New age constraints for orogenic collapse and voluminous late-tectonic magmatism in the southern part of the East African-Antarctic Orogen

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Summary The southern third of the more than 8000 km long, Late Neoproterozoic/Early Paleozoic East African-Antarctic Orogen in Dronning Maud Land and northern Mozambique is characterised by lateral extrusion, late tectonic extensional shearing and large volumes of late tectonic igneous rocks. We provide new SHRIMP data for extensional shearing and the timing of late-tectonic igneous activity. The new geochronological ages for the late tectonic granitoid intrusions range between 508-500 Ma, whilst metamorphism along a significant extensional shear zone was dated at c. 510 Ma. The granitoids are part of a > 15,000 km^2 large igneous province that can be traced to the Lurio Belt in northern Mozambique. The granitoids have A2-type geochemistry and are thought to represent lower crustal partial melting, that probably resulted from asthenosphere influx after part of the orogen root had delaminated. The northern margin of this large igneous province appears as a tectonic boundary, the Lurio Belt.

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Introduction

The high-grade rocks of Central Dronning Maud Land and Northern Mozambique represent the southernmost segment of the East African-East Antarctic Orogen (Jacobs and Thomas, 1994), (Fig. 1). The orogen formed during Late Neoproterozoic to Cambrian (Pan-African) collision of various fragments of East- and West-Gondwana. Along the southern part of the orogen, the protolith ages of the crustal rocks are predominantly Mesoproterozoic in age. The latter were extensively overprinted during the Pan-African collision, with only small volumes of juvenile material from the closure of the "Mozambique Ocean" preserved, e.g. in the Shackleton Range.

The Pan-African collision history of the southern part of the orogen in Antarctica and Mozambique can be separated into three major phases:

1) An earliest stage recorded in the Schirmacher Oasis at ca. 620 Ma (Henjes-Kunst, 2004), followed by anorthosite magmatism in the main mountain range of Dronning Maud Land at ca. 600 Ma.

2) The main deformation and medium- to high-grade metamorphism in the main mountain range of Dronning Maud Land and the Nampula Province of Northern Mozambique is bracketed in age by metamorphic zircon rims between ca. 590 and 550 Ma and is interpreted to represent the collision phase (e.g. Jacobs et al. 2003).

3) A late Pan-African stage is associated with extension, tectonic exhumation and south-directed extrusion between ca. 530 and 500 Ma, exposing mid- to lower crustal levels (e.g. Jacobs and Thomas, 2004). This period is accompanied by syn-tectonic and late- to post-tectonic intrusions. The volume of igneous rocks seems to drastically increase towards the end of the extensional period, culminating in voluminous and extensive granitoid-charnockoid magmatism. Late to post-tectonic granitoids with dominantly charnockitic mineralogy cover an area of at least 15000 km^2 in East Antarctica (where they can be traced under the ice by geophysical means) and NE Mozambique (Fig. 1). In Mozambique, the igneous rocks intrude the southernmost Nampula Complex, a major Mesoproterozoic terrane bounded in the north by the Lurio Belt (Fig. 1).

Here, we present new preliminary SHRIMP data on the latest tectonic imprint that is characterised by extensional shearing and associated voluminous granitoid intrusion.

Samples and method

In central Dronning Maud Land, we selected two samples for SHRIMP zircon dating from two late- to post-tectonic granitoid-charnockoid intrusions from western Mühlig-Hofmann-Gebirge at Schneide (J1870) and Oddesteinen (J1670) to directly date the intrusion of these plutons. To date the late shearing event, we selected a sample (J3012/1) from an extensional high-strain zone at Armlenet, which contains complex zircons. A number of additional samples from late-tectonic igneous rocks were dated from northern Mozambique.

Zircons were separated using conventional separation techniques (Wilfley table, magnetic separation, heavy liquids and hand picking). Prior to analysis, cathodoluminescence images (CL) of sectioned zircon grains were taken,

e.g. in order to identify core-rim relationships in the metamorphic sample. SHRIMP zircon dating was performed at the John de Laeter Centre of Mass Spectrometry, Curtin University of Technology, Western Australia.

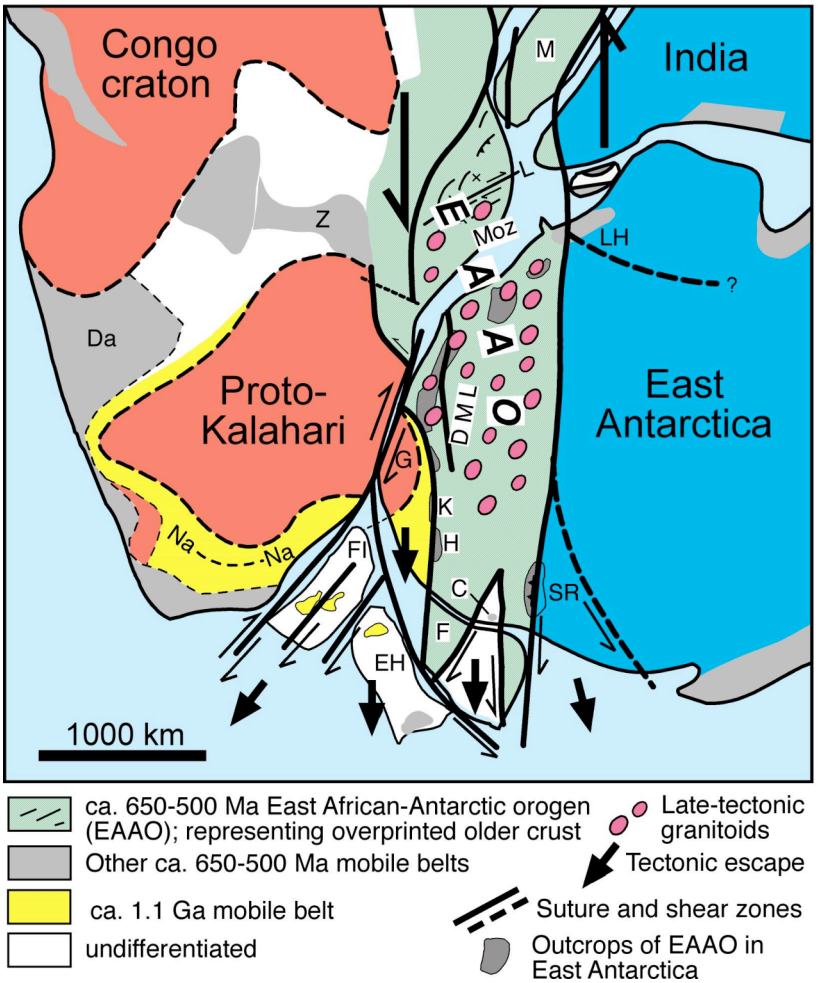

Figure 1. Geological setting of the southern part of the East African-Antarctic Orogen after Jacobs and Thomas (2004). The southern part of the orogen is characterised by lateral extrusion, orogenic collapse and voluminous granitoid intrusions. Abbreviations: C—Coats Land; DML—Dronning Maud Land; EH—Ellsworth-Haag; F—Filchner block; FI—Falkland Islands; G—Grunehogna; H—Heimefrontfjella; K—Kirwanveggen; L – Lurio Belt; Moz – Mozambique; Na-Na—Namaqua-Natal; SR—Shackleton Range; Da—Damara belt; LH—Lützow-Holm Bay; M—Madagascar; Z—Zambesi belt.

Results

J1870:Post-tectonic charnockite from Schneide, Dronning Maud Land

Sample J1870 is from a post-tectonic charnockitic granitoid at Schneide. It consists of large grains of meso-perthitic K-feldspar, plagioclase, quartz, hornblende relics of altered orthopyroxene and accessory apatite, zircon and orthite. The sample contains clear to brownish and stubby to very elongate zircons (width ratio up to 6). Some grains are zoned with high-U cores and many zircons represent fragments. Additionally, CL images show strong oscillatory growth zoning. Areas of oscillatory (magmatic) growth zoning was chosen for analyses, whilst the high-U cores were avoided. The analysed areas contained between c. 70 and 440 ppm U with Th/U ranging from c. 0.4 - 0.8. Ten spots in ten zircon were analysed. These gave a preliminary weighted mean $^{206}Pb/^{238}U$ date of 502 ± 6 Ma (MSWD = 0.37). This date is interpreted as the crystallisation age of the charnockite.

J1670: Monzogranite from Oddesteinen, Dronning Maud Land

This sample is a coarse-grained, unfoliated granitoid composed of quartz, sub-equal plagioclase and perthitic K-feldspar, olive-green hornblende minor biotite and accessory xenomorphic titanite, apatite, zircon and opaque minerals. The zircons often occur as inclusions in hornblende. They are typically clear and yellowish, predominantly fragmentary and elongate up to 0.3 mm in length with length-width ratios up to 5. Fourteen spots in thirteen zircon grains were analysed, mostly targeted on domains with magmatic oscillatory growth zoning. The fourteen concordant analyses form a single age population, which give a preliminary weighted mean $^{206}Pb/^{238}U$ date of 498.7 ± 4.3 Ma (MSWD = 1.2), an age interpreted as the crystallisation age of the monzogranite

J3012/1: Mylonitic felsic gneiss from Armlenet, Dronning Maud Land

This sample is a mylonitic felsic gneiss from a high strain zone, several tens of meters wide. The sheared rock types affected are granitic gneisses, augen gneisses and highly dismembered amphibolites. The shear zone is dissected by pegmatite veins, that are themselves also locally sheared. The highest strain is partitioned into the central part of the shear zone where no mesoscopic shear sense indicators are preserved, though oblique folds with fold axes dipping towards the NNE are recorded. Shear strains decrease towards the margins of the shear zone where abundant shear sense indicators show an extensional sense of movement with NNE plunging stretching lineations. The analysed mylonite sample comes from the central part of the shear zone. It contains small (50 – 150 µm), clear to dark brown, rounded to elongate zircons with length-width ratios up to 5. Many zircons are metamict and inclusions-rich. Metamorphic overgrowths and/or resorption textures are common and a number of grains have been stretched and show necking. CL images reveal complex internal structures. Eleven spots in five cores and six rims were analysed. The preliminary data indicate, that the analysed areas fall approximately onto a discordia line with intercepts at 1108 ± 44 Ma and 540 ± 46 Ma. The upper intercept clearly represents the protolith age of the mylonite, with the lower intercept allied to a metamorphic overprint. The weighted mean $^{206}Pb/^{238}U$ age of the rim analyses is 510.1 ± 8.5 Ma (MSWD = 0.67). This date is regarded as the best estimate of metamorphism during shearing along the Armlenet shear zone.

Northern Mozambique

In northern Mozambique comparable late-tectonic granitoids are exposed. The granitoids are often undeformed within their plutonic centre, but they have in part highly sheared margins. The strain increases towards the Lurio Belt. Here, two late-tectonic intrusions were dated at c. 508 Ma. This age corresponds with similar ages recently obtained by LA-ICPMS dating of other late-tectonic granitoids of the same region (NORSONSULT 2007).

Discussion

The coarse grained to megacrystic, generally undeformed, granitoid-charnockite bodies in central and eastern DML are exposed over an estimated area of more than 15,000 km^2 between 2°E and 28°E. Within Gondwana, this igneous province can be traced for a considerable distance into the Nampula Complex of NE Mozambique as far north as the Lurio Belt (Fig. 1). In Dronning Maud Land, a compositional range from granite, quartz monzonites, monzonite, syenites and minor anorthosite is seen, typically associated with reddish brown weathering charnockite, which are volumetrically the most abundant rocks exposed. Thermobarometrical and petrological studies suggest that the charnockites were emplaced as relatively dry melts at temperatures exceeding 900°C and pressures of approximately 4.8 kbar (e.g. Markl & Henjes-Kunst, 2004). Geochemically, the rocks can be characterized as peraluminous to metaluminous, or subalkaline with a weak trend to alkaline, A-type granites (Roland 2004). Most of the Dronning Maud Land charnockites and related granitoids are enriched in Ba, Sr, Zr, Y, Zn and Fe, but they are relatively low in Cs, Rb and Ca normalized to a primitive mantle composition (e.g. Markl & Henjes-Kunst 2004, Roland 2004), i.e. they represent highly fractionated melts but not typical A-type granitoids. The geochemical signature of the charnockites and related granitoids coincides with the field of A_2-type granitoids (Eby, 1992), which represent magmas derived from continental crust of tonalitic to granodioritic composition or underplated crust. According to Roland (2004) the charnockites were derived from lower continental or underplated crust, explaining their relatively heterogeneous geochemical signature. The megacrystic, sometimes rapakivi-type textures furthermore suggest crustal growth of dry melts at a lower crustal level. The extensive high-temperature dry melt generation in the lower crust could have been accomplished by continental lithospheric mantle delamination after the collision between East and West Gondwana, with the heat source provided by the large-scale uprise of hot asthenosphere. The resulting highly fractionated charnockitic magmas intruded the high-grade metamorphic basement at ~500 Ma, probably facilitated by extensional shearing starting at c. 510 Ma. The associated PT-path shows near isothermal decompression (Engvik and Elvevold, 2004). Cooling to below ~300°C only occurred by around 460-450 Ma giving a relatively slow cooling rate of 10°/Ma (Markl & Henjes-Kunst 2004). Slow cooling was presumably due to the high volumes of hot melt invading the lower to middle crust and synchronous mechanical

thinning of the crust. This large igneous granitoid province sharply terminates along the northern Mozambiquan Lurio Belt. The Lurio Belt might represent the northern boundary of a partial delaminated orogenic root.

Conclusion

A widespread late-to post-tectonic Cambrian (Pan-African) magmatic province is recognised in the southern part of the East African-Antarctic Orogen in NE Mozambique and Central Dronning Maud Land, two areas that were thought to be contiguous within Gondwana. It covers an area of at least 15000 km ^{2}, and would have stretched from the northern margin of the Nampula Province (the Lurio Belt) in Mozambique, through to central Dronning Maud Land, decreasing gradually westwards in volume to the eastern Sverdrupfjella, where the magmatism stops, close to the frontal zone of the orogen in that region.

The three new SHRIMP dates from Dronning Maud Land reveal that the intrusion of the granitoids is tightly constraint almost exactly at 500 Ma, preceded and/or accompanied by extensional shearing dated here at c. 510 Ma. The intrusions are interpreted to have crystallised at mid-crustal levels after collapse and extension of the orogen, possibly accompanied by delamination of the lithosphere root. Hot asthenosphere, rising to the lower crust above the subsiding orogenic root would have provided the heat source for the magmatism which is typically anhydrous, high-temperature and charnockitic.

References

Eby, G. N. (1992) Chemical subdivision of the A-Type granitoids: petrogenetic and tectonic implications. *Geology*, 20, 641-644.

Engvik, A. K. and S. Elvevold (2004), Pan-African extension and near-isothermal exhumation of a ranulite facies terrain, Dronning Maud Land, Antarctica. *Geol. Mag*., 141, 649-660.

Frost, B. R. and K. Bucher (1993) Charnockites and granulites of the Thor Range, Queen Maud Land, Antarctica; the granulite uncertainty principle exemplified. *Abstracts Annual Meeting of the GSA*, p. A-448.

Jacobs, J., W. Bauer and C. M. Fanning (2003), Late Neoproterozoic/Early Palaeozoic events in central Dronning Maud Land (East Antarctica) and significance for the southern extension of the EAO into East Antarctica. *Precambrian Res*., 126, 27-53.

Jacobs, J., R. J. Thomas (2004), A Himalayan-type indenter-escape tectonic model for the southern part of the Late Neoproterozoic/Early Paleozoic East African-Antarctic Orogen. *Geology*, 32, 721-724.

Norconsult Consortium (2007), Mineral resources management capacity building project, Republic of Mozambique, Component 2: Geological infrastructure development project, Geological Mapping Lot 1, Report No. B6.f. Unpublished, 778 pp.

Markl, G. and F. Henjes-Kunst (2004), Magmatic conditions of formation and autometasomatism of post-kinematic charnockites in central Dronning Maud Land, East Antarctica: a model of magmatic evolution. *Geol. Jb.*, B 96, 139-185 [published in 2005].

Roland, N. W. (2004), Pan-African granite-charnockite magmatism in central Dronning Maud Land, East Antarctica: petrography, geochemistry and plate tectonic implications. Geol. Jb., B 96, 187-231 [published in 2005].