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Involvement of fluids in the metamorphic processes within different zones of the Southern Marginal Zone of the Limpopo complex, South Africa: An oxygen isotope perspective

E.O. Dubinina[a,b,*], L.Y. Aranovich[a,b,c], D.D. van Reenen[b], A.S. Avdeenko[a], D.A. Varlamov[c], V.V. Shaposhnikov[a], E.B. Kurdyukov[a]

[a] Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry Russian Academy of Sciences, Staromonetnyi per., 35, Moscow 119017, Russia

[b] University of Johannesburg, Auckland Park Kingsway Campus, P.O. Box 524, Johannesburg, South Africa

[c] Institute of Experimental Mineralogy, Russian Academy of Sciences, Academician Ossipian Str., 4, Chernogolovka, Moscow District 142432, Russia

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ABSTRACT

We present oxygen isotope data obtained by laser fluorination for three outcrops from the South Marginal Zone (SMZ) of the Limpopo granulite complex, South Africa. These outcrops are located within the granulite zone (Bandelierkop quarry), on the retrograde (anthophyllite-in) isograd (Manamead locality), and within the zone of rehydrated granulite south of the retrograde isograd (Klipbank locality). Studied samples also include felsic (granitoid) rocks that occur as intrusive bodies, veins and veinlets in the host tonalite gneisses or the metapelite. The tonalite gneiss (TG) and the K-feldspar-rich segregations (Kfs-G) at Klipbank have marginally different $\delta^{18}O$ (whole rock, WR) values (7.9 and 7.3% correspondingly). The Kfs-G may have formed by partial melting of the TG in the presence of external saline H_2O–CO_2 fluid. Metapelites at Manamead locality have $\delta^{18}O$ values (9.5–10.3‰) lower than those at Bandelierkop quarry (10.0–11.4‰). The two-mineral oxygen isotope temperature estimates for metapelite minerals from Manamead cluster around two values: 620 ± 30 and $730 \pm 40\,^{\circ}C$. Oxygen isotope temperature estimates for the metapelites from Bandelierkop quarry define a narrow temperature range of 700–740 °C. The oxygen isotope temperatures are in reasonable agreement with the results of "classical" geothermobarometry. The $\delta^{18}O$ values of the whole rocks and individual constituent minerals of metapelites strongly negatively correlate with the rocks' volatile content (LOI values). This suggests that a fluid phase was involved in the hydration of metapelites in the vicinity of the regional anthophylite-in isograd of the Southern Marginal Zone. The fluid may have been released during crystallization of leucogranite melt. Oxygen isotope and geochemical features of the leucogranite indicate genetic relation to the tonalitic Baviaanskloof gneisses, but do not support the formation of leucogranite via in situ partial melting of metapelites.

1. Introduction

The Southern Marginal Zone (SMZ) of the Limpopo granulite complex comprises foliated, banded and migmatitic enderbitic gneisses (locally known as the Baviaanskloof gneiss) that are complexly infolded with mafic, ultramafic, and metapelitic granulite and minor granulite facies BIF of the Bandelierkop Formation (Fig. 1). The SMZ has been studied in great detail with respect to the tectonics, age relationships, petrology, geochemistry and metamorphic *P*–*T* evolution (Kreissig et al., 2000, 2001; Perchuk et al., 1996, 2000a,b; van Reenen, 1983; Smit et al., 2001). Major-, trace element-, and isotope geochemical data have shown that tonalite gneisses, comprising the most common rock type of the SMZ, represent 3.20–2.99 Ga granite-greenstone material similar to that of the North Kaapvaal Craton (Kreissig et al., 2000, 2001). The SMZ has been subdivided into a northern granulite zone that is separated from a southern zone of retrograde hydrated granulite by a retrograde (Anth-in) isograd (van Reenen, 1986; van Reenen et al., 2014). According to this subdivision hydrated granulite occupies ~4500 km^2 of retrogressed crust located in the hanging wall

* Corresponding author at: Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry Russian Academy of Sciences, Staromonetnyi per., 35, Moscow 119017, Russia. Tel.: +7 4953471903.
E-mail address: elenadelta@gmail.com (E.O. Dubinina).

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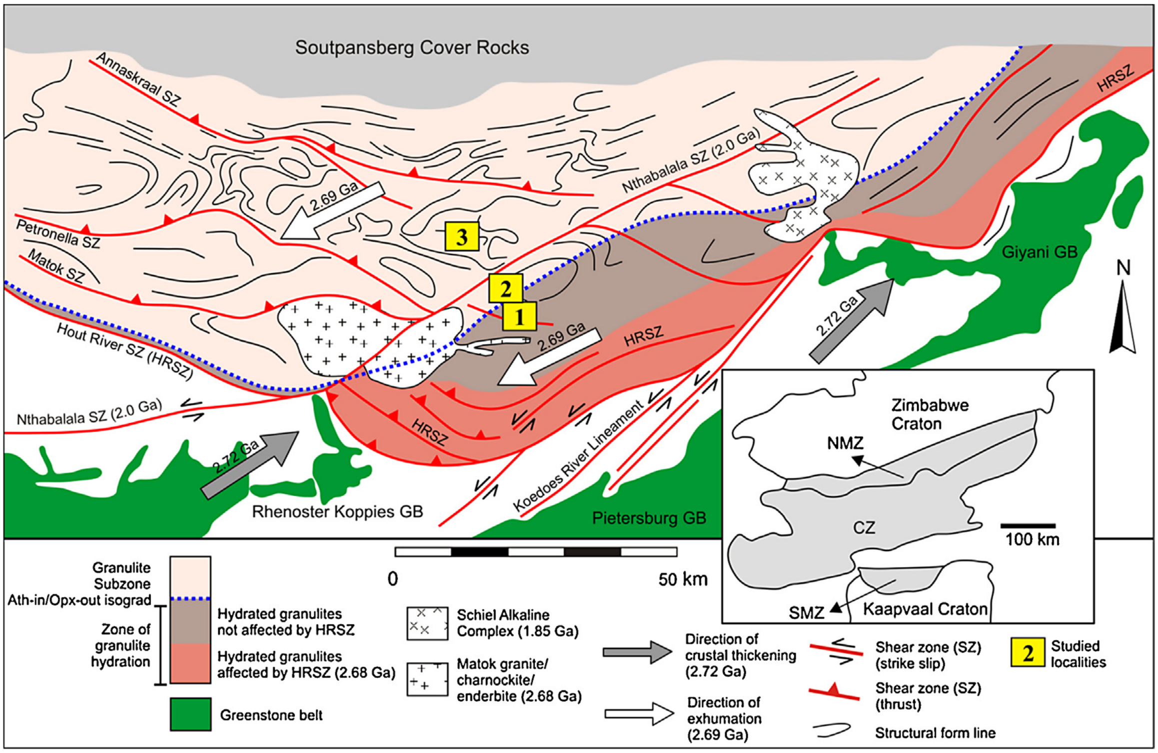

Fig. 1. Geological map of the Southern Marginal Zone of Limpopo belt (after van Reenen et al., 2014). Yellow squares: 1–Klipbank locality, 2–Manamead locality, 3–Bandelierkop Quarry locality. Also shown is the position of the Anth-in (retrograde) isograd. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

section of the shallow north dipping Hout River Shear Zone that bounds the Southern Marginal Zone in the south (Fig. 1) (van Reenen et al., 2014). The SMZ, therefore, presents an exceptional natural field laboratory to investigate the potential role of fluids in deep-crustal processes, particularly given the fact that this topic has been the subject of passionate debate regarding both theoretical petrology (e.g., Aranovich et al., 1987; Clemens and Vielzeuf, 1987; Fyfe, 1973; Newton, 1989; Newton et al., 1998; Thompson, 1982; Touret and Huizenga, 2011, 2012), and regional high-grade metamorphism (Hoernes et al., 1995; van Reenen, 1986; van Reenen and Hollister, 1988; Stevens, 1997; Vennemann and Smith, 1992). The aim of this paper is to further contribute to this discussion through investigation of the oxygen isotope geochemistry of representative high-grade metamorphic rocks and associated leucogranitoids from the SMZ.

The occurrence of rocks of distinct oxygen isotope composition within a single metamorphic zone has led to the conclusion that no pervasive fluid infiltration took place during retrograde metamorphism in the SMZ of the Limpopo Belt (Hoernes and van Reenen, 1992; Vennemann and Smith, 1992). Huebner et al. (1986) reached a similar conclusion from the data obtained in a study of rocks from the Central Zone of the Limpopo Belt. The regional zone of hydrated granulite in the SMZ (Fig. 1) was suggested to result from fluids released during crystallization of anatectic melts derived from felsic rocks that are widespread in the area (Vennemann and Smith, 1992).

To consider potential involvement of fluids in the metamorphic processes within the different zones of the SMZ, a S–N transect from Klipbank locality (retrograde hydrated granulite zone of van Reenen, 1986; van Reenen et al., 2014; see Fig. 1 for sample localities) through the Anth-in isograd (Manamead locality) to Bandelierkop quarry (granulite zone) was chosen for the present study. The studied samples represent the most common lithologies of the SMZ: tonalitic Baviaanskloof gneiss (Klipbank) and metapelite of the Bandelierkop Formation (Manamead and Bandelierkop Quarry). They also include samples of small leucocratic granite bodies adjacent to Manamead and Bandelierkop localities, and apparent migmatitic leucosome hosted by metapelite at Bandelierkop. Here we report on (1) thermometry based on the oxygen isotope composition of coexisting minerals as compared to temperature estimates using "classical" geothermobarometry for the same samples; (2) estimation of the presence of fluid and the degree of openness of the oxygen isotope systems at both the metamorphic peak and during metamorphic retrogression; and (3) possible genetic links of the felsic rocks with the major lithological types of rocks of the SMZ.

2. Methods

2.1. Analytics

Whole rock chemical composition was determined on the 40–50 g powdered samples by XRF method using a vacuum spectrometer Axios Advanced (PANalytical, Netherlands) with 4 kWt power and Rh-anode X-ray tube. Modal abundances of minerals were estimated by point counting under petrographic microscope.

Analyses of coexisting minerals in representative thin sections were obtained using a JEOL JXA-8200 electron microprobe equipped with 5 wave-length spectrometers. Analytical conditions of 20 kV accelerating voltage, 20 nA beam current, counting times of 10–20 s, and 1–3 μm beam spot size were applied. Synthetic and natural analogs of the analyzed minerals were used as the standards.

To study oxygen isotope composition, minerals were separated by hand-picking under binocular microscope. Purity of the separates was controlled by X-ray diffraction; it was always close to 100% except for the samples SA-4-4 and SA-4-5 (Bandelierkop