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Formation and emplacement of two contrasting late-Mesoproterozoic magma types in the central Namaqua Metamorphic Complex (South Africa, Namibia): Evidence from geochemistry and geochronology

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ABSTRACT

The Namaqua Metamorphic Complex is a Mesoproterozoic low-pressure, granulite facies belt along the southern and western margin of the Kaapvaal Craton. The NMC has formed between ~1.3 and 1.0 Ga and its central part consists essentially of different types of granitoids intercalated with metapelites and calc-silicate rocks. The granitoids can be subdivided into three major groups: (i) mesocratic granitoids, (ii) leucocratic granitoids and (iii) leucogranites. The high-K, ferroan mesocratic granitoids (54–75 wt% SiO_2) have a variable composition ranging from granitic to tonalitic, and contain biotite and/or hornblende or orthopyroxene. They are strongly enriched in REE and LILE, indicating A-type chemical characteristics, and are depleted in Ba, Sr, Eu, Nb, Ta and Ti. The leucocratic granitoids and leucogranites (68–76 wt% SiO_2) differ from the other group in having a granitic or slightly syenitic composition containing biotite and/or garnet/sillimanite. They have lower REE and MgO, FeO_t, CaO, TiO_2, MnO concentrations, but higher Na_2O and K_2O contents. Compositional variations in mesocratic granitoids indicate their formation by fractional crystallization of a mafic parental magma. Leucocratic granitoids and leucogranites lack such trends, which suggests melting of a felsic crustal source without subsequent further evolution of the generated magmas. The mineralogical and geochemical characteristics of the mesocratic granitoids are consistent magmatic differentiation of a mantle derived, hot (>900 °C) parental magma. The leucocratic granitoids and leucogranites granites were formed from low-temperature magmas (<730 °C), generated during fluid-present melting from metasedimentary sources.

New U-Pb zircon ages reveal that both magma types were emplaced into the lower crust within a 30–40 million years interval between 1220–1180 Ma. In this time period the crust reached its thermal peak, which led to the formation of the leucocratic granitoids and leucogranites. A prolonged period of relatively high crustal temperatures is followed by a second heat pulse at ~1100 Ma, that was intense enough to facilitate zircon growth in the older plutons and it produced a younger granite suite. The crust cools down below amphibolite facies conditions after a further 100 million years. The prolonged high-temperature history is best compatible with steady and long-lasting heat transfer from mantle sources, suggesting a continental back-arc situation as the most likely setting of the NMC in the late Mesoproterozoic.

1. Introduction

The Namaqua Metamorphic Complex (NMC) in South Africa and southern Namibia is a Mesoproterozoic belt, which is characterized by three stages of voluminous emplacement of granitoid plutons including granites, granodiorites or tonalites. The magmatic history spans over >200 million years with a main phase of emplacements between 1210 and 1180 Ma and less common younger plutons forming around 1100 and 1000 Ma (e.g. Robb et al., 1999; Raith et al., 2003; Clifford et al., 2004). Although granitoid plutons constitute the largest proportion of the NMC crust, no regional geochemical study has investigated their potential sources and their genetic relationships. In this study we present a geochemical assessment of granitoids from two areas in the central NMC, one in the Kakamas Terrane (Thomas et al., 1994) in South Africa and a second in the Grünau Terrane (Colliston and Schoch, 1998) in southern Namibia. In both areas abundant and variably composed granitoid rocks are hosted in high-grade to ultra-high grade metamorphic metapelites and calc-silicates with only small proportions

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of mafic granulites. We have determined major and trace element compositions of the granitoids using standard geochemical tools (XRF, ICP-MS, ICP-AES; the analytical procedures are outlined in Appendix A) in combination with U-Pb isotopic data of zircon (laser ablation ICP-MS) in order to unravel the geochemical evolution of granitoid magmas, their relative and absolute age of emplacement, and we discuss their role in the regional geological evolution of the NMC.

2. Geological framework

The Namaqua-Natal Belt surrounds the western and southern margin of the Kaapvaal Craton in South Africa and southern Namibia (Fig. 1) and has been correlated with similar crustal segments in east Antarctica (Jacobs et al., 1993, 2008; Thomas et al., 1994). The NMC is the western part of the Namaqua-Natal Belt, exposed along the west coast of southern Africa. It consists of crustal igneous and metamorphic rocks, which are in large parts covered by Phanerozoic sedimentary rocks. Peak metamorphic conditions vary from amphibolite to upper granulite facies conditions (850–900 °C) reaching ultra-high temperature conditions at low pressures (4–6 kbar) (e.g. Waters, 1986, 1988, 1989; Raith and Harley, 1998; Robb et al., 1999; Clifford et al., 2004).

The subdivision of the NMC into lithostratigraphic units is controversial and proposed tectonic or lithostratigraphic boundaries are often not supported by field evidence (Moen and Toogood, 2007). In this paper we follow the nomenclature of Thomas et al. (1994) as a descriptive tool without necessarily following their proposed regional tectonic evolution.

Thomas et al. (1994) proposed for the NMC four shear zone-bounded tectonic units, which are from west to east the Bushmanland, Kakamas, Areachap, and Kaaien Terranes (Fig. 1). The authors furthermore propose the juxtaposition of these units during Mesoproterozoic crustal accretion and continent collision.

Samples for the current study were taken from the Kakamas Terrane in the central NMC (Fig. 1), which is, after the Bushmanland Terrane, the largest tectonic unit of the NMC. It forms a northwest trending strip that can intermittently be traced from Lüderitz in Namibia south-eastwards into the Northern Cape Province of South Africa. The Kakamas Terrane is partly covered under younger sedimentary rocks but three areas are generally well exposed. These are the Aus- and Grünau-areas in Namibia and the Pofadder-Warmbad-Upington area, which also includes the town of Kakamas, south of the Orange River in South Africa. (Fig. 1).

Previous investigations suggest that the Kakamas Terrane consists of strongly reworked Palaeoproterozoic basement rocks and younger Mesoproterozoic igneous and supracrustal rocks (Jackson, 1976; Blignault, 1977; Becker et al., 2006 and references therein). The largest parts of the area are made up of a wide variety of granitoids or granitoid gneisses that are intercalated with metasediments and subordinate quartzite, mafic granulites and calc-silicate rocks and marbles. Most host rocks of Namaquan plutons, and those plutons that were emplaced early in the tectono-metamorphic history of the NMC, were deformed and metamorphosed under low-pressure, granulite facies conditions. Nowhere in the Namaqua-Natal belt the documented palaeo-pressures exceeded magnitudes compatible with crust of normal thickness. Mafic rocks that could be interpreted as former ophiolites, high-pressure rocks, alpine-style nappe tectonics, or orogenic suture zones, have not been described in the NMC.

Waters (1989) established an anticlockwise P-T path for the evolution of the granulite facies rocks in the Bushmanland Terrane with

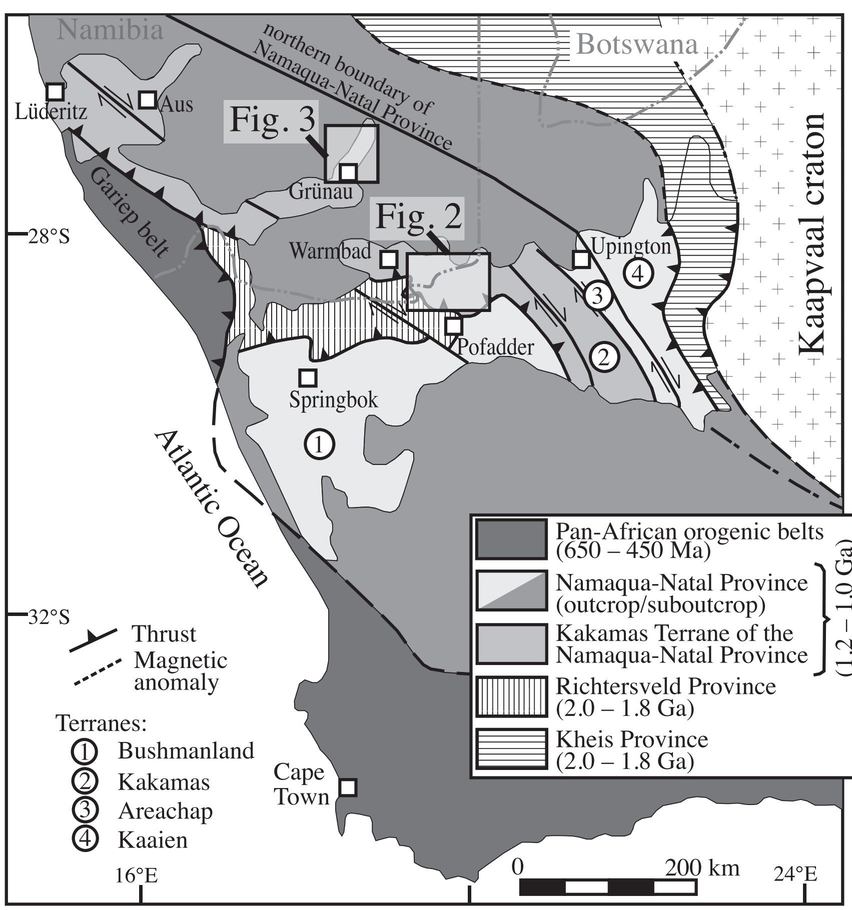

Fig. 1. Geological setting of the Namaqua sector of the Namaqua-Natal Province in South Africa and southern Namibia, modified after Cornell et al. (2006). The positions of Figs. 2 and 3 are indicated.