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Timing and conditions of regional metamorphism and crustal shearing in the granulite facies basement of south Namibia: Implications for the crustal evolution of the Namaqualand metamorphic basement in the Mesoproterozoic

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ABSTRACT

Granulite facies basement gneisses from the Grünau area in the Kakamas Domain of the Namaqua-Natal Metamorphic Province in south Namibia show high-grade mineral assemblages, most commonly consisting of garnet, cordierite, sillimanite, alkali feldspar and quartz. Cordierite + hercynitic spinel, and in some places quartz + hercynitic spinel, indicate granulite facies P-T conditions. The peak assemblage equilibrated at 800–850 °C at 4.0–4.5 kbar. Sillimanite pseudomorphs after kyanite$_1$ and late-stage staurolite and kyanite$_2$ indicate that the metamorphic record started and ended within the stability field of kyanite. Monazite in the metamorphic basement gneisses shows a single-phase growth history dated as 1210-1180 Ma, which we interpret as the most likely age of the regional metamorphic peak. This time coincides with the emplacement of granitic plutons in the Grünau region.

The ~10 km wide, NW-SE striking Grünau shear zone crosscuts the metamorphic basement and overprints high-temperature fabrics. In sheared metapelites, the regional metamorphic peak assemblage is largely obliterated, and is replaced by synkinematic biotite$_2$, quartz, alkali feldspar, sillimanite and cordierite or muscovite. In places, gedrite, staurolite, sillimanite and green biotite$_3$ may have formed late- or post-kinematically. The mylonitic mineral assemblage equilibrated at 590–650 °C at 3.5–5.0 kbar, which is similar to a retrograde metamorphic stage in the basement away from the shear zone. Monazite cores in two mylonite samples are similar in texture and age (~1200 Ma) to monazite in metapelites away from the shear zone. Chemically distinct monazite rims indicate a second growth episode at ~1130-1120 Ma. This age is interpreted to date the main deformation episode along the Grünau shear zone and the retrograde metamorphic stage seen in the basement.

The main episode of ductile shearing along the Grünau shear zone took place 70–80 million years after the thermal peak metamorphism and granite emplacement, and after substantial isobaric cooling of the basement. Metamorphism and regional shearing in the Grünau area can be correlated with the crustal evolution in the Kakamas Domain in South Africa, but not with the timing of metamorphism in the Aus area, 230 km to the NW of Grünau, which is significantly younger.

1. Introduction

1.1. Geological context

The Mesoproterozoic Namaqua-Natal Metamorphic Province (NNP) formed along the margins of the Archean Kaapvaal Craton in South Africa and southern Namibia (e.g. Miller, 2012). From its age, it may be seen as a part of the worldwide network of 1.38–1.0 Ga orogenic belts (Thomas et al., 1993, 1994; Tack et al., 2010), which has been associated with the assembly of the supercontinent Rodinia (e.g. Dalziel et al., 2000; Karlstrom et al., 2001; Meert and Torsvik, 2003). The existing literature commonly refers to this episode as “Kibaran” or even “Grenvillian”, which is somewhat misleading, because the Kibaran event is likely to be much older

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(~1375 Ma; Tack et al., 2010) than the main phases of the tectono-magmatic evolution in the NNP, which spans essentially the time between ~1230 and 1000 Ma. The Mesoproterozoic evolution in the NNP is probably better described as Namaqua Orogeny.

The part of the Namaqua-Natal Metamorphic Province in south Namibia, where the study area is located, and the adjacent north-western South Africa, is referred to as the Namaqua Sector (NS, Fig. 1a) of the NNP (Cornell et al., 2006). The metamorphic basement of the NS formed during a protracted period of heat influx into the Mesoproterozoic continental crust (e.g. Miller, 2012). High crustal temperatures were maintained at least from ~1230 to 1200 Ma to around 1100 Ma (Bial et al., 2015a, b). Additional earlier episodes around 1370-1275 Ma, associated with magmatism and/or the growth of magmatic zircon (e.g. Pettersson et al., 2007; Cornell and Pettersson, 2007; Bailie et al., 2010; Bial et al., 2015b; Cornell et al., 2015), are less commonly documented, and are not well constrained within the geological evolution of the NS. They may well be associated with the long-standing Kibaran (?)-Namaquan high-temperature evolution of the NS (cf. Bial et al., 2015b). The thermal peaks at ~1230-1200 Ma and at ~1100 Ma commonly led to granitoid magmatism, but not all these magmatic episodes are seen in all parts of the NS. The ~1240-1200 Ma episode appears to be the most widespread metamorphic and melt-forming stage (e.g. Miller, 2012, and references therein), but it appears not to be associated with major deformation (Bial et al., 2015b). In some places, the high-temperature metamorphic history and magma emplacement are extended by another 40–100 million years towards latest Mesoproterozoic time (~1060-1000 Ma; e.g. Robb et al., 1999; Clifford et al., 2004; Diener et al., 2013). Pegmatite emplacement between 1000 and 950 Ma (Melcher et al., 2015) concludes the Mesoproterozoic orogeny in the NS.

Characteristic of the metamorphism in the NS are amphibolite to granulite facies conditions, with ultra-high temperature metamorphism reached in western Namaqualand (e.g. Waters, 1986a, b; 1990; Robb et al., 1999) and in the south-western part of the Kakamas "Terrane" (Bial et al., 2015b). However, nowhere the high-temperature metamorphism appears to have taken place at pressures that would imply or indicate the presence of thickened continental crust (Miller, 2012; Bial et al., 2015b; and references therein). Accordingly, significant crustal or lithospheric thickening, or collisional duplication of the continental crust, has not been demonstrated on petrological grounds for the NS in Mesoproterozoic time.

The NS consists of several shear zone-bounded tectonic units, which in the existing literature have been referred to as the Richtersveld Subprovince, and the Bushmanland, Kakamas, Areachap, Kaaien Terranes (e.g. Thomas et al., 1994; Cornell et al., 2006). In Namibia, along the north-eastern border of the NS, the Konkiep Terrane/Subprovince (Miller, 2008) shows magmatic activity reaching back to late Kibaran/early Namaquan (?) time (~1359-1327 Ma). In addition, the widespread ~1200 Ma igneous activity is well documented (Cornell et al., 2015). The area to the north-east of the Excelsior-Lord Hill shear zone (Fig. 1b) is part of the Konkiep Terrane. Other literature uses different terrane boundaries and different terrane names (e.g. Colliston and Schoch, 1998). The term "terrane" may be understood as advocating for the accretion of exotic crustal fragments in a continent-collisional tectonic environment, and it has been used in this way in much of the existing literature (e.g. Joubert, 1986; Jacobs et al., 1993; Thomas et al., 1994; Cornell and Pettersson, 2007; Pettersson et al., 2007; Miller, 2012; Colliston et al., 2015). However, this is not intended here, and we consider such a setting unlikely for the NS in the Mesoproterozoic (cf. Bial et al., 2015b). We agree with the terminology used in a recent paper by Thomas et al. (2016), who have replaced the term "Terrane" in the NS with the term "Domain". We will use this new and in our view much more appropriate terminology further on in this study.

The Kakamas Domain is the second largest of these litho-tectonic units and forms a north-west trending section that can intermittently be traced from South Africa into southern Namibia. Neoproterozoic and Phanerozoic cover rock sequences separate three main outcrop areas of the Kakamas Domain. Two smaller ones are located in the areas of Aus and Grünau in Namibia; the largest coherent outcrop is in South Africa (Fig. 1a). The local naming of these areas differs in the literature. Our study area near Grünau (Fig. 1a–c) has been referred to as a part of the "Gordonia Subprovince", the "Aus Terrane" or the "Grünau Terrane" (Joubert, 1986; Colliston and Schoch, 2006; Miller, 2008, 2012), either of which may be regarded as the continuation of South Africa's Kakamas Domain in southern Namibia (Thomas et al., 1994). For the sake of simplicity and consistency we refer to the study area as a part of the Kakamas Domain. However, in our discussion section we will show that the Aus and the Grünau areas are distinct in the timing of peak metamorphism.

1.2. The Kakamas domain in south Namibia

Most studies of the Kakamas Domain were carried out in South Africa, but its counterparts in Namibia are comparatively poorly studied. Reconnaissance mapping during the 1970s and preliminary structural and petrographic investigations (Toogood, 1976; Blignault, 1977; Schreuder and Genis, 1977; cf. Becker et al., 2006) acted as basis for only few further studies. Our study area in south Namibia lies in the central part of the Kakamas Domain, north-east of Grünau (Fig. 1). The Mesoproterozoic basement in this region is exposed in a ~30 km wide and ~100 km long north-east trending corridor from Noordooewer in the southwest, to Narubis in the north-east (Fig. 1a, b). In addition to rocks of the Kakamas Domain this corridor includes a part of the Richtersveld Domain. Beyond the Excelsior-Lord Hill-shear zone in the north-easternmost part of the Noordooewer-Grünau-Narubis area (Fig. 1b) rocks of the Konkiep Domain are exposed. The "Namaqua front" is marked by a NW-trending, linear aeromagnetic feature that is covered by Neoproterozoic sedimentary rocks of the western Nama Basin (Hoal et al., 1995; Miller, 2008).

Previous work in that area (Blignault, 1977; Schreuder and Genis, 1977; Becker et al., 2006) produced geological maps and a litho-stratigraphy of different types of para- and orthogneisses, and includes also basic structural information. In addition, fieldwork in course of the current study identified metapelites, calc-silicates and subordinate mafic rocks in the Grünau area. The distribution of the P-T-indicative mineral assemblages, initially described by Blignault (1977), shows upper granulite facies rocks in the central part (near Grünau), and decreasing metamorphic grade towards both the northeast and the southwest (Fig. 1b).

Bial et al. (2015a) dated one leucogranite (ZA-81-2), one mesocratic granitoid (ZA-82-2), and two leucocratic granitoid gneisses (ZA-93-1 and ZA-103-1). LA-ICPMS U-Pb data of zircon indicate a magmatic stage between 1229 and 1189 Ma. The tonalitic sample ZA-82-2 is partly foliated and some zircons are recrystallized. Such recrystallized zircon has been dated as 1098 ± 10 Ma. Sample ZA-93-1 contains zircon of 1307 ± 30 Ma, which possibly is related to an early stage of Namaquan metamorphism. Pre-Namaquan zircon cores, some of which show detrital textures, yield Paleoproterozoic ages (~1600–1800 Ma). These age patterns are commonly seen in the Kakamas Domain (Eglington, 2006; Miller, 2008; Bial et al., 2015a,b).

Within the Kakamas Domain, Diener et al. (2013) and Bial et al. (2015b) have contributed studies investigating the P-T-t history of the high-grade metamorphic basement near Aus, some 230 km NW