Precambrian Research 227 (2013) 389–408

Contents lists available at SciVerse ScienceDirect

Precambrian Research

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

Petrology of the Neoproterozoic granulites from Central Dronning Maud Land, East Antarctica – Implications for southward extension of East African Orogen (EAO)

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ARTICLE INFO

Article history:
Received 4 December 2011
Received in revised form 7 June 2012
Accepted 25 June 2012
Available online 17 July 2012

Keywords:
East Antarctica
East African Orogen
Granulites
Neoproterozoic
Gondwanaland

ABSTRACT

Suturing of east and west Gondwana occurred during the Neoproterozoic along the East African Orogen (EAO) through continent–continent collision. The southern extension of EAO is projected in central Dronning Maud Land (CDML) in east Antarctica. CDML is considered to be a magmato-metamorphic terrain where high-grade metamorphism occurred during Mesoproterozoic. Granulite grade metamorphic assemblages from metapelites (garnet + sillimanite + K feldspar (perthite) + graphite ± plagioclase + quartz ± melt), mafic granulite (orthopyroxene + garnet ± clinopyroxene + plagioclase + quartz) and granitic orthogneiss (garnet + Fe-clinopyroxene + K feldspar + plagioclase + quartz) in the Humboldt Mountains in CDML have been used to deduce the peak metamorphic conditions as ~850 °C and 6–8 kbar pressure. In situ chemical dating of monazite in matrix and inclusions in garnet indicates metamorphism to have occurred between 640 and 580 Ma and was partially overprinted at ~540 Ma which is correlatable with extensive charnockite and A-type granite emplacements. This Neoproterozoic metamorphism and its correlation with the coast margin Neoproterozoic granulites at Schirmacher oasis is inferred as the extension of EAO in east Antarctica.

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1. Introduction

The idea of existence of a single supercontinent during entire Proterozoic (Piper, 1976) was shown to be inconsistent with the geological and palaeomagnetic evidence. This data can be better explained by assumption of the presence of two separate continental masses, i.e. east and west Gondwana, which came together in Neoproterozoic (McWilliams, 1981; Meert et al., 1995). In the east Gondwana continental block (India, Australia, Antarctica) a continuous Circum-East Antarctic belt of Mesoproterozoic age was considered to be present which implied the presence of a global scale ~Grenville age collisional Orogen all along east Antarctica (Hoffman, 1991). However, the discontinuity of this Mesoproterozoic belt in two major domains, i.e. Dronning Maud Land and Prydz bay-Denman Region Glacier has been well demonstrated in east Antarctica (Fitzsimons, 2000a) by the disrupting presence of Neoproterozoic to Pan-African tectonic belts. Based on analysis of geochronologic data showing disparate histories of tectonometamorphic evolution from three segments of east Antarctica separated by these two Neoproterozoic belts (Fitzsimons, 2000b; Fig. 2), it has been shown that the present day alignment of Mesoproterozoic Circum-East Antarctic belt is a consequence of collision of the east and the west Gondwana blocks. This collision led to suturing of these two continental masses along the Mozambique Belt or the East African Orogen (Stern, 1994) resulting into the Palaeozoic Gondwanaland assembly.

The East African Orogen (EAO) modelled as a continent–continent collision zone (e.g. Collins et al., 2012) has been proposed to extend into east Antarctica (Jacobs et al., 1999) in CDML though its precise extension is not well defined. The issues involved in this reconstruction can be listed as;

1. Lithological continuity of rocks of EAO in the projected area of east Antarctica.
2. Identification and characterization of the suture zone and its extension.
3. Identification of Neoproterozoic metamorphic event consistent with the suturing of east and west Gondwana Land.
4. The geodynamic context of anorogenic magmatism (anorthosite, charnockite, granite) spatially associated with this suture.

In recent years, there have been several studies (e.g. Jacobs et al., 2003; Paulsson and Austrheim, 2003; Mikhalasky et al., 2006) which have attempted to bridge this gap. Granulites representing the 600–660 Ma East African Orogeny (Stern, 1994) have been correlated with those present in a small (~35 km^2) coast-margin

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0301-9268/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.precamres.2012.06.013

exposure at Schirmacher Oasis (Ravikant et al., 2004, 2007; Baba et al., 2006) and these have been shown to be late Neoproterozoic. Though there are differences in interpretation of metamorphic paths in Schirmacher oasis from isobaric heating-isothermal decompression-isobaric cooling (Ravikant and Kundu, 1988) to isobaric cooling during retrograde metamorphism (Baba et al., 2006), two major conclusions are apparent in having clockwise P–T–t paths and the timing of peak metamorphism to be significantly younger than envisaged earlier (Baba et al., 2008, 2010), thus establishing an affinity with the EAO. However, characterization of definite Neoproterozoic metamorphism, evaluating the metamorphic conditions and establishing its context in terms of East African Orogen (EAO) has not been done from the Wohlthat Massif which represents the main outcrop area of the CDML. The present work attempts to fill this gap by evaluating metamorphic conditions and providing age constraints from metapelites and orthogneisses.

2. Geological setting

The Central Dronning Maud Land (CDML) in east Antarctica (Boger, 2011) is characterized by two major types of rock exposures. The northernmost of these is the Schirmacher oasis representing a smaller (~35 km^2), coast-marginal area and ~80 km south, a much larger group of exposures (several hundred km^2) known as Wohlthat massif with Gruber mountains in the east, the Petermann ranges in the centre and the Humboldt mountains towards west (Fig. 1). The Sør Rondane Mountains towards east and the Mühlig Hofman Mountains towards west are the major rock outcrops on the two sides of the Wohlthat massif. In eastern parts of CDML (Gruber Mountains and Petrmann ranges) large exposures of plutonic rocks occur (Gruber anorthosites, Ravich and Soloviev, 1966; A-type granite, Joshi et al., 1991) describing the anorthosite–mangerite–charnockite–granite (AMCG) association (Joshi and Pant, 1995; Mikhalasky et al., 2006) while the western part of the CDML (Humboldt Mountains) is dominantly composed of metamorphics (Fig. 1) with sedimentary precursors in the northern part and the orthogneisses in the southern part (Humboldt Series of Ravich and Kamenev, 1975). Based on petrologic and tectonic comparison with other protogeosynclinal sequences in Gondwanaland, Ravich and Kamenev (1975) assigned upper Archaean ages to the Humboldt Series while gneisses in the Humboldt Mountains were considered middle Proterozoic in some subsequent correlations (James and Tingey, 1983; Yoshida and Kizaki, 1983). Additional geochronological data (Jacobs et al., 1998, 1999) indicated 1080 ± 10 Ma as the age of first major metamorphic event in CDML. This was based on age derived from zircons from the volcanic and sheet like intrusives in the Humboldt Mountains and adjacent areas. The widespread magmatic activity has three major components in CDML viz. anorthosite, charnockites and granites. Anorthosites have been dated at ~600 Ma (Jacobs et al., 1998), charnockites at ~510 Ma (Mikhalasky et al., 1997) and the granite at ~500 Ma (Bisnath et al., 2006) all indicating post peak-metamorphism extensional components possibly in two phases. This succeeded a compressional phase of penetrative foliation development and high grade peak metamorphism. Generally the development of penetrative foliation has been ascribed Mesoproterozoic age (Groenewald et al., 1995; Grantham et al., 1995).

The metasedimentary-orthogneiss metamorphites in the Humboldt Mountains preserve evidence of polyphase deformation. The first phase of deformation (D1) is present as rarely preserved, small scale interfolial folds (F1). These folds are nearly coaxial with the folds produced by second episode of deformation (D2). These F2 folds are tight isoclinals to nearly recumbent. Regional strike of the foliation of these rocks is nearly east–west with the average dip of ~25°. A metamorphic sequence of >8 km thickness constituted dominantly by garnet sillimanite gneiss-migmatite and garnet–clinopyroxene gneiss has been inferred in the Humboldt Mountains in CDML (Pant and Verma, 1994).

3. Petrography

3.1. Garnet–sillimanite gneiss

Garnet sillimanite gneiss is dominantly made up of quartz, garnet, sillimanite, K-feldspar and small amount of biotite, graphite and plagioclase. Two samples of this rock (CH51 and CH1) have been examined in detail. The major difference between the two is in the relative proportion of plagioclase + non-perthitic K feldspar (inferred to represent melt) which is significantly higher in CH51 (high melt) than CH1 (low melt). Thin section scale X-ray element maps of CH51 for Fe Kα, Al Kα, K Kα and Ca Kα (Fig. 2A–D) were obtained to understand the disposition and relative proportions of constituent minerals. Garnet is red coloured rounded poikiloblastic porphyroblasts in Fe Kα X-ray map (Fig. 2A) and constitute about 15% area of the thin section. These are embayed and anhedral, define a crude foliation and occur as refractory phase. Sillimanite occurring as red coloured prismatic grains in Al Kα X-ray maps (Fig. 2B) constitute ~10% to 12% of the thin section occurs along with garnet and graphite (Fig. 3A) and defines a strong alignment. Garnet and sillimanite show widely variable size with garnet grains up to 4 mm and sillimanite up to 2 mm in their maximum dimension. Fibrolite sillimanite occurs exclusively as inclusions in garnet and these garnets generally have overgrowths which are relatively inclusion free (Fig. 3B) indicating two-stage growth of garnet. Sporadically, sympletctitic biotite with quartz occurs close to the margins of garnet (Fig. 3C). Overall the rock contains low amount of biotite. K-feldspar is medium grained, anhedral to subhedral (1–4 mm) and is extensively present in this rock. It is observable as yellow and red coloured areas in K Ka X-ray map (Fig. 2C). It constitutes ~50% of the thin section area. It occurs in two textural modes, i.e. foliation defining (e.g. K Ka maps) and interstitial. Perthitic K-feldspar is anhedral (Fig. 3D) and it occurs with intergrowth of plagioclase and quartz with sporadic subhedral to euhedral non-perthitic K-feldspar (Fig. 3E). For computing the composition of perthitic K-feldspar two grains of perthites (Fig. 3G and H) were selected representing large variation of host versus exsolved phase. Areal proportion of the two in a single grain has been taken as the representative volumes of exsolved plagioclase and host K feldspar. Exsolved plagioclase varies from 4.9% to ~9% and the integrated compositions representing these are listed in Table 1 along with composition of the non-perthitic K feldspar. There are differences in composition of the perthitic K feldspar and non-perthitic K feldspar as former has higher Ca and Na and lower Ba than the latter. The non-perthitic K feldspars having a different composition and its association with quartz and plagioclase indicates it to be locally crystallized melt possibly as a result of biotite melting. It is thus inferred that there was no significant melt extraction. The green coloured, interstitial, relatively fine sized (0.1–0.4 mm) grains in Ca Kα X-ray map (Fig. 2D) represent the plagioclase and these occur in association with quartz and minor K-feldspar (Fig. 3D and E). Monazite has grown in association with the garnet overgrowth over fibrolite inclusion containing core (Fig. 3F).

3.2. Garnet–clinopyroxene gneiss (orthogneiss)

Major minerals in this rock are garnet, K-feldspar, clinopyroxene, calcic amphibole (hornblende), quartz and minor amounts of plagioclase. Garnet and green coloured clinopyroxene occur in textural equilibrium (Fig. 4A) and their smooth grain

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