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Petrology of ferroan alkali-calcic granites: Synorogenic high-temperature melting of undepleted felsic lower crust (Damara orogen, Namibia)

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ABSTRACT

The 556 ± 4 Ma-old Bloedkoppie granite (Central Damara orogen, Namibia) is a metaluminous to slightly peraluminous, alkali-calcic to calc-alkalic and ferroan granite. Its composition implies high-temperature, reduced, and anhydrous conditions during granite formation. The granite is fractionated, but heterogeneous radiogenic isotope data ($^{87}Sr/^{86}Sr_{(init.)}$: 0.712 to 0.727; $\varepsilon Nd_{(init.)}$: −7.2 to −13.1; $^{206}Pb/^{204}Pb$: 17.30–17.72; $^{207}Pb/^{204}Pb$: 15.54–15.67; $^{208}Pb/^{204}Pb$: 37.80–38.23) indicate also that combined assimilation–fractional crystallization processes played an important role in the generation of the granite. Major and trace element compositions and isotope data of the least evolved samples and U–Pb data from zircon cores demonstrate that the source rocks are dominated by ca. 1.95 Ga old felsic orthogneisses from the underlying basement. Zircon saturation temperatures and normative Qz–Ab–Or compositions indicate minimum melting P–T conditions of ca. 860 °C at >5 kbar and <5 wt.% H_2O. The most likely petrogenetic model involves high temperature partial melting of a Paleoproterozoic felsic source in the lower crust ca. 10–20 Ma before the first peak of regional high-temperature metamorphism. Underplating of the lower crust by magmas derived from the lithospheric mantle may have provided the heat for melting of the undepleted basement to produce reduced and anhydrous melts.

1. Introduction

Granite plutons contain information on processes related to their generation and differentiation, including (i) the conditions of melting, (ii) the geochemical and isotopic signatures of their sources, (iii) the extent of fractional crystallization processes and (iv) evidence for possible assimilation of wall rock (e.g., Castro, 2013; Chappell et al., 1987; Clemens and Stevens, 2012; DePaolo, 1981). Primary melts of granitic composition can form by partial melting of pre-existing crustal rocks (e.g., Chappell and White, 2001; Clemens et al., 1986; Collins et al., 1982; King et al., 2001), by differentiation of juvenile material (Frost and Frost, 1997; Loiselle and Wones, 1979), or by the interaction of juvenile melts with older crust (Frost and Frost, 1997). The wide range of sources and processes that may be involved in the formation of granites is reflected in the compositional range of granitoid rocks, in particular in their trace element abundances and radiogenic isotope compositions.

Collisional orogens are generally characterized by widespread high-grade metamorphism and major crustal magmatism producing felsic melts. Among these magmatic rocks, early syn-orogenic granites are particularly interesting for unraveling the nature and extent of crustal processes and conditions in the early history of orogens. The development of such granites provides direct insights into the local evolution of an orogen and in general processes of crust-internal material redistribution. The Damara orogen with its regional exposures of deep crustal metamorphic and plutonic rocks allows for studying in detail the spatial, temporal and genetic relation between granite and high-grade metamorphic rocks. In the Damara orogen, the main interval of igneous activity during the Pan-African orogeny broadly coincides with granulite-facies metamorphism in the deep crust. Therefore, granite formation was inferred to be bound to relatively dry conditions during high-temperature melting (Jung and Mezger, 2001; Jung et al., 1999; McDermott et al., 1996).

Recent work provided new and precise temporal constraints on the igneous and metamorphic activity in the orogenic belt. In collisional orogens the production of large quantities of granitic melt at dominantly dry conditions requires additional heat input (Clark et al., 2011). This can be generated by raised radiogenic heat production in the crust or heat influx through the base of the crust, either due to lithospheric thinning or mantle derived melts that intrude into the lower crust. This work studies the generation of early syn-orogenic high-T granites, focusing on the Bloedkoppie granite, which is located within the Okahandja Lineament Zone, in the Central Damara orogen.

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2. Geologic setting

The Damara orogen is part of the Neoproterozoic Pan-African mobile belt system in southern Africa and is a remnant of the collision of the Congo craton in the north, with the Kalahari craton in the south and the Río de la Plata craton in the west. These collisions formed the NNW–SSE oriented Gariep belt, the N–S oriented Kaoko belt and the NE–SW trending Damara belt (Fig. 1; Miller, 1983, 2008).

Based on stratigraphy, metamorphic grade, structure, and age, the Damara belt has been divided into a Northern Zone (NZ), Central Zone (CZ) and a Southern Zone (SZ) (e.g., Miller, 1983). The age of the basement is ca. 2.5 Ga in the Kaokoveld (Franz et al., 1999; Seth et al., 1998) and ca. 1.9–2.1 in the CZ and NZ (Jacob et al., 1978; Tegtmeyer and Kröner, 1985) and ca. 1.2–1.8 Ga in the Southern Zone (Ziegler and Stoessel, 1993). Basement gneisses are overlain by Neoproterozoic metasedimentary sequences that include deep-water turbidites, passive margin carbonate–pelite–quartzite sequences, and molasse deposits. These sediment sequences possibly have been deposited in an intracontinental rift that may have developed after ca. 780–746 Ma (Gray et al., 2008; Jung et al., 2007) and was subsequently closed from 580–550 Ma, eventually culminating in the Damara orogeny with crustal thickening and thrusting and emplacement of Pan-African plutonic rocks. Whether the Damara belt originates from a former ensialic basin (e.g., Martin and Porada, 1977; Porada, 1989) or an ocean basin with oceanic lithosphere followed by subduction (Barnes and Sawyer, 1980; Kasch, 1983) is still a subject of discussion. A recent compilation (Miller, 2008) favors a rather narrow (ocean) basin with an exclusive ensialic evolution. The Okahandja Lineament Zone (OLZ), which separates the Central Zone from the Southern Zone, is supposed to represent the suture of this Neoproterozoic intracontinental subduction of the Southern Zone beneath the Central Zone (Porada, 1989; Prave, 1996).

The Central Zone was intruded by large volumes of 570 to 480 Ma-old plutonic rocks that according to Miller (1983) comprise mostly of true granites and only rarely include diorites and tonalites/granodiorites. Metamorphism reached increasingly higher grade from east to west, with partial melting and granulite facies conditions at 680–750 °C and 5–6 kbar in the coastal area (Jung and Mezger, 2003; Jung et al., 1998b, 2009; Masberg et al., 1992). This metamorphism in the Central Zone

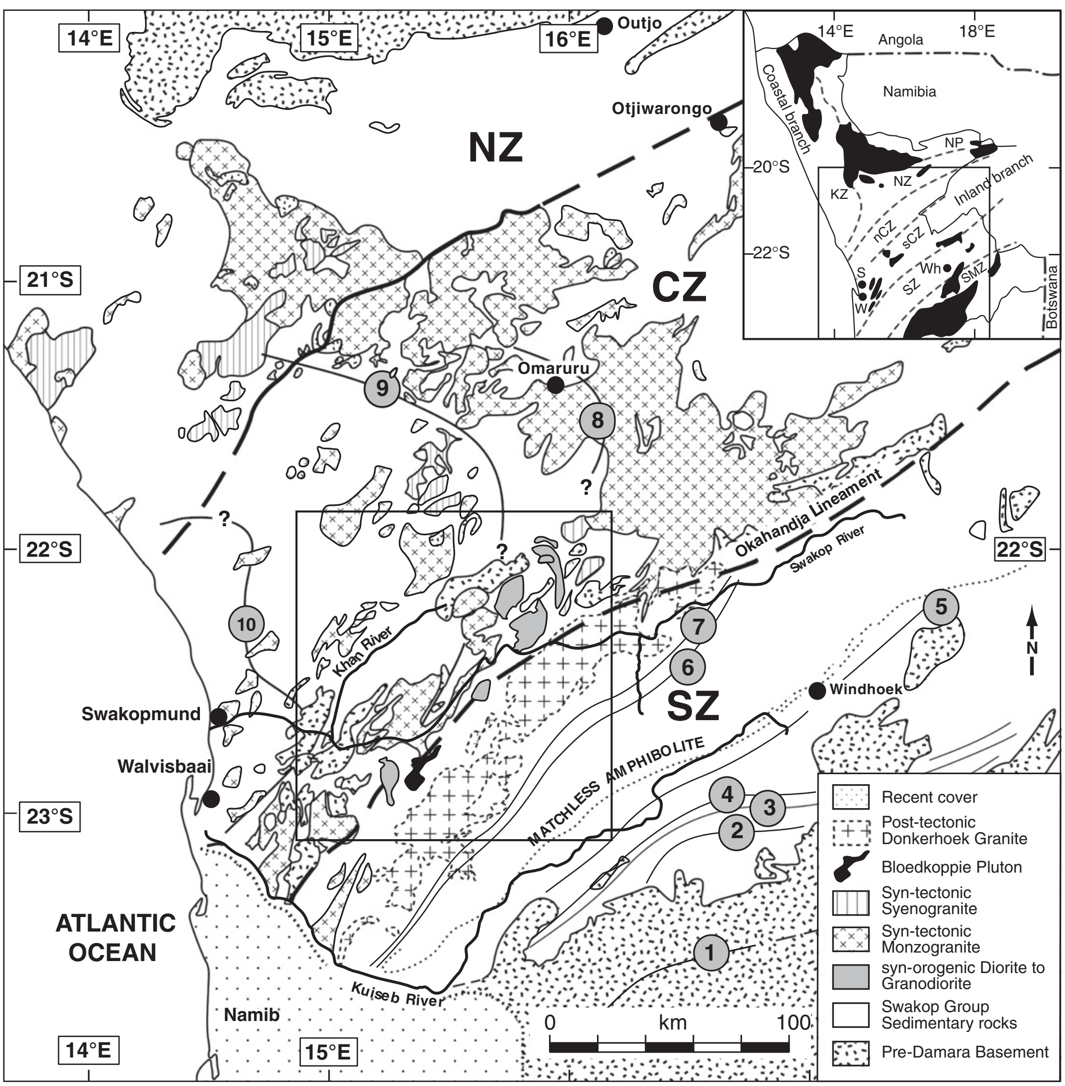

Fig. 1. Generalized geological map showing the study area within the Central Zone of the Damara orogen, Namibia. NZ: Northern Zone; CZ: Central Zone; SZ: Southern Zone. Distribution of regional metamorphic isograds within the southern and central Damara orogen according to Hartmann et al. (1983). Isograds: (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 as a result of muscovite + plagioclase + quartz + H_2O ↔ melt + sillimanite; (9) K-feldspar + cordierite-in; (10) partial melting as a result of biotite + K-feldspar + plagioclase + quartz + cordierite ↔ melt + garnet. The Okahandja Lineament corresponds to the southern one of the two dashed lines. Abbreviations in inset map: KZ: Kaoko Zone; NP: Northern Platform; nCZ: northern Central Zone; sCZ: southern Central Zone; SMZ: Southern Margin Zone; S: Swakopmund; W: Walvisbaai; Wh: Windhoek.