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A SHRIMP U–Pb and LA-ICP-MS trace element study of the petrogenesis of garnet–cordierite–orthoamphibole gneisses from the Central Zone of the Limpopo Belt, South Africa

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Abstract

The Central Zone of the Limpopo Belt (South Africa) underwent high-grade metamorphism at ~2.7–2.5 and ~2.03 Ga. Quartz-rich, garnet-, cordierite-, biotite- and orthoamphibole-bearing, feldspar-free gneisses from the western Central Zone reached granulite-facies conditions (~800 °C at ~8–10 kbar) followed by decompression. Garnet from one such sample shows significant zonation in trace elements but little zonation in major elements. Zoning patterns suggest that the early prograde breakdown of REE-rich accessory phases contributed to the garnet trace element budget. Monazite from the sample yields a SHRIMP weighted mean ^{207}Pb–^{206}Pb age of 2028 ± 3 Ma, indistinguishable from a SHRIMP zircon age of 2022 ± 11 Ma previously measured on metamorphic overgrowths on ~2.69 Ga igneous zircon cores. New zircon and monazite formed before, or at, the metamorphic peak, and occur as inclusions in garnet. Monazite appears to have formed through the breakdown of early allanite ± xenotime ± apatite. Trace element zoning patterns in garnet and the age of accessory phases are most consistent with a single tectonometamorphic event at ~2.03 Ga.

The plagioclase and K-feldspar-free composition of the garnet–cordierite–orthoamphibole gneisses requires open system processes such as intense hydrothermal alteration of protoliths or advanced chemical weathering. In the studied sample, the ~2.69 Ga igneous zircons show a prominent negative Eu anomaly, suggesting equilibrium with plagioclase, or plagioclase fractionation in the precursor magma. In contrast, the other minerals either show small negative (~2.03 Ga monazite), no (~2.02 Ga zircon and garnet) or positive Eu anomalies (orthoamphibole). This suggests that the unusual bulk compositions of these rocks were set in after ~2.69 Ga but before the peak of the ~2.03 Ga event, most probably while the protoliths resided at shallow or surficial crustal levels.

Keywords: U–Pb age; LA-ICP-MS; REE; Alteration; Metamorphism; Limpopo Belt

1. Introduction

Constraining the timing of high-grade metamorphism is commonly difficult because age determinations that involve U–Pb geochronology of accessory phases (monazite, zircon, titanite, xenotime) need to be

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linked to pressure–temperature–time (P–T–t) paths through the growth/resorption of major P–T sensitive rock-forming minerals such as garnet. Making this link is non-trivial in high-grade rocks because accessory phases may: 1) pre-date and be unrelated to metamorphism (e.g., detrital zircon); 2) form during prograde metamorphic reactions involving other accessory phases and/or silicate minerals (Smith and Barreiro, 1990; Pyle and Spear, 2003; Kohn and Malloy, 2004); 3) form at the metamorphic peak (Pyle and Spear, 2003); 4) precipitate after the metamorphic peak, during the crystallisation of partial melt or exsolution of fluid at the solidus (Roberts and Finger, 1997); 5) form along the retrograde P–T–t path due to breakdown of major rock-forming minerals (Fraser et al., 1997; Degeling et al., 2001; Pyle and Spear, 2003); or 6) form due to solid state recrystallisation of pre-existing grains at any time during metamorphism (Hoskin and Black, 2000).

In addition, high-grade metamorphic terranes may have experienced more than one granulite-facies metamorphic event. Determining whether rocks have mono- or polycyclic high-grade histories is itself commonly difficult because major element compositional discontinuities that might indicate multiple garnet growth events are erased by volume diffusion at temperatures above ~700–750 °C (Tracy, 1982). In contrast, diffusion rates for trace elements, including the trivalent REE are commonly much slower than for major elements such as Fe and Mg in garnet (Van Orman et al., 2002), making it possible to use these tracers in garnet to determine growth histories in otherwise compositionally homogeneous grains (e.g., Pyle and Spear, 1999, 2003; Hermann and Rubatto, 2003). Integration of high-spatial resolution geochronology with the trace element chemistry of dated accessory phases and major rock-forming minerals provides a tool for better constraining the timing of high-grade (poly)metamorphism.

The Limpopo Belt of southern Africa (Fig. 1) is a terrain where the timing and distribution of polyphase granulite-facies metamorphism is uncertain. It comprises the Central Zone (CZ) and the flanking Southern and Northern Marginal Zones (SMZ and NMZ, respectively), which are separated by major ductile shear

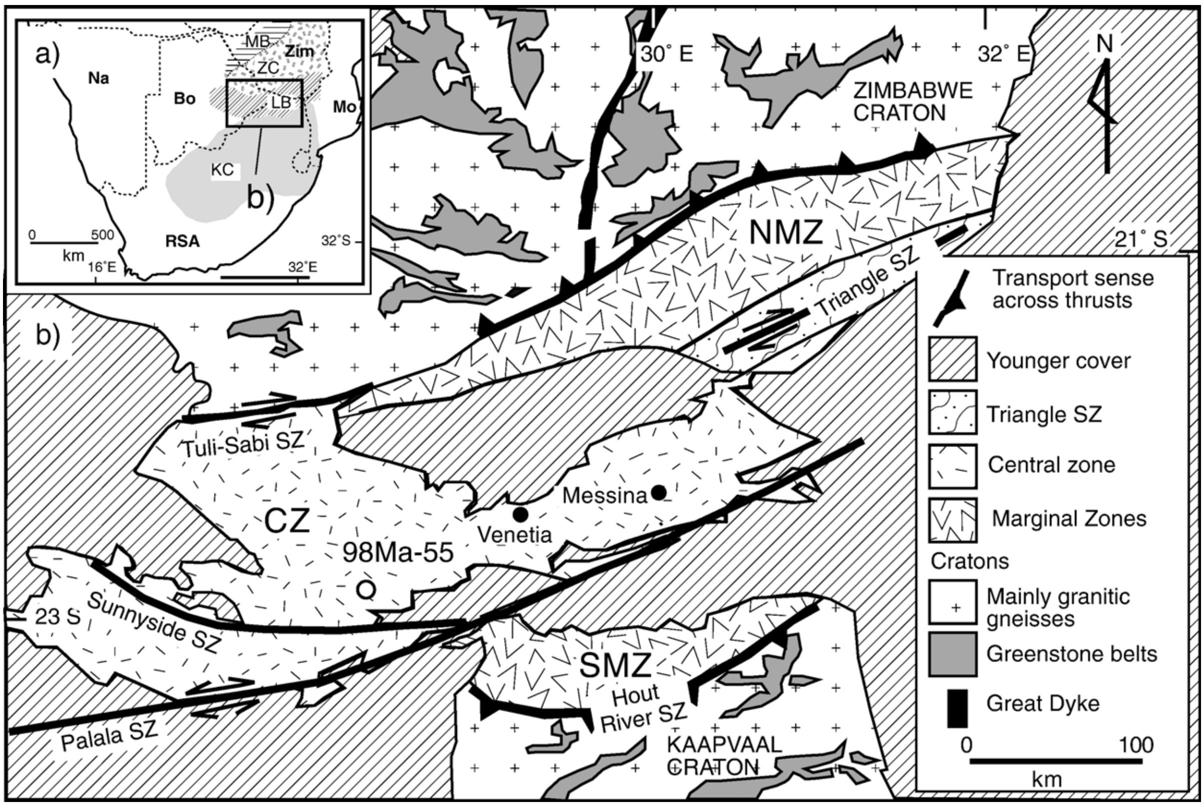

Fig. 1. a) Inset map showing the location of the Limpopo Belt and surrounding cratons; b) simplified geological map of the Limpopo Belt and adjacent Kaapvaal and Zimbabwe cratons. Abbreviations: Bo = Botswana; CZ = Central Zone; KC = Kaapvaal craton; LB = Limpopo Belt; MB = Magondi Belt; Mo = Mozambique; Na = Namibia; NMZ = Northern Marginal Zone; RSA = Republic of South Africa; SMZ = Southern Marginal Zone; SZ = shear zone; Zim = Zimbabwe; ZC = Zimbabwe craton. The location of sample 98 Ma-55 is shown by a white circle in b).