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Fluid-present melting of meta-igneous rocks and the generation of leucogranites — Constraints from garnet major- and trace element data, Lu–Hf whole rock–garnet ages and whole rock Nd–Sr–Hf–O isotope data

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ABSTRACT

Pan-African high-grade metamorphism in the Proterozoic Damara orogen (Namibia) led to formation of garnet-bearing leucosomes in potassic meta-igneous gneisses producing a meta-igneous migmatite. In addition, the migmatite (gneiss (mesosome) plus leucosome) was intruded by small-scale leucogranitic melts with a high amount of accumulated biotite and garnet. U–Pb zircon ages obtained on the mesosome and the leucosome indicate late Proterozoic (ca. 850 Ma) concordia upper intercept ages which are interpreted as minimum ages of the precursor rock of the migmatite. U–Pb monazite ages obtained on the leucogranite give a concordant age of 512 ± 1 Ma and two reversely discordant ages with $^{207}Pb/^{235}U$ ages of 544 ± 1 and 534 ± 1 Ma, indicating the growth of monazite before or close to the age of high-grade metamorphism in the Damara orogen. High precision Lu–Hf garnet–whole rock dating gave ages of 492.6 ± 1.7 Ma for the mesosome, 497.6 ± 1.7 Ma for the leucosome and 494.0 ± 1.7 Ma for the garnet- and biotite-bearing leucogranite indicating that the growth of garnet postdates the growth of monazite during high-grade metamorphism. In addition, it is suggested that melting and intrusion was coeval and occurred probably shortly after the main peak of metamorphism which occurred at c. 512 Ma. *P*–*T* estimates obtained by conventional thermobarometry (c. 690–720 °C) and accessory mineral dissolution thermometry on the leucogranite (c. 730 °C) suggest that partial melting occurred through limited fluid present melting of biotite via the reaction: bt + kfs + plg + qtz + H_2O ⇔ grt + melt. Outcrop evidence (diffuse relationship between the gneiss domain and the leucosomes, similar size of the leucosomes, homogeneous distribution of leucosomes on the sample scale) suggests that minor melt segregation had occurred. Whole rock Sr, Nd, Hf and O isotope data of the mesosome indicate that it belongs to basement rocks from this area. Geochemical and isotope data obtained on the leucosomes argue for derivation by in-situ melting of the mesosome. Both, leucosome and leucogranite originated from the same source rock but the leucogranite represents an accumulated melt that was able to segregate and to intrude the gneiss domain. The similar isotope features of the mesosome, leucosome and leucogranite indicate a direct relationship for the gneiss and the melts. Chemical and mineral data favour a derivation of both types of melt through fluid-present melting of isotopically and chemically comparable biotite + plagioclase + K-feldspar + quartz-bearing gneisses.

1. Introduction

Within the common ranges of *P*, *T* and xH_2O conditions of the lower crust, major rock types can undergo partial melting, often on a regional scale. If so, these melts may segregate and form mobile magmas. This segregation is one of the fundamental means that play an important role in the chemical differentiation of the continental crust. Dehydration melting of metapelites (Thompson, 1982; Clemens and Vielzeuf, 1987; LeBreton and Thompson, 1988; Vielzeuf and Holloway, 1988 among many others) is an attractive model for the generation of crust derived granitic melts as it is an intra-crustal process that can account for the identity of *P*–*T* conditions of granite and granulite genesis and for the water-undersaturated nature of most granitic magmas (Clemens and Vielzeuf, 1987). Despite this importance, the details of melting and melt segregation remain poorly understood. This is because the crust is lithologically heterogeneous and thus, it is very difficult to simulate its behaviour by simple

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physical models. Although a number of different processes have been proposed for the segregation of anatectic melts (gravity compaction, filter pressing, magma fracturing etc), a wealth of knowledge has been collected through field-based studies of migmatites that may represent an arrested stage of melting and melt extraction (Barbey et al., 1990; Sawyer, 1998). One of the major problems in interpreting data from regional-scale migmatite terranes is that migmatites often do not behave as closed systems. Part of this problem is related to the spatial scale chosen for the observation particular in terranes where regional-scale migmatites are often associated with abundant syn- to late tectonic granites of different affinity such as the Proterozoic Damara Belt of Namibia. Here, migmatites may represent rare examples of in-situ partial melts from the surrounding high-grade Crd–Grt–Kfs–Sil-bearing gneisses (Jung et al., 2000; Masberg, 2000) or may owe their existence due to the interaction of intruding granitic melts with country rock gneisses close to the peak of regional metamorphism or during several stages of the metamorphic evolution (Weber and Barbey, 1986; Barbey et al., 1996; Jung et al., 1998; Jung and Mezger, 2003). The difficulty to choose the appropriate spatial scale may be reduced if one chooses an area of observation where source rock, inferred poorly segregated partial melts and intrusive veins are closely associated and probably genetically related to each other.

Generally, rocks of pelitic composition are particularly responsive to changes in pressure and temperature, as they undergo a range of reactions during metamorphism. These reactions make metapelites valuable monitors for the *P–T* paths during a tectonothermal event, and may have profound consequences for the evolution of metamorphic belts as they form silicate melts at high temperature. Less attention has been paid to partial melting of meta-igneous rocks in the mid to lower crust although they may be volumetrically much more important than metapelitic rocks (Villaseca et al., 1998; Castro et al., 2000).

In this contribution, we present a case study on a meta-igneous migmatite and intrusive leucogranitic veins that are closely associated in a high-grade terrane, namely the granulite-facies coastal area of the Proterozoic Damara Belt of Namibia. Based on petrographic observations, electron microprobe and ionprobe data, U–Pb zircon and monazite ages, Lu–Hf garnet–whole rock data, major- and trace element abundances and whole rock Sr, Nd, Hf and O isotope data we discuss this particular type of crustal anatexis in the continental crust.

2. Geological setting and previous work

The coastal area of the high grade part of the Damara orogen (Namibia) is located between 14.5–15.0°E and 22.0–23.0°S and belongs to the Central Zone of the Pan-African Damara orogen of Namibia (Fig. 1). The area is generally covered with sand but outcrops in the nearby Khan and Swakop areas suggest that the coastal area also comprises a deeply eroded mid- to lower crustal section through the Damara orogen. This suggestion is supported by the work of Masberg et al. (1992) and Masberg (1996, 2000) who investigated a

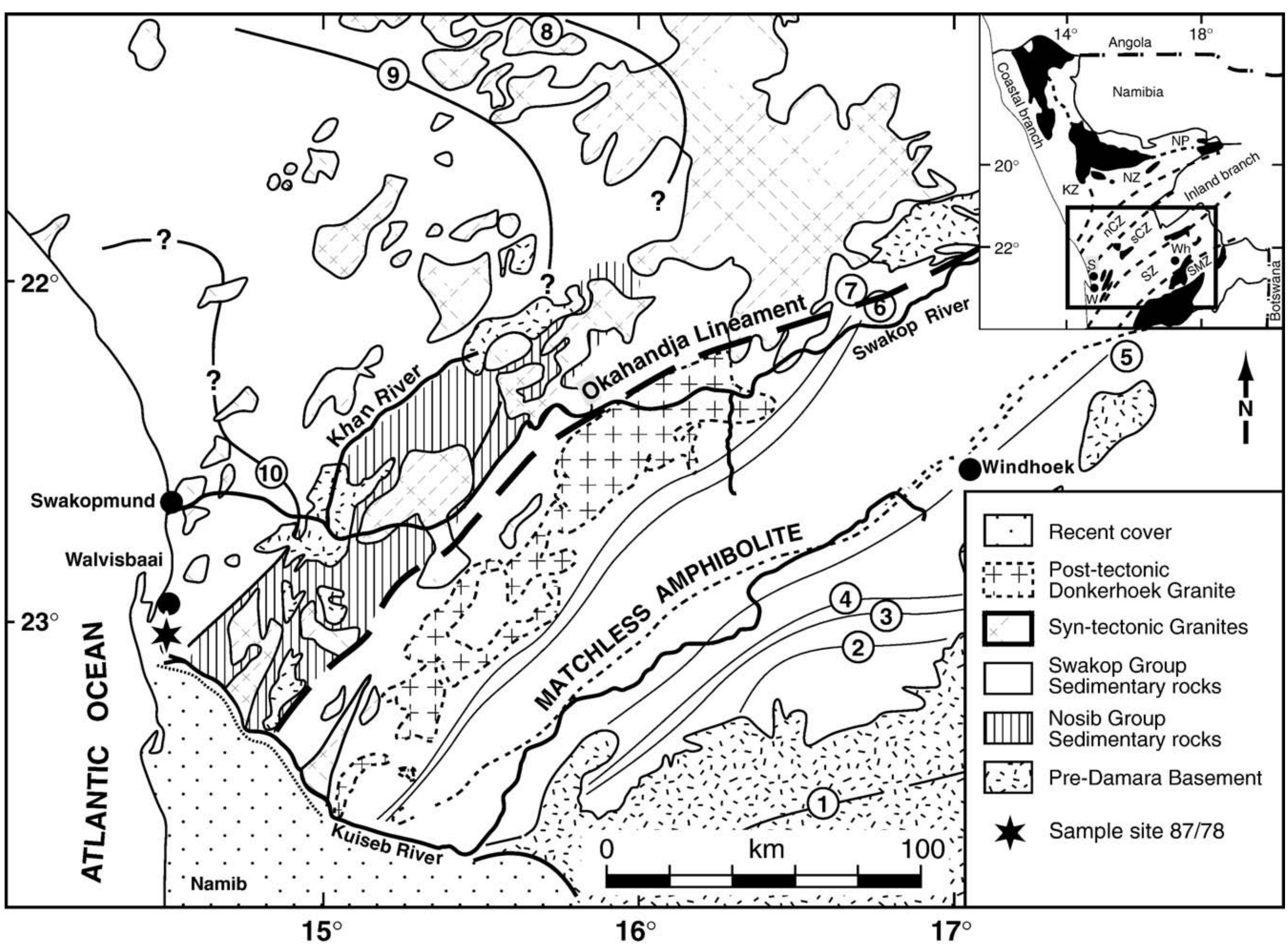

Fig. 1. Generalized geological map showing the study area within the coastal area of the Central Zone of the Damara orogen, Namibia. Abbreviations in inset: KZ: Kaoko Zone, NP: Northern Platform, NZ: Northern Zone, nCZ: northern central Zone, sCZ: southern Central Zone, SZ: Southern Zone, SMZ: Southern Margin Zone. Isograd map (Hartmann et al., 1983) gives the distribution of Pan-African regional metamorphic isograds within the southern and central Damara orogen. Isograds: (1) biotite-in, (2) garnet-in, (3) staurolite-in, (4) kyanite-in, (5) cordierite-in, (6) andalusite ↔ sillimanite, (7) sillimanite-in according to staurolite-breakdown, (8) partial melting due to: muscovite + plagioclase + quartz + H_2O ↔ melt + sillimanite, (9) K-feldspar + cordierite-in, (10) partial melting due to: biotite + K-feldspar + plagioclase + quartz + cordierite ↔ melt + garnet.