au (C. Clark).

http://dx.doi.org/10.1016/j.gr.2014.11.005
1342-937X/

The aim of this paper is to investigate the heat source required by the occurrence of regional-scale high temperature metamorphism in the Southern Granulite Terrane through the application of in situ microprobe dating techniques and a better understanding of the links between accessory mineral growth and the evolution of the major silicate mineral assemblages (Fraser et al., 1997; Degeling et al., 2001; Kelly and Harley, 2005; Kelsey et al., 2007, 2008; Clark et al., 2009a; Buick et al., 2010; Korhonen et al., 2011, 2013; Yakymchuk and Brown, 2014). We constrain the duration of UHT metamorphism in the Southern Granulite Terrane through the application of U–Pb geochronometers (monazite and zircon) coupled with the pressure–temperature evolution as constrained using phase equilibria modelling, and propose a viable scenario for heating crust to high or ultra-high temperatures on an orogenic scale.

2. Geological setting

The Southern Granulite Terrane, together with central and eastern Madagascar and Sri Lanka, is considered to form part of the microcontinent of Azania, a terrane that was located between East Africa (the Congo Craton) and Greater India (the Dharwar Craton) during the amalgamation of Gondwana (Fig. 1a–d; Collins and Pisarevsky, 2005). The collision of Azania with East Africa was preceded by the docking of a juvenile intra-oceanic arc, comprised of the Vohibory succession (Emmel et al., 2008; Jöns and Schenk, 2008; Collins et al., 2012) in Madagascar and the Eastern Granulites in Tanzania (Möller et al., 1998), with the Tanzania Craton (part of the Congo Craton). Although it is difficult to constrain precisely the timing of this collision, the rocks of the Eastern Granulites and western Madagascar contain

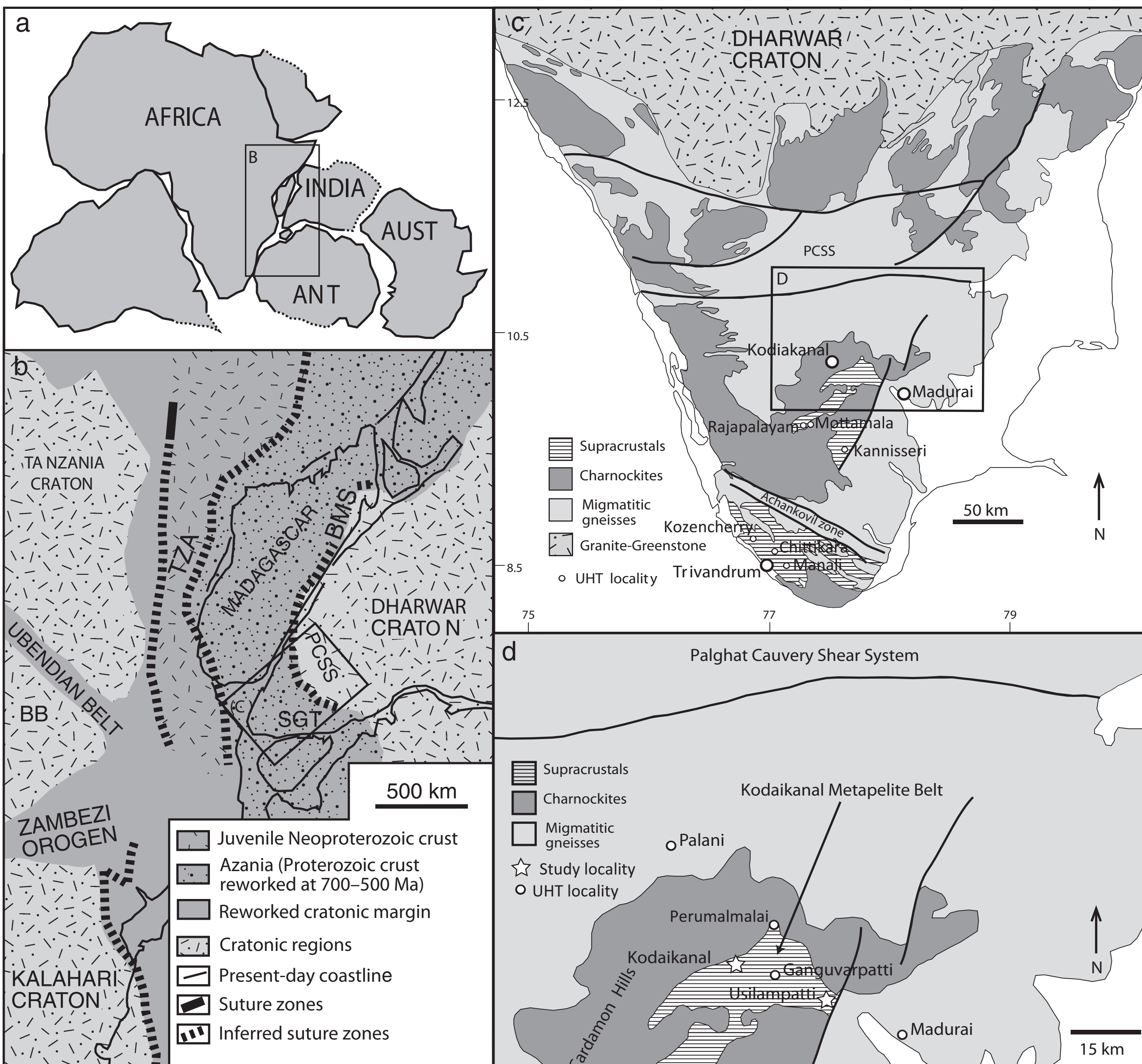

Fig. 1. (a, b) Geology of the East African Orogen within Gondwana modified after Fitzsimons and Hulscher (2005). Line of cross-section X–Y indicated. The Bangweulu Block (BB) and Tanzania Craton (TC) are both part of the Congo Craton, separated by intracratonic deformation along the Ubendian Belt. Also marked on the map are Betsimisaraka Suture (BMS), Tanzanian Arc/Vohibory Group (TZA), Palghat Cauvery Shear System (PCSS) and the Southern Granulite Terrane (SGT). Gondwana fit after Reeves et al. (2002). (c) Geology of Southern India indicating the area of this study. (d) Local map of the Madurai Block showing the sample localities (marked by white stars) and other UHT outcrops within the area. (e) Schematic east–west section through the East African Orogen showing the relationships between the main blocks.