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Earth and Planetary Science Letters 230 (2005) 355–378

EPSL

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Time constraints for Mesoproterozoic upper amphibolite facies metamorphism in NW Namibia: a multi-isotopic approach

Barbara Seth[a,b,*,1], Richard A. Armstrong[c,2], Annett Büttner[b,1], Igor M. Villa[b,1]

[a]*Department of Geology, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom*
[b]*Institute of Geological Sciences, Isotope Geology Group, University of Berne, Erlachstrasse 9A, CH-3012 Bern, Switzerland*
[c]*Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia*

Received 24 July 2004; received in revised form 25 October 2004; accepted 24 November 2004

Editor: B. Wood

Abstract

This study presents the chronological evolution of the upper amphibolite facies Orue Unit in NW Namibia. Metasedimentary and meta-igneous rocks of the Orue Unit were investigated using the Pb–Pb stepwise leaching technique on garnet and rutile, U–Pb multi-grain analysis on rutile, Sm–Nd–Lu–Hf leaching technique on garnet, SHRIMP analysis on zircon and Ar–Ar dating on amphibole. Each of these techniques pertains to different processes that occurred before, during, or after the metamorphic peak. Our age data can be integrated with petrological constraints to provide a more complete understanding of the metamorphic cycle. Our pre-peak metamorphic zircon ages, peak metamorphic garnet ages and peak to late peak metamorphic amphibole ^{39}Ar–^{40}Ar ages bracket the upper amphibolite facies metamorphic event including hydration or dehydration processes into a time span of only ca. 20 Ma. The age data obtained by peak metamorphic mineral analyses cluster around 1340–1320 Ma. Based on age data and field observation, we interpret the upper amphibolite facies metamorphism as a large-scale regional mid-crustal event. Spot analyses of inherited zircon cores obtained by SHRIMP reflect the sedimentary origin of the respective rocks of the Orue Unit and derivation from Palaeoproterozoic protoliths. The metamorphic rocks south of the anorthositic Kunene Intrusive Complex (KIC) have previously been ascribed to the Palaeoproterozoic Epupa Complex at the SW margin of the Congo craton and were thus thought to be older than the Mesoproterozoic KIC. Our data show that the high-grade metamorphic overprint took place 30–50 Ma after emplacement of the KIC. Rutile growth ages of 1248 Ma in one sample reflect fluid activity which seems to be a local phenomenon since there is no other evidence of geological activity throughout the Orue Unit at that time. The

* Corresponding author. Department of Geology, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom. Tel.: +44 1784 443625; fax: +44 1784 471780.

E-mail addresses: b.seth@gl.rhul.ac.uk (B. Seth), richard.armstrong@anu.edu.au (R.A. Armstrong), annett.buettner@geo.unibe.ch (A. Büttner), igor@geo.unibe.ch (I.M. Villa).

[1] Tel.: +41 31 6318533/6318777; fax: +41 31 6314988.

[2] Tel.: +61 2 6125 5508; fax: +61 2 6125 4835.

doi:10.1016/j.epsl.2004.11.022

rutile ages predate the emplacement of satellite intrusions in that area by 30 Ma and there is no causal relation between these two events.

Keywords: Mesoproterozoic; upper amphibolite facies; high-grade metamorphism; geochronology; Namibia

1. Introduction

The combined use of geochronological data of different metamorphic minerals is a valuable tool to reconstruct a continuous metamorphic history of high-grade provinces. This study presents garnet, zircon, amphibole and rutile geochronological data and aims to evaluate the evolution of a Proterozoic upper amphibolite facies terrain in NW Namibia and its genetic links to adjacent rock units.

The metamorphic minerals from upper amphibolite facies rocks investigated in this study grew under different petrological conditions and thus reflect different segments on the *P–T–t* path. Various geochronological techniques are discussed according to their applicability and are carried out on several minerals that record a plurality of *P–T–X* conditions: *Garnet* often constitutes a major mineral phase in high-grade metamorphic rocks and its growth stages in relation to peak metamorphic conditions can be evaluated by petrographic investigations and traced by isotope characteristics. Metamorphic *zircon*, in contrast, is an accessory mineral in most high-grade metamorphic rocks and the application to calculate precise metamorphic conditions of the host rock using petrologic or isotope signatures of zircon is rather limited. However, Vavra et al. [1] have shown that zircon growth in high-grade metamorphic rocks occurs on the prograde segment of high-grade *P–T* paths shortly before the metamorphic peak, i.e., shortly before the interacting fluids are squeezed out of the rock at upper amphibolite and beginning granulite facies conditions. Additionally, zircon might have older cores that were not affected by metamorphism and reflect earlier events or protolith characteristics. The composition of *amphibole* is known to change according to different *P–T* conditions and fluid chemistry [2]. As for many metamorphic minerals (e.g. garnets), only small differences in temperature and pressure during formation of the amphibole crystal result in chemical differences between amphibole generations. Thus, the presence of different amphibole generations reflects a polyphase history. The growth of *rutile* is strongly dependent on fluid activity within a rock. In this study Pb isotope signatures of rutile are investigated since Pb diffusion rates are very low in rutile [3] and, therefore, the Pb isotopic signatures are not modified significantly subsequent to rutile growth.

Garnet and rutile have been dated using the Pb–Pb stepwise leaching technique (PbSL) [4,5]. A critical aspect in dating metamorphic minerals by PbSL is the possible presence of Th- and U-rich inclusions. This problem is studied in detail by [6] who have shown that the PbSL technique is a convincing tool for ascertaining whether or not inclusions achieved isotope equilibrium with each other and with the host mineral at the time of its crystallisation. This is important when dealing with zircon inclusions which might themselves have older zircon cores. Rutile has also been investigated by multi-grain U–Pb dating for verifying the Pb–Pb age. Garnet has been dated using a Sm–Nd–Lu–Hf leaching technique [7,8], which improves the precision of Lu–Hf and Sm–Nd garnet dating and is an advanced solution to the phosphate inclusion problem [7].

The high-grade metamorphic unit studied is located in NW Namibia, south of the large Kunene Anorthosite Complex, and was mapped as two distinct, fault-bounded upper amphibolite facies terrains, which are collectively named Orue Unit [9,10]. In terms of the geological evolution of NW Namibia, this study tightly follows a recent paper of Seth et al. [10], which focuses on adjacent granulite facies terrains of the so-called Epembe Unit. The Epembe Unit is interpreted as representing a complete early Mesoproterozoic orogenic cycle with metamorphic ages between 1520 and 1450 Ma [10]. The present study investigates the geochronology of the Orue Unit and additionally attempts to apply different geochronological techniques to several minerals that record various *P–T–X* conditions. This documents both the metamorphic and pre-metamorphic evolution