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Granulite-facies metamorphic events in the northwestern Ubendian Belt of Tanzania: Implications for the Neoarchean to Paleoproterozoic crustal evolution

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ABSTRACT

We present a geological evolution model for the Paleoproterozoic Ubendian Belt. This model is deduced from the metamorphic histories of metasediments and metamafites combined with previously obtained crust formation and metamorphic ages obtained from different rock types of the Katuma Block in the NW Ubendian Belt.

Geothermobarometry and pseudosection modelling of metabasites indicate that the granulite-facies coronas containing garnet–clinopyroxene–quartz–hornblende formed at about 8.9–6.6 kbar and 790–700 °C. The formation of the corona textures is attributed to the post magmatic cooling history in the deep crust following their intrusion at about 2.65 Ga. This period correlates with the age of deposition of sediments in the Katuma Block, as deduced from the age of detrital zircon grains. The metamorphic P–T path of these sediments contrasts with that of the Archean mafic rocks. The common occurrence of sillimanite pseudomorphs after cm-sized kyanite crystals in migmatitic metapelites provides evidence that an early stage of metamorphism took place in the kyanite stability field whereas the subsequent peak metamorphism was characterised by the stability of the mineral assemblage sillimanite-garnet/cordierite-K-feldspar. Modelling of the X_{Mg} ratios of compositionally homogenous cores of garnet porphyroblasts together with GASP barometry suggest peak P-T conditions of about 7 kbar and 770 °C. The formation of plagioclase coronas around garnet in metapelites, the decrease in X_{Mg} and an increase of the spessartine fraction in rims of garnet porphyroblasts point to a near isothermal uplift after peak metamorphism.

Texturally controlled in situ U–Th–total Pb microprobe dating of monazite in metapelites resulted in two ages for metamorphic events. The monazite of the two dated samples is mostly complex and patchy zoned. The cores record ages of 1957 ± 10 Ma and 1967 ± 16 Ma, whereas the rims give ages of 1837 ± 6 Ma and 1848 ± 16 Ma. As the two ages of monazite growth zones (core and rims) are found in monazite of the rock matrix and in monazite inclusions of garnet porphyroblasts, we conclude that garnet growth occurred during or after the second metamorphic event at 1840 Ma. This interpretation is in agreement with the depletion of HREE and Y in the monazite rims. We correlate the second, high-grade event with the collisional stage between the Tanzania Craton and the Bangweulu Block. The first event that preceded the collision for about 120 Ma is attributed to the kyanite grade metamorphism during accretionary processes and associated calc-alkaline magmatism along the continental margin of the Tanzania Craton.

Combining our new data with those of previous studies on the geochemistry and zircon geochronology we develop a new evolutionary model for the Paleoproterozoic orogenic cycle. The geologic history in the Ubendian Belt began in the Neoarchean (2.7–2.6 Ga) with a magmatic crust formation phase in an active continental margin setting. In the following Neoarchean–Paleoproterozoic (2.65–2.05 Ga) stage of a tectonically inactive, passive continental margin the protoliths of metabasites cooled under near-isobaric conditions and sediments were deposited on the Neoarchean crust. Subsequently, there was a protracted period of subduction (2.05–1.84 Ga) at an active continental margin, which was

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associated with magmatic additions and metamorphic events during tectonic accretions, that led to kyanite-grade metamorphism in wedge sediments. The final collision at 1.84 Ga leading to garnet–sillimanite–cordierite grade metamorphism in metapelites most likely was responsible for the exhumation of the 1880–1860 Ma MORB-type eclogites in the Ubendian Belt.

1. Introduction

The Ubendian Belt in SW Tanzania forms a linear belt that was traditionally interpreted to be formed entirely during the Paleoproterozoic (Lenoir et al., 1994; McConnell, 1969; Ring et al., 1997). However, recent studies showed that this belt was affected, at least in some blocks or terranes, also by Mesoproterozoic and Neoproterozoic orogenic events (Boniface and Schenk, 2012; Boniface et al., 2014). Despite the wealth of new petrological and age data that have been obtained in the course of these new studies, it was not possible to develop an evolutionary model for the Paleoproterozoic period of the Ubendian Belt. This unsatisfactory situation was due to the dearth of magmatic protolith ages, the missing knowledge about the number, nature and ages of metamorphic events and the lack of information about the duration and timing of sediment deposition recorded by detrital zircon. To develop an evolutionary model for the Paleoproterozoic Ubendian Belt, we studied the metamorphic histories of metasediments and metamafites in the northwestern part of the belt by petrological methods and in situ U–Th–total Pb monazite dating. Combining these new data with those of previous (Boniface et al., 2012) and concomitant studies on the geochemistry and zircon geochronology of the metamagmatites (Kazimoto et al., 2014b), we develop an evolutionary model for the Paleoproterozoic orogenic cycle including the age and nature of the pre-existing continental crust that was involved in the formation of the Ubendian Belt.

2. Geologic background

2.1. Ubendian Belt

The Ubendian Belt is a NW-SE trending metamorphic belt that borders the Tanzania Craton on its southwest side and separates the craton from the Bangweulu Block and the Irumide Belt to the southwest (Fig. 1a). Like the Paleoproterozoic and Neoproterozoic metamorphic belts of the eastern margin of the Tanzania Craton, the Ubendian Belt also consists in part of Neoarchean rocks that have been overprinted by younger metamorphic events (Kazimoto et al., 2014b; Lawley et al., 2013a). In this way part of the Ubendian Belt can be seen as a cratonic margin that has been reworked and received additions of new crustal material during the amalgamation of the Paleoproterozoic supercontinent Columbia between 2.1 and 1.8 Ga. The Ubendian Belt has been subdivided into eight lithologically distinct blocks (Fig. 1a), which are separated by NW-SE striking ductile shear zones (Daly, 1988). Some of these blocks may indeed represent terranes either during the Paleoproterozoic or the Neoproterozoic era as they differ in lithology and experienced different metamorphic overprints during Proterozoic orogenic events. However, the formation histories and the regional extent of the different orogenic events is not known for all the 'blocks' of the Ubendian Belt, which were defined by Daly (1988). Previous authors subdivided the geodynamic evolution of this belt into two stages: an initial stage at 2.1–2.0 Ga characterised by arc magmatism, granulite-facies metamorphism and a late-stage deformation that was associated with greenschist-facies overprint (Lawley et al., 2013a; Lenoir et al., 1994; Ring et al., 1997) and a second stage at 1.9–1.8 Ga characterised eclogite formation (Boniface et al., 2012), magmatism and amphibolite- to granulite-facies metamorphism and deformation (Lawley et al., 2013b; Lenoir et al., 1994). The latter events led to orogenic gold mineralisation in the Lupa Block (Lawley et al., 2013a; Lawley et al., 2013b; Lawley et al., 2013c).

In addition to Paleoproterozoic tectonothermal activities, Boniface et al. (2012, 2014) recognised a Mesoproterozoic amphibolite grade crustal thickening event in the Wakole Block of the northwestern Ubendian Belt (Fig. 1) and a Mesoproterozoic metamorphic overprint of the Ubende Block. The Neoproterozoic eclogites recognised in the northern Ufipa Block reflect a Pan-African subduction event (0.59–0.52 Ga) between the Tanzania craton and the Bangweulu Block (Boniface and Schenk, 2012).

2.2. Katuma Block

The rocks of the Katuma Block of the northwestern Ubendian belt (Fig. 1b), have been subdivided into two groups (Semyanov et al., 1977; Smirnov et al., 1970): the Katuma Group consisting primarily of metabasites, gabbronorites, meta-granites and meta-granodiorites, and the Ikulu Group consisting mainly of metasediments (Fig. 1b). The rocks of the Katuma Group formed mainly during Neoarchean time (2.71–2.64 Ga) and during the Paleoproterozoic time (2.02–1.94 Ga; Kazimoto et al., 2014b). The recognition of two timely widely separated magmatic phases in the Katuma Group makes the traditional grouping of the rocks questionable. The age of a Neoarchean metamorphism is slightly older (2650 ± 8 Ma) than the magmatic crystallisation of an unmetamorphosed gabbronorite (2643 ± 4 Ma) enclosing blocks of schistose garnet amphibolite (Kazimoto et al., 2014b). The detritus of the Ikulu metasediments derived from Neoarchean ($\approx$2.64 Ga) and Paleoproterozoic (2.0 Ga) provenances, similar in age to that of rocks of the Katuma Group. The minimum deposition age of these sediments is constrained by their first metamorphic event at about 1.96 Ga, associated with the intrusion of calc-alkaline granites (1.99–1.94 Ga; Kazimoto et al., 2014b). The nature of the metamorphism of the two lithological groups is still enigmatic. In the north, the rocks of both groups are overlain by a Neo- to Mesoproterozoic and a Cenozoic sedimentary cover (Fig. 1b). All the rocks are cut by E-W and NW-SE trending fracture and shear zones, which host Mesoproterozoic hydrothermal Au–Cu–Pb bearing quartz–siderite–barite–sulphide veins. The hydrothermal event correlates with the Mesoproterozoic crustal thickening event at about 1.2 Ga (Boniface et al., 2014; Kazimoto et al., 2014a).

3. Petrography and mineral chemistry

3.1. Analytical methods

Mineral compositions were determined using a JEOL Superprobe JXA-8900R electron probe analyser at the University of Kiel equipped with five wavelength-dispersive spectrometers (WDS). The mineral analyses, except for that of monazite, were performed using an accelerating voltage of 15 kV and a probe current ranging between 15 nA and 20 nA. Synthetic and natural mineral