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Fluid compositions and local fluid buffering during the retrograde metamorphism of Al-bearing dolomitic calc-silicate granulites in the Limpopo Central Zone, southern Africa

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Abstract

Calc-silicate granulites were examined to evaluate the fluid composition and retrograde metamorphic conditions in the Central Zone of the Limpopo Belt, southern Africa. Quartz deficient assemblages are characterized by minerals such as diopside, forsterite, spinel and/or magnesiohornblende and tremolite in the presence of calcite and dolomite. Although the granulites are Al-poor (Al_2O_3 is less than or equal to 1.0 wt.%) and dolomitic in composition, they include Al-bearing phases. Phase analyses for the assemblages in the two model systems CaO–MgO–SiO_2–H_2O–CO_2 and CaO–MgO–SiO_2–Al_2O_3–H_2O–CO_2 provide constraints on fluid compositions in the granulite facies and retrograde metamorphisms in the Limpopo Central Zone. In the presence of amphiboles, isobaric T–$X(CO_2)$ phase relations suggest that high $X(CO_2)$ conditions were established in the calc-silicate rocks of present study. The phase relations with tschermakitic amphiboles at 0.35 GPa restrict diopside-spinel occurrences in the presence of calcite, dolomite and forsterite within very-high $X(CO_2)$ with low $\mathbf{a}(H_2O)$. The fluid compositions, $X(CO_2)$, were effectively buffered by the mineral assemblages during granulite facies metamorphism to subsequent decompression and cooling stages. The presence or absence of retrograde magnesiohornblende and tremolite appeared to be controlled not only by infiltration of H_2O-rich fluid during retrograde metamorphism but also Al content in the local bulk rock compositions. The presence of the two-amphibole phases shows that the fluid compositions were locally buffered in the Al-bearing dolomitic granulites. Comparing the calculated $X(CO_2)$ values in the present study area and in the Alldays area, a difference of retrograde hydration effects is observed.

Keywords: Regional metamorphism; Calc-silicate granulites; Magnesiohornblende; Spinel; Limpopo Belt; Fluid compositions

1. Introduction

Calc-silicate granulites reported from East Antarctica (e.g. Harley and Buick, 1992) and southern India (e.g. Satish-Kumar et al., 1996, 2001) provided information on P–T–t paths and fluid evolution histories of high-grade terrains. These calc-silicate rocks are characterized by wollastonite–scapolite assemblage and distinctive retrograde mineral reaction textures. Siliceous dolomites containing Al-bearing minerals (spinel and tschermakitic amphibole) occur in the eastern part of the Archean Limpopo Central Zone (Fig. 1). In the siliceous dolomite, minerals show several prograde and retrograde reaction textures. Although these silica deficient calc-silicate granulites are devoid of wollastonite and

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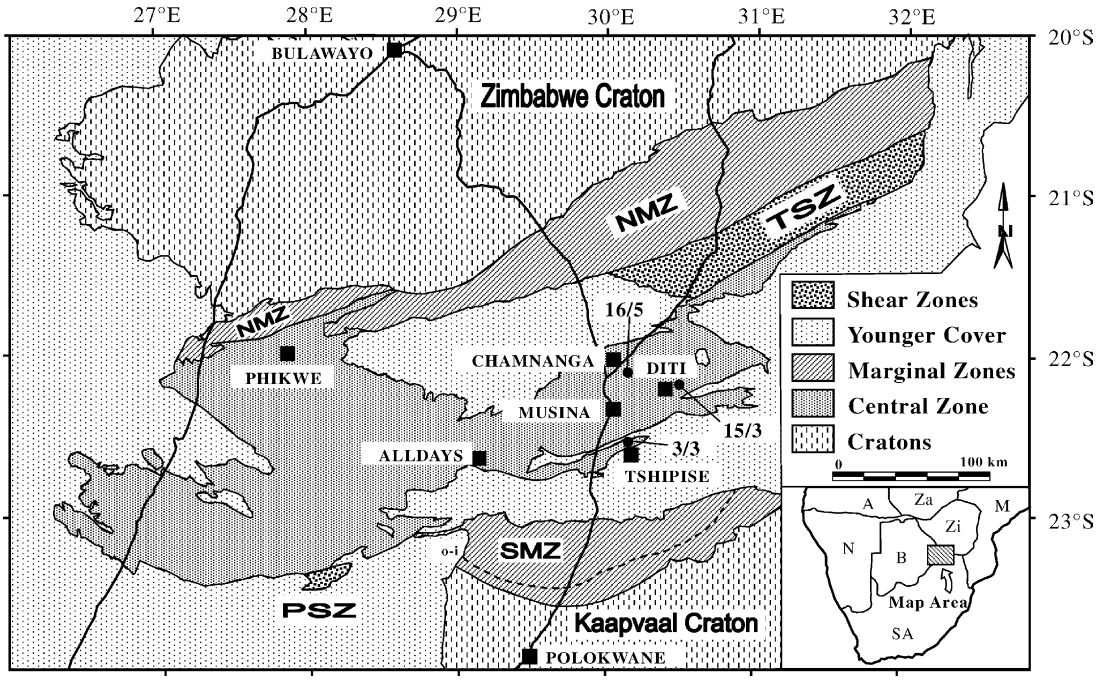

Fig. 1. Simplified geological map of the Limpopo Metamorphic Belt after Van Reenen et al. (1995). Dashed curve with a label "o-i" represents the orthoamphibole-isograd in the Southern Marginal Zone. Numbers denote sample localities (3/3, 15/3 and 16/5). NMZ, SMZ, TSZ and PSZ refer to the Northern Marginal Zone, the Southern Marginal Zone, the Triangle Shear Zone and the Palala Shear Zone, respectively. Abbreviations for countries in the inset denote A: Angola, Za: Zambia, M: Mozambique, Zi: Zimbabwe, B: Botswana, N: Namibia and SA: South Africa.

scapolite, the mineral textures with mineral assemblages including Al-bearing minerals may provide useful constraints on the *P–T–t* path and fluid history of the Limpopo Central Zone.

Siliceous dolomites have been generally described within the $CaO–MgO–SiO_2–H_2O–CO_2$ (CMShc) system, however, even a small amount of alumina (less than or equal to 1.0 wt.% in bulk composition) can lead to the appearance of Al-bearing minerals in the granulites. Although many papers have dealt with the Al-free system for phase analyses of siliceous dolomites (e.g. Metz and Trommsdorff, 1968; Skippen, 1971, 1974; Kretz and Garrett, 1980; Valley and Essene, 1980; Eggert and Kerrick, 1981), several authors (e.g. Rice, 1977; Bucher-Nurminen, 1981; Bowman and Essene, 1982; Letargo et al., 1995) have performed analyses in the $CaO–MgO–SiO_2–Al_2O_3–H_2O–CO_2$ (CMSAhc) system. However, these studies were restricted to siliceous marbles and related hornfelses in contact aureoles, showing the presence of chlorite and spinel as Al-bearing phases instead of magnesiohornblende. Al-bearing tremolites with spinel are found only in a few studies on the Ballachulish aureole, Scotland (e.g. Masch and Heuss-Aßbichler, 1991; Ferry, 1996) and on the Achankovil Shear Zone, southern India (e.g. Satish-Kumar et al., 2001), yet these authors did not focus on magnesiohornblende as an Al-bearing phase. Such Al-bearing mineral assemblages therefore have been rarely reported in regionally metamorphosed impure dolomitic rocks.

Low $\mathbf{a}(H_2O)$ fluids at the peak and the following decompression and cooling stage in the Limpopo granulite terrain have been reported on the basis of the stability relations of hydrosilicates in pelitic and mafic granulites (e.g. Van Reenen, 1983; Harris and Holland, 1984; Van den Berg and Huizenga, 2001). Although it may provide important information for the presence or absence and degree of melting in the granulites in the Limpopo Central Zone, fluid behavior and composition in the high-grade calc-silicate rocks of this zone have not been fully investigated. Feldtmann (1996) studied siliceous marbles and calc-silicate rocks collected from the Alldays area (Fig. 1). She estimated a fluid composition ($\mathbf{a}(H_2O) < 0.3$) based on microthermometry of fluid inclusions in a small quartz boudin; the low $\mathbf{a}(H_2O)$ value was supported by the absence of wollastonite in siliceous marbles and calc-silicate rocks. Fluid compositions during retrograde metamorphism in the Limpopo Belt were reported as both CO_2-rich (e.g. Van Reenen, 1986) and H_2O-rich (Van den Berg and Huizenga, 2001) for the Southern Marginal Zone and as intermediate to H_2O-rich for the Central Zone (e.g. Van Reenen et al., 1990; Feldtmann, 1996).

Based on the phase relations in the CMSAhc- and CMShc-systems, the fluid compositions of calc-silicate granulites of siliceous dolomite origin are estimated quantitatively, and the compositions are compared to those of siliceous limestone origin in the Alldays area. Retrograde fluid composition in the Central Zone is