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Lead isotope evolution across the Neoproterozoic boundary between craton and juvenile crust, Bayuda Desert, Sudan

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ABSTRACT

Metaigneous mafic and ultramafic rocks from the juvenile Neoproterozoic Arabian Nubian Shield (ANS) and the Proterozoic, reworked Saharan Metacraton (SMC) have been analysed for major- and trace elements and Sr, Nd, and Pb isotopes. Most of the rocks are amphibolites metamorphosed at amphibolite facies conditions, some with relicts of a granulite facies stage. The other rocks are metapyroxenites, metagabbros, and some ultramafic rocks. Trace element compositions of the metabasaltic (dominantly tholeiitic) rocks resemble the patterns of island arcs and primitive lavas from continental arcs. Variable Sr and Nd isotope ratios indicate depleted mantle dominance for most of the samples. $^{207}Pb/^{204}Pb$ signatures distinguish between the influence of high $^{207}Pb/^{204}Pb$ old SMC crust and depleted mantle signatures of the juvenile ANS crust. The Pb isotope signatures for most metabasaltic rocks, metapyroxenites and metagabbros from SMC indicate an autochthonous formation. The interpretation of the new data together with published evidence from mafic xenoliths on SMC and ophiolite from ANS allows an extrapolation of mantle evolution in time. There are two lines of evolution in the regional mantle, one, which incorporates potential upper crust material during Neoproterozoic, and a second one with a depleted mantle signature since pre-Neoproterozoic that still is present in the Red Sea and Gulf of Aden spreading centres.

1. Introduction

The transition between juvenile Neoproterozoic crust and older areas of the NE African craton in the Bayuda Desert, Sudan has been recently investigated by field methods, isotopic dating of magmatism and metamorphism, geochemical tracing, and unravelling of the thermal history (e.g. Küster and Liégeois, 2001; Bailo et al., 2003; Küster et al., 2008; Evuk et al., 2014; Karmakar and Schenk, 2015a). These new data, especially the isotopic dating added abundant details to the Neoproterozoic history of the Saharan Metacraton (SMC) in the west (Abdelsalam et al., 2002, 2011; Liégeois et al., 2013). Here, magmatism already started at the eastern margin between ~1000 and 900 Ma (Küster et al., 2008; Evuk et al., 2014) before the onset of Neoproterozoic juvenile addition of material in the east from 900 Ma onwards leading finally to the amalgamation of Gondwana (Fig. 1; e.g. Greenwood et al., 1980; Kröner et al., 1987, 1992; Johnson and Woldehaimanot, 2003). The amalgamation of the juvenile crust east of the SMC within the Arabian Nubian Shield (ANS) resulted in a complex pattern of terranes and respective suture zones (e.g. Kröner, 1985; Abdelsalam and Stern, 1996; Stoeser and Frost, 2006; Fritz et al., 2013). The suture zones are partly decorated with prominent ophiolite complexes that preferentially occur within the juvenile crust of the ANS (e.g. Kröner, 1985; Kröner et al., 1992; Zimmer et al., 1995; Brueckner et al., 1995; Abdelsalam and Stern, 1996; Stern et al., 2004; Ali and Abdel-Rahman, 2011). The mafic igneous and peridotite rocks of the ophiolite give insight into the composition of the Neoproterozoic upper mantle and therefore into derivatives of such mantle, e.g. magmatic rocks that formed in the Neoproterozoic magmatic arcs (e.g. Brueckner et al., 1988, 1995; Zimmer et al., 1995; Stern and Abdelsalam, 1998; Teklay et al., 2002; Bailo et al., 2003; Basta et al., 2011).

In this study, mafic and ultramafic rocks were sampled across the suture zone between ANS and SMC bounded by latitudes ca 18° and 19°N in the Bayuda Desert (Fig. 2). Within the ANS these rocks were interpreted as dismembered ophiolite (e.g. Abdel-Rahman,

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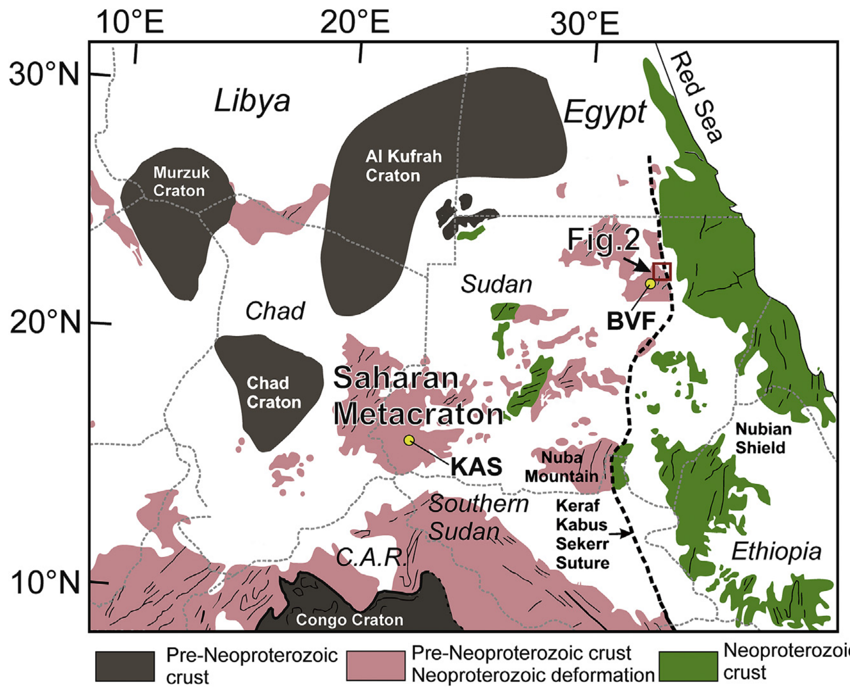

Fig. 1. Overview of NW Africa showing the outline of pre-Neoproterozoic cratons, cratonic crust with Neoproterozoic deformation referred to as the Saharan Metacraton, and Neoproterozoic juvenile crust (modified after Abdelsalam et al., 2002; Evuk et al., 2014). The approximate positions of the Bayuda volcanic field (BVF), where lower crustal and lithospheric mantle xenoliths and young intraplate magmatism are found, and of the Kas granite (KAS) within the Jebel Marra/Darfur basement are also shown. The inset indicates the position of the sampling area in Fig. 2. For a more detailed overview of the surroundings of the sample area see Fig. 3 in Abdelsalam et al., (2003) and Fig. 1 in Evuk et al., (2014).

1993; Abdelsalam et al., 1998) and within the SMC as poly-metamorphic amphibolite from magmatic arc environments (e.g. Küster and Liégeois, 2001). Ophiolites on SMC could also represent remains of nappes from the ANS in Neoproterozoic collision zones (e.g. Atmur-Delgo suture zone; see Fig. 3 in Abdelsalam et al., 2003 or Fig. 1 in Evuk et al., 2014; also: Schandelmeier et al., 1994). The geochemical data especially Pb isotopes identify contributions from the SMC to the Neoproterozoic juvenile material, i.e. they constrain the distribution of SMC within the crust and hence the tectonic or autochthonous origin of the mafic rocks on SMC. We show that the Pb isotope composition of new and published juvenile ANS material (e.g. Kröner, 1985; Kröner et al., 1992; Zimmer et al., 1995; Brueckner et al., 1995; Abdelsalam and Stern, 1996; Stern et al., 2004; Ali and Abdel-Rahman, 2011) including the mantle lithosphere below the Bayuda from xenoliths and Neogene intraplate magmatism (Lucassen et al., 2008a, b; 2011) indicates two lines of evolution in the regional mantle. One incorporates potential upper crust material during Neoproterozoic and a second presents the depleted mantle since pre-Neoproterozoic that still is present in the Red Sea and Gulf of Aden spreading centres.

2. Geological framework of the SMC – ANS section

The border between the African Cratons and the NE-African Neoproterozoic orogen and the extent of Neoproterozoic reworking of SMC are still debated for the whole NE–African area (e.g. Abdelsalam et al., 2002; Karmakar and Schenk, 2015b), but the relations between the two realms are fairly well constrained on the scale of the Bayuda Desert – Keraf Suture section (e.g. Küster and Liégeois, 2001; Küster et al., 2008; Evuk et al., 2014; Karmakar and Schenk, 2015a). The Neoproterozoic magmatism in the SMC of the Bayuda Desert starts as early as ~970 Ma culminating with the Bayuda Event around 920–900 Ma (Küster et al., 2008; Evuk et al., 2014). The ~890 Ma age of metamorphism in westernmost ANS, Bayuda Desert (Fig. 2; Karmakar and Schenk, 2015a) represents the earliest accretion stage of the eastward growing orogen (e.g. Fritz et al., 2013). Intrusion ages of ~800 Ma, ~700 Ma, and ~640 Ma in the ANS are found in the thermally reset ages in bordering SMC (Fig. 2; Küster et al., 2008; Evuk et al., 2014). Neoproterozoic activity in the SMC and ANS ends with the intrusion of post-collisional granite <600 Ma (Fig. 2; Küster et al., 2008; Evuk et al., 2014).

The rock inventory of the SMC comprises mainly felsic medium to high grade poly-metamorphic granitoids, including metagranite and rare metamonzonite (details in Barth and Meinhold, 1979; Küster et al., 2008; Evuk et al., 2014 and references therein). The ANS comprises metasedimentary rocks with marine protoliths, arc-related metavolcanic rocks and (meta)intrusions of intermediate to granitoid composition (e.g. Barth and Meinhold, 1979; Bailo et al., 2003; Küster et al., 2008; Evuk et al., 2014 and references therein). Generally the metamorphic grade does not exceed conditions of amphibolite facies, but is locally transitional to granulite facies (above references; Karmakar and Schenk, 2015a). For a detailed discussion of the ANS-SMC distinction in the study area we refer the reader to Evuk et al., 2014. Occurrences of mafic and ultramafic rocks ("ophiolite") are of minor importance west of the Keraf Suture and rare in the SMC (above references). Age data from the mafic rocks are not reported, but an approximate age of 900 Ma is assumed for the last high-grade metamorphic overprint and dynamic recrystallization in the mafic rocks that is based on the regional age distribution in their metamorphic host rocks of felsic composition.

In contrast to the extended ophiolite complexes east of the Keraf Suture, the outcrops of mafic and ultramafic rocks in the sampling area are small and discontinuous and do not allow for reconstruction of magmatic histories of individual outcrop areas. Sampling aimed at getting an overview of the inventory of mafic magmatic rocks according to their estimated abundance in the field.