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Zircon geochronology of the Koraput alkaline complex: Insights from combined geochemical and U–Pb–Hf isotope analyses, and implications for the timing of alkaline magmatism in the Eastern Ghats Belt, India

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ABSTRACT

Zircon formation and modification during magmatic crystallization and high-grade metamorphism are explored using TIMS and LA-ICP-MS U–Pb geochronology, Lu–Hf isotope chemistry, trace element analysis and textural clues on zircons from the Koraput alkaline intrusion, Eastern Ghats Belt (EGB), India. The zircon host-rock is a granulite-facies nepheline syenite gneiss with an exceptionally low Zr concentration, prohibiting early magmatic Zr saturation. With zircon formation occurring at a late stage of advanced magmatic cooling, significant amounts of Zr were incorporated into biotite, nearly the only other Zr-bearing phase in the nepheline syenite gneisses. Investigated zircons experienced a multi-stage history of magmatic and metamorphic zircon growth with repeated solid-state recrystallization and partial dissolution–precipitation. These processes are recorded by complex patterns of internal zircon structures and a wide range of apparently concordant U–Pb ages between 869 ± 7 Ma and 690 ± 1 Ma. The oldest ages are interpreted to represent the timing of the emplacement of the Koraput alkaline complex, which significantly postdates the intrusion ages of most of the alkaline intrusion in the western EGB. However, Hf model ages of TDM = 1.5 to 1.0 Ga suggest an earlier separation of the nepheline syenite magma from its depleted mantle source, overlapping with the widespread Mesoproterozoic, rift-related alkaline magmatism in the EGB. Zircons yielding ages younger than 860 Ma have most probably experienced partial resetting of their U–Pb ages during repeated and variable recrystallization events. Consistent youngest LA-ICP-MS and CA-TIMS U–Pb ages of 700–690 Ma reflect a final pulse of high-grade metamorphism in the Koraput area and underline the recurrence of considerable orogenic activity in the western EGB during the Neoproterozoic. Within the nepheline syenite gneisses this final high-grade metamorphic event caused biotite breakdown, releasing sufficient Zr for local saturation and new subsolidus zircon growth along the biotite grain boundaries.

1. Introduction

Defining the conditions of zircon crystallization in magmatic and metamorphic environments is one of the main challenges in zircon U–Pb geochronology in order to understand which geological processes are being dated. Particularly in rocks with a high-grade metamorphic overprint, the obtained age information often reflects a complex history of polyphase zircon growth, dissolution and/or recrystallization (e.g., Harley et al., 2007). With the development of high-precision mass spectrometry and small-diameter spot measurements the analysis of single grains or specific domains within single crystals has become possible. These techniques allow us to date multiple stages of crystal growth or modification and, thus, to shed light on detailed regional tectonometamorphic histories. In this context, any geologic interpretation of zircon U–Pb data requires a thorough evaluation of zircon textures and morphology as obtained by high-resolution imagery, e.g., cathodoluminescence (CL), electron backscattering (BSE) or secondary electron microscopy (cf. Corfu et al., 2003). Additionally, crucial information about zircon growth conditions and the source of the magmatic host rock can be drawn from trace element distribution as well as the Hf isotope composition (e.g., Watson and Harrison, 1983; Belousova et al., 2002, 2006; Watson et al., 2006; Scherer et al., 2007; Kemp et al., 2009).

In this study, we discuss the processes of zircon formation and modification in granulite facies, alkaline rocks from the Indian Eastern Ghats Belt (EGB). This work combines U–Pb zircon dating with analyses of

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zircon chemical composition, especially rare-earth element (REE) abundances and Lu–Hf isotope composition, correlated to zircon textures and zoning patterns. Zircon REE patterns have been suggested to change with different pressure–temperature conditions and therefore might identify specific stages of mineral growth or metamorphism (e.g., Rubatto, 2002; Rubatto and Hermann, 2003). Similarly, for Hf, Y, P, and rarely for U and Th, trace element partitioning related to metamorphic zircon overgrowth and recrystallization has been documented (e.g., Williams et al., 1996; Rubatto et al., 2001; Hoskin and Schaltegger, 2003; Möller et al., 2003). The Lu–Hf system in zircon can be used as a geochemical tracer of magma provenance. Because of the strong fractionation of Lu/Hf in zircon, changes in the initially incorporated $^{176}Hf/^{177}Hf$ ratio due to decay of ^{176}Lu are negligible (Hoskin and Black, 2000; Kinny and Maas, 2003; Gerdes and Zeh, 2009). In most instances, Hf isotopes in zircon show closed-system behavior and, thus, effectively preserve the initial $^{176}Hf/^{177}Hf$ ratio of the igneous host rock even in highly metamorphic environments (Patchett, 1983; Amelin et al., 2000; Hoskin and Black, 2000). Metamorphic zircon overgrowth, however, can exhibit a variation in the $^{176}Hf/^{177}Hf$ and $^{176}Lu/^{177}Hf$ ratio caused, e.g., by co-precipitation with other metamorphic phases and/or alteration by metamorphic fluids (Kinny et al., 1991; Gerdes and Zeh, 2009; Zeh et al., 2010).

Timing and conditions of zircon formation will be further evaluated from the whole-rock chemical composition and the use of Ti-in-zircon thermometry, which allow us to estimate Zr saturation in the nepheline syenite host rock. In this regard, the petrographic context of the zircon crystals as documented in thin sections provides crucial constraints on potential Zr sources for metamorphic zircon growth. Finally, we will discuss the integrated geochronological and geochemical data set in terms of the regional geologic evolution and re-evaluate the timing of alkaline magmatism and the duration of orogenic activity (with high-grade metamorphism) along the western EGB.

2. Geological setting

2.1. Regional geology and previous dating

The alkaline complex of Koraput is part of the Precambrian Eastern Ghats Belt situated along the east coast of the Indian peninsular (Fig. 1a). Bounded by Archaean cratons along its western margins, the EGB comprises multiply deformed and highly metamorphosed rocks of igneous and supracrustal origin (Mezger and Cosca, 1999). A division of the EGB into geologically coherent entities has been debated by several authors and was summarized and revised by Dobmeier and Raith (2003). Accordingly, the Koraput alkaline complex is located within the Meso- to Neoproterozoic Eastern Ghats Province that is characterized by strongly deformed metasedimentary rocks, granulites and anorthosites, and multi-intrusive granite–charnockite complexes (Dobmeier and Raith, 2003). The western border of the Eastern Ghats province is marked by the prominent Sileru shear zone that forms the contact to the Archean Jeypore Province only few kilometers west of the Koraput alkaline complex (Fig. 1a).

The alkaline complex at Koraput is one of several alkaline plutons that are located within the western part of the EGB (Fig. 1a). Most of these occur along shear zones and are associated with the contact between the EGB and the cratonic basement (Ratnakar and Leelanandam, 1989; Leelanandam, 1998). The earliest phase of alkaline magmatism in the Eastern Ghats Province is documented by U–Pb zircon ages of 1500 ± 3/4 Ma (Aftalion et al., 2000) and 1480 ± 17 Ma (Upadhyay et al., 2006a) from the intrusive complex of Khariar (Fig. 1a). Possibly coeval crustal magmatism has been dated at 1464 ± 63 and 1455 ± 80 Ma (Sm–Nd WR; Shaw et al., 1997), followed by a second magmatic pulse dated at 1176 ± 201 Ma (Pb–Pb WR; Paul et al., 1990) and 1159 ± 59/30 Ma (U–Pb zircon; Aftalion et al., 1988). Although the emplacement ages of the Khariar nepheline syenites have been challenged by Biswal

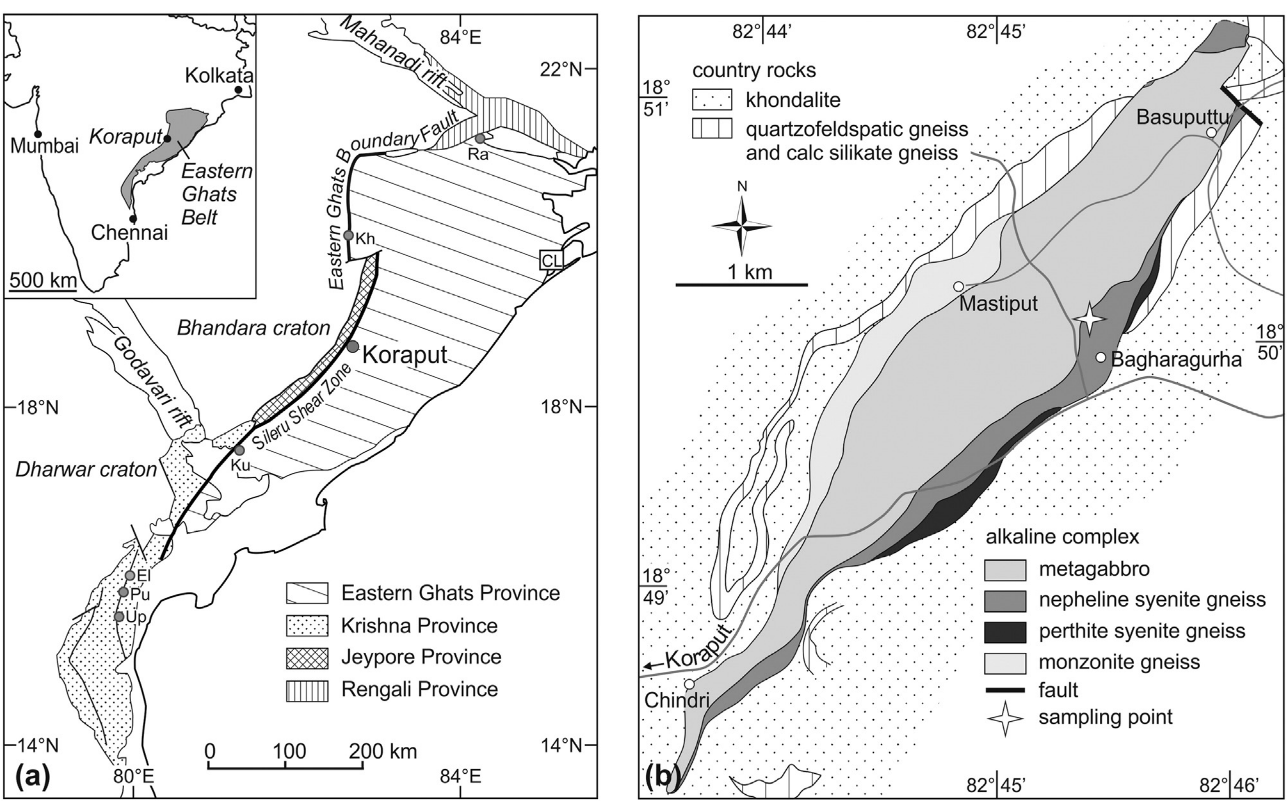

Fig. 1. (a) Simplified geological map of the Eastern Ghats Belt (modified after Dobmeier and Raith, 2003) and the location of major alkaline bodies (gray circles); Ra = Rairakhol, Kh = Khariar, Ku = Kunavaram, El = Elchuru, Pu = Purimetla, Up = Uppalapadu (Leelanandam, 1998; Upadhyay, 2008); White rectangle = Chilka Lake domain. (b) Geological sketch map of the Koraput alkaline complex and its country rocks. The star indicates the sample location for KO1.