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Early Neoproterozoic arc magmatism in the Lützow-Holm Complex, East Antarctica: Petrology, geochemistry, zircon U–Pb geochronology and Lu–Hf isotopes and tectonic implications

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ABSTRACT

The Lützow-Holm Complex (LHC) in East Antarctica has prominently figured in Proterozoic supercontinent reconstructions and is an important region to address subduction-collision process. Here we present petrological, geochemical and zircon U–Pb geochronological and Lu–Hf data on a suite of meta-igneous rocks from the LHC. The rocks that we investigated include hornblende-biotite gneiss (Bt + Hbl + Pl + Kfs + Qtz), charnockite (Pl + Qtz + Kfs + Opx + Hbl + Grt), and amphibolite (Hbl + Pl + Bt ± Cpx). Metamorphic temperature based on Hbl-Pl assemblage increases from the western part (710–740 °C) to the eastern part (780–820 °C) of the complex. The REE and trace element patterns as well as Rb-Y-Nb and Rb-Yb-Ta plots reveal volcanic arc affinity for the Hbl-Bt gneiss from Kasumi Rock, Tama Point, and Innhovde, suggesting that the protoliths of the rocks were derived from felsic to intermediate arc magmas. The amphibolite sample from Kasumi Rock also suggests subduction-related volcanic arc affinity. In contrast, the protolith of charnockite from Futatu-iwa is inferred as within-plate granite, as its geochemical signature is distinct from that of the other granitic to dioritic rocks in the LHC. The protolith of amphibolite from Tama Point is inferred as ocean-island basalt, suggesting the accretion of remnant oceanic lithosphere along with the arc components during the subduction-collision event. Zircon grain morphology and internal structure as examined from CL images indicate that the oldest population in all the samples preserves magmatic crystallization history, as also supported by their high Th/U ratios. The $^{206}Pb/^{238}U$ mean ages of the oldest population of magmatic zircons in the four rocks show 984 ± 6.9 Ma (Kasumi Rock), 965 ± 7.7 Ma (Tama Point), 981 ± 18 Ma (Innhovde), and 999 ± 6.3 Ma (Futatu-iwa) clearly marking a prominent Early Neoproterozoic magmatic event. Subsequent thermal events during the mid Neoproterozoic are also indicated by the concordant ages of a distinct population of zircons with high Th/U values, and $^{206}Pb/^{238}U$ ages in the range of 899–753 Ma from Futatu-iwa charnockite and Tama Point Hbl-Bt gneiss. The youngest population of zircons in these rocks is evidently metamorphic, characterized by structureless overgrowth domains with low Th/U values that yield $^{206}Pb/^{238}U$ mean ages in the range 582 ± 11–574 ± 9.5 Ma, probably related to late Neoproterozoic collisional event and high-grade metamorphism. Zircon Lu–Hf data indicate juvenile sources that contributed to the Neoproterozoic magmatism in the study area. A continental arc-type setting is suggested with magma sourced from Late Paleoproterozoic to latest Mesoproterozoic components, which might have formed during an earlier subduction cycle. Such Early Neoproterozoic arc magmatism has been inferred from other Gondwana fragments such as the Kadugannawa Complex in Sri Lanka, which is regarded as an extension of the LHC. The results of this study therefore suggest that the magmatic arcs in the LHC and the Kadugannawa Complex might have formed under a similar continental arc-setting during Early Neoproterozoic, and that the LHC is a collage of several crustal blocks including Early Neoproterozoic (ca. 1 Ga) juvenile volcanic arcs and Neoarchean (ca. 2.5 Ga) basement, which were amalgamated during the latest Neoproterozoic related with the final stage of amalgamation of the Gondwana supercontinent.

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1. Introduction

The Madagascar–Southern India–Sri Lanka–East Antarctica region, which corresponds to the central part of the late Neoproterozoic to early Cambrian collisional orogen (termed as the East African – Antarctic Orogeny; Jacobs and Thomas, 2004) preserves important records of the final phase of amalgamation of continental fragments related to the Gondwana assembly (e.g., Meert, 2003; Jacobs and Thomas, 2004; Collins and Pisarevsky, 2005; Santosh et al., 2009b). Recent tectonic models suggest that the East African – Antarctic Orogeny witnessed a series of collisional events of various proto-East Gondwana fragments or magmatic arcs against West Gondwana between 750 and 520 Ma (e.g., Meert and Voo, 1997; Meert, 2003; Jacobs and Thomas, 2004; Collins and Pisarevsky, 2005; Collins et al., 2007a,b, 2014; Meert and Lieberman, 2008; Santosh et al., 2009a,b, 2013, 2014, 2015). One of the examples of such complex accretion and collision tectonics is the southern part of the Indian shield where the Archean Dharwar Craton is juxtaposed against a number of discrete granulite-facies crustal blocks (e.g., Madurai, Trivandrum, Salem, Nilgiri, and Coorg Blocks) separated by major suture zones (Drury et al., 1984; Bhaskar Rao et al., 2003; Santosh et al., 2009a, 2013, 2015). The Palghat-Cauvery Suture Zone is regarded as the trace of the suture zone formed by the closure of Mozambique Ocean (e.g., Santosh et al., 2009a,b) as also supported by the occurrence of dismembered ophiolite complexes representing the remnants of oceanic lithosphere within the suture zone (e.g., Yellappa et al., 2010; Santosh et al., 2012, 2013). The Palghat-Cauvery Suture Zone probably continues to Madagascar (e.g., Collins and Windley, 2002), but its possible extension to Sri Lanka and Antarctica remains equivocal. Recently Santosh et al. (2014) reported detailed petrographic, geochemical, and U–Pb and Hf isotopic studies on meta-igneous rocks from Highland, Wanni, and Kadugannawa Complexes in Sri Lanka, and identified Early Neoproterozoic (980–916 Ma) arc magmatism from the Kadugannawa Complex, representing a major magma chamber in the Wanni Complex. They further proposed a double-side subduction model for the evolution of high-grade rocks in Sri Lanka, and regarded the Highland Complex as a suture zone formed by collision of two continental arcs (Wanni and Vijayan arcs).

The Lützow-Holm Complex (LHC) of East Antarctica has been regarded as an extension of the Highland Complex in Sri Lanka on the basis of lithological, structural, and geochronological similarities as well as consistent *P-T* evolution (e.g., Yoshida et al., 1992; Shiraishi et al., 1994; Kriegsman, 1995). Although numerous petrological and geochronological data have been published so far from the LHC (Satish-Kumar et al., 2008 and references therein), these works mostly focused on Late Neoproterozoic to Cambrian high-grade metamorphism related to the final collision associated with Gondwana assembly. However, detailed petrological and geochronological study focusing on the pre-metamorphic magmatic evolution is limited. In this study we present new petrological, geochemical, and zircon U–Pb and Lu–Hf isotopic data on a representative suite of felsic and mafic orthogneisses from various parts of the LHC that reveal a prominent phase of Early Neoproterozoic (965–999 Ma) crustal growth related to arc magmatism. The results of this study are further compared with recent petrological and geochronological data from the Kadugannawa Complex in Sri Lanka (Santosh et al., 2014; He et al., 2015) to evaluate the juxtaposition of Antarctica and Sri Lanka fragments, within the Gondwana supercontinent assembly.

2. Regional geology and previous studies

2.1. Regional geology

The Lützow-Holm Complex, exposed along the Prince Olav Coast and Lützow-Holm Bay of East Antarctica (Fig. 1), is known for exposures of regionally metamorphosed amphibolite- to granulite-facies rocks formed during the Late Neoproterozoic to Early Cambrian convergent tectonics (~0.55 Ga, e.g., Shiraishi et al., 1994, 2003, 2008). The LHC is bordered to the east by the Meso- to Neoproterozoic Rayner Complex, whereas its western and southern extension into the Neoproterozoic Yamato-Belgica Complex and Sør Rondane Mountains is unknown due to thick ice cover. The dominant lithologies of the complex are felsic to intermediate orthogneiss (charnockite and hornblende-biotite gneiss) and various metasedimentary (pelitic and psammitic rocks, quartzite, and marble) and metabasic (mafic to ultramafic) rocks, the metamorphic grade of which increases from amphibolite-facies in the northeast to granulite-facies in the southwest (e.g., Hiroi et al., 1991).

Yoshida et al. (1992) correlated the sedimentary units of the LHC along the Lützow-Holm (LH) Bay region (Ongul and Skallen Groups) to those of the Highland Complex in Sri Lanka based on structural patterns and lithological similarities. Shiraishi et al. (1994) regarded the LHC as a supracrustal basin developed in a suture zone with the Highland Complex in Sri Lanka during the final phase of Gondwana assembly. Nogi et al. (2013) traced several geological structures within the LHC, and separated the complex into four blocks possibly bounded by NE-SW-trending right lateral strike-slip faults. They further argued the presence of crustal gaps between the granulite-facies zone and the transitional zone, and also between the transitional zone and the amphibolite-facies zone of the LHC, and inferred the transitional zone as a remnant of the western Rayner Complex. Hiroi et al. (2006) reported granulite-facies assemblage (Opx + Cpx + Hbl + Pl) in meta-tonalite from Cape Hinode in the amphibolite-facies region of the LHC, and regarded the region as a Grenvillian allochthonous block in the LHC. Iwamura et al. (2013) evaluated the high-grade mafic granulite from Akarui Point in the transitional zone, and inferred the locality as an exotic block of high-grade metamorphism. Suda et al. (2008) performed systematic geochemical studies of various mafic orthogneisses from the LHC and observed regional shifts from island arc to ocean-floor affinities toward southwest from the Price Olav Coast to the LH Bay areas. Their neodymium isotopic data suggest that metabasites from the Price Olav Coast and the northern LHB areas were derived from immature continental crust formed by active Mesoproterozoic crustal growth, whereas those from the southern LHB area were derived from mature continental crust and oceanic crust of older age, based on which they concluded that the LHC includes lithological units with different origin and ages possibly amalgamated by multiple subduction before the Neoproterozoic-Cambrian high-grade metamorphism.

2.2. Metamorphic P-T conditions

Hiroi et al. (1991) performed systematic petrological studies of the LHC, and reported increase of metamorphic grade from amphibolite-facies in the northeast to granulite-facies in the southwest of the complex. The highest-grade metamorphic rocks of the complex are exposed at Rundvågshetta (Fig. 1) in the southwestern part of the LHC, where several diagnostic mineral assemblages of extreme crustal metamorphism at $T > 900\,^{\circ}C$ such as spinel + quartz (Motoyoshi et al., 1985; Kawasaki et al., 2011), orthopyroxene + sillimanite + quartz (Kawasaki et al., 1993; Motoyoshi and Ishikawa, 1997; Fraser et al., 2000), sapphirine + quartz (Yoshimura et al., 2008a), and osumilite-bearing assemblage (Kawasaki et al., 2011) have been reported. The peak *P–T* condition of Rundvågshetta has been estimated at 1040 °C and 13–15 kbar. Such granulites formed by ultrahigh-temperature (UHT) metamorphism (e.g., Kelsey, 2008; Kelsey and Hand, 2014) have also been reported from adjacent localities such as Skallen and Skallevikshalsen, about 30 km northeast of Rundvågshetta (Osanai et al., 2004; Yoshimura