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P–T record of two high-grade metamorphic events in the Central Zone of the Limpopo Complex, South Africa

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Abstract

Many Precambrian granulite facies terrains experienced two regional *high-grade* events, with the first one having occurred in the Neoarchaean and the subsequent overprints in the Palaeoproterozoic. Since structural and geochronological studies often are unable to discriminate between these two tectono-metamorphic events (D/M), we used the configuration of a composite *P–T* path as a signature of two granulite facies metamorphisms. The path has a forked lightning shape, composed of two high-grade decompression cooling (DC) branches: a higher-pressure (DC1) and a lower pressure (DC2) trajectory, which are connected by an isobaric heating (IH) path, indicating the *start of the second* high-grade metamorphism. This approach was used to distinguish different D/M events in the Central Zone of the Limpopo high-grade (HG) terrain, which previously had been considered to mainly reflect evidence for a Palaeoproterozoic event (∼2 Ga). We developed a method that allowed us to discriminate between two different HG events based on strong chemical heterogeneity of coexisting minerals in metapelitic gneisses. Using this method we have studied Al-rich gneisses from key geological structures in different parts of the Central Zone, for which we provided evidence for the first Neoarchaean HG event D2/M2 (∼2.6 Ga), that is mostly reflected by DC1. Evidence for a subsequent Palaeoproterozoic HG tectono-metamorphic event, D3/M3 (∼2 Ga) in the same rocks is reflected by both the IH and relatively low-pressure DC2 segments of a the composite *P–T* path. Although all studied rock samples preserve records of both the HG metamorphic events, the D3/M3 *strongly sheared* gneisses contain lesser amounts of the D2/M2 relics compared to rocks less affected by shearing. The results of our studies and a review of published data allow a correct interpretation of *questionable isotopic* ages and *structural* data with the following conclusion: the CZ of the Limpopo Complex was subjected to three superimposed tectono-metamorphic events: the earliest D1/M1 (∼3.33 Ga) is related to greenstone metamorphic conditions (Kreissig et al., 2000), followed by two high-grade events that respectively occurred at ∼2.6 Ga (D2/M2) and ∼2 Ga (D3/M3).

Keywords: Polymetamorphism; *P–T* paths; Granulites; Limpopo Complex; Geothermobarometry; Local equilibria

1. Introduction

Majority of Phanerozoic UHP eclogitic complexes show monometamorphic metamorphism followed by exhumation and the formation of granulite facies assemblages along their *P–T* paths. For example, in

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diamondiferous rocks of both the 528 Ma Kokchetav (Kazakhstan) and 225–258 Ma Su–Lu (China) complexes as well as for an eclogite complex of south Korea (Chang Whan Oh et al., 2005) temperatures (*T*) at the peak pressure (*P*) stages are approximately the same as those recorded at the granulite stages, implying rapid nearly isothermal decompression (e.g., Nakamura & Hirajima, 2000; Hermann et al., 2001). An increase of *T* at lower *P* along a single *P*–*T* path was demonstrated for the Northern Tibet UHP complex (Song et al., 2003). In contrast, Phanerozoic complexes of the Bohemian massive rather show polymetamorphic evidence and their true history is still hidden (e.g., O'Brien et al., 1997).

Mainly decompression cooling (DC) or isobaric cooling (IC) *P*–*T* histories characterize Precambrian high-grade (HG) terrains (Harley, 1989). However, many Precambrian HG terrains have experienced a second high-*T* metamorphism, and neither structural studies, nor isotopic dating are often able to document and discriminate between the M2 and M3 events. (e.g., Ouzegane et al., 2003; Kusky and Li, 2003; Boshoff et al., 2006, in total about 25 well studied complexes). Recent publications (Perchuk, 2005; Perchuk et al., 2006a) demonstrate that the configuration of a *P*–*T* trajectory similar to Fig. 1, may serve as an efficient tool to distinguish two HG events in one granulite facies terrain.

The goal of this paper is to show that composite *P*–*T* paths that reflect clear evidence for superimposed Neoarchaean and Palaeoproterozoic high-grade metamorphic events characterize the majority HG rocks from the Central Zone of the Limpopo Complex. This approach also appears to be useful for UHP complexes, for which zircon isotopic ages do not show evidence for monometamorphic metamorphism (e.g., Song et al., 2003).

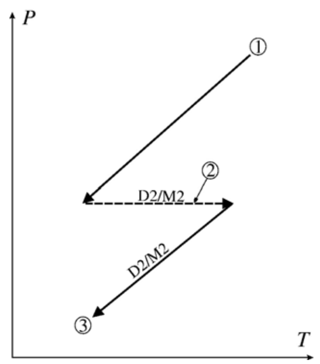

Fig. 1. Scheme of thermal and dynamic history of a Precambrian granulite facies terrain experienced two high-temperature events: (1) = D2/M2 the oldest decompression cooling path, i.e. exhumation from the lower to the middle continental crust, (2) = D3/M3 near isobaric heating followed by (3) = D3/M3 decompression cooling during the second high-temperature metamorphism (after Perchuk, 2005).

1.1. Geological outline of the Limpopo HGT

The general geology of the Limpopo HGT is described in numerous publications (e.g., van Reenen and Smit, 1996; Kramers et al., 2006 and references therein), which allow us to briefly outline the most important geological features (Fig. 2).

The 700 × 250 km Limpopo HGT is located in between the Kaapvaal Craton in the south and the Zimbabwe Craton in the north, from which the granulite complex is separated by Neoarchaean inward-dipping high-grade thrust zones with reverse sense of motion: the Hout River Shear Zone in the south, and the North Limpopo Thrust Zone in the north. In turn, the Limpopo HGT is internally subdivided into three tectonic zones (Fig. 2): the *monometamorphic* Neoarchaean Southern (SMZ) and Northern (NMZ) Marginal Zones, and the Central Zone (CZ), of which evidence of high-grade *polymetamorphism* is the goal of this paper. The CZ is separated from both the SMZ and the NMZ by reactivated ~2 Ga mylonitic shear zones, respectively the Palala shear zone and Triangle Shear Zone (Fig. 2).

1.2. Geological outline of the Central Zone

Many authors (e.g., Hofmann et al., 1998; McCourt and Armstrong, 1998; van Reenen and Smit, 1996; van Reenen et al., 2004, in press) suggested that the D2/M2 event was the major fabric-forming episode in CZ, while the D3/M3 Palaeoproterozoic event was considered to be mainly a "static" thermal process reflected solely by partial melting (Hofmann et al., 1998; Kröner et al., 1998, 1999), while no metamorphic reactions occurred at ~2.6 Ga. Other researchers (e.g., Holzer et al., 1998) are of the opinion that the main tectonic event occurred at ~2 Ga, and that his event is reflected by the regional deformational pattern of Fig. 3. However, new structural and geochronological data (Boshoff et al., 2006; van Reenen et al., 2004, in press), suggest a different scenario, namely that major N–S trending fold-like structures (Fig. 2) are composite structures that reflect the superimposition of discrete N–S trending Palaeoproterozoic high-grade D3/M3 shear zones onto the Neoarchaean D2/M2 high-grade fold event.

1.2.1. The Baklykraal structure, Alldays area

The N–S trending Baklykraal fold-like structure (Fig. 3a) is the best example of a composite structure that reflects the superimposition of D3 high-grade strike-slip shear zones onto the regional D2 fold pattern (Boshoff et al., 2006, van Reenen et al., in press). The structure (Fig. 3a) is comprised of D3/M3 highly sheared