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Neoproterozoic crustal evolution in Sri Lanka: Insights from petrologic, geochemical and zircon U–Pb and Lu–Hf isotopic data and implications for Gondwana assembly

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ABSTRACT

Sri Lanka, the 'pendant' of Gondwana, is a collage of distinct crustal blocks that preserve important records of major Neoproterozoic tectonothermal events. Here, we present the petrology, geochemistry, zircon U–Pb geochronology and Lu–Hf isotopes on a suite of meta-igneous rocks including granodiorite, diorite and garnet amphibolite from the Kadugannawa Complex (KC), granodiorite from the Wanni Complex (WC) and mafic granulites, gabbros and garnet-bearing charnockite from the Highland Complex (HC) along a NW–SE transect. The regional metamorphic peak *P–T* conditions were estimated from garnet-clinopyroxene-plagioclase-quartz assemblage in the metagabbro as 830–860 °C and 9.4–9.8 kbar. Slightly lower temperature ranges of 700–780 °C were obtained from garnet amphibolite, metagranodiorite and metadiorite, corresponding retrograde conditions. Trace element and rare earth element patterns as well as Rb-Y-Nb and Rb-Yb-Ta discrimination plots show volcanic arc affinity for the granodiorite, diorite and garnet charnockite suggesting that the protoliths of the rocks were formed from felsic to intermediate arc magmas. The mafic granulites and magnesian metagabbro also suggest volcanic arc affinity and indicate subduction-related mafic magmatism and magma underplating. The garnet-bearing metagabbro shows N-MORB signature, whereas the garnet amphibolite displays oceanic island alkali basalt affinity. These rocks therefore represent accretion of the remnants of oceanic lithosphere during the subduction-collisional event.

Zircons in a metadiorite and the surrounding metagranodiorite from the KC yield ages of 980 ± 16 Ma to 916 ± 57 Ma marking early Neoproterozoic magmatism followed by metamorphism at 532 ± 18 Ma. Zircons in the garnet amphibolite from this complex show extensive metamorphic recrystallization yielding a weighted mean $^{206}Pb/^{238}U$ age of 520.7 ± 6.6 Ma. From the WC, zircons in a metagranodiorite define three groups of weighted mean $^{206}Pb/^{238}U$ ages at 805 ± 12 Ma (emplacement of the magmatic protolith), 734.0 ± 4.6 Ma (Cryogenian thermal event) and 546.0 ± 5.7 Ma (latest Neoproterozoic-Cambrian metamorphism). Zircons from the HC record multiple late Neoproterozoic-Cambrian thermal events with weighted mean $^{206}Pb/^{238}U$ ages of 576.8 ± 9.3 Ma and 523.0 ± 7.1 Ma (metagabbro) and 579 ± 10 Ma, 540.4 ± 6.0 Ma and 511.1 ± 5.9 Ma (garnet charnockite), 553.0 ± 3.2 Ma (mafic granulite), and 539.1 ± 4.4 Ma (mafic granulite sill). Lu–Hf data reveal dominantly positive $\varepsilon_{Hf}(t)$ values for zircons in the metadiorite and metagranodiorite from the KC (−1.1 to 7.2) and Hf crustal model ages ($T_{DM}{}^{C}$) in the range of 1206–1733 Ma suggesting a mixed source from both juvenile and Paleo-Mesoproterozoic components. However, zircons in the garnet amphibolite from this complex show dominantly negative $\varepsilon_{Hf}(t)$ values (mean −16.5) with $T_{DM}{}^{C}$ in the range of 2356–2828 Ma suggesting reworked

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Neoarchean-Paleoproterozoic crustal source. Zircons in metagranodiorite of the WC also possess negative $\varepsilon_{Hf}(t)$ values (mean −6.2) with $T_{DM}{}^{C}$ in the range of 1799–2498 Ma suggesting reworked Paleoproterozoic crust as the magma source. The HC rocks also preserve distinct imprints of reworking of older crust. The zircon $\varepsilon_{Hf}(t)$ values in mafic granulite show a tight cluster from −2.2 to 0.1 with $T_{DM}{}^{C}$ in the range of 1501–1651 Ma suggesting a mixed source from both juvenile Neoproterozoic and reworked Mesoproterozoic components. Zircons in the metagabbro from this complex show negative $\varepsilon_{Hf}(t)$ values (mean −6.3) and $T_{DM}{}^{C}$ of 1847–1978 Ma. Zircons in the garnet charnockite also display highly negative $\varepsilon_{Hf}(t)$ values (mean −17.7) and older $T_{DM}{}^{C}$) (mean 2614 Ma) suggesting reworked Paleoproterozoic crust. Zircons in the mafic granulite sample show negative $\varepsilon_{Hf}(t)$ values (mean −14.1) and $T_{DM}{}^{C}$ between 2263 and 2790 Ma indicating that the source material for the magma evolved from the Neoarchean-Paleoproterozoic crust. In summary, the 916–980 Ma ages from the KC represent arc magmatism during early Neoproterozoic, followed by the 805 Ma granodioritic magma emplacement in the WC. Repeated thermal events during mid and late Neoproterozoic are also recorded from the Wanni and Highland Complexes, culminating in Cambrian high-grade metamorphism that reached ultrahigh-temperature conditions. We propose a model of double-sided subduction during the Neoproterozoic, where the Wanni Complex to the west and the Vijayan Complex to the east represent continental arcs, culminating in collision along the HC during late Neoproterozoic-Cambrian.

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1. Introduction

Crustal evolution models on both Archean and Phanerozoic Earth identify the role of arc magmas derived from both juvenile and reworked older components (e.g., Condie and Kröner, 2013; Condie and Aster, 2013; Santosh et al., 2013a; Xiao and Santosh, 2014). In convergent margins, continental growth occurs through vertical addition of magmas derived by the melting of downgoing oceanic slabs, as well as lateral accretion of oceanic and trench material, together with other exotic oceanic and crustal fragments. For instance, the Central Asian Orogenic Belt (CAOB) representing the largest Phanerozoic accretionary orogen on the globe is a typical example of continental growth through lateral accretion of young arc complexes and old micro-continents together with vertical growth through underplating of mantle-derived magmas (e.g., Xiao and Santosh, 2014, and references therein). Many of the major Precambrian collisional orogenic belts were also constructed through prolonged subduction-accretion processes, similar to the modern analog of the ongoing subduction and accretion in the Western Pacific (Santosh et al., 2009). Accretionary orogens also characterize the margins of the major supercontinents built through the amalgamation of continental fragments (Cawood and Buchan, 2007).

The geology of Sri Lanka provides important insights into continental growth in the Neoproterozoic Earth. Tectonics of Sri Lanka has also been in focus in relation to the history of assembly of supercontinents, particularly because of its central position within the India–Madagascar–Africa–East Antarctica collage of the late Neoproterozoic Gondwana supercontinent (Yoshida et al., 1992). The Sri Lankan Precambrian basement has been subdivided into four major terrains (e.g. Cooray, 1994): the Wanni Complex (WC) to the west together with the Kadugannawa Complex (KC), the Highland Complex (HC) at the middle, and the Vijayan Complex (VC) to the east (Fig. 1), largely based on Nd-model age mapping and regional structural interpretations (Milisenda et al., 1988, 1994; Kröner et al., 1987, 1991; Kehelpannala, 1991, 2003, 2004). The WC is considered to represent a higher crustal level than that of the HC although there is no clear structural break between the rocks of the two complexes, and the contact between these two has been obliterated by later events (Voll and Kleinschrodt, 1991). The boundary between the VC and the HC is well defined as a thrust/shear contact (Hatherton et al., 1975; Vitanage, 1985; Voll and Kleinschrodt, 1991; Kriegsman, 1994). Three tectonic klippens of similar petrological and structural features to the HC are exposed in the south eastern part of Sri Lanka as inliers, namely Kataragama Klippe, Buttala Klippe and Kuda Oya Klippe. Some authors (e.g. Kehelpannala, 1991, 1997) have suggested that the KC forms part of the WC based on geochronological, geochemical and structural evidence. The HC domain is interpreted to be a part of a supracrustal basin developed in a suture zone with the Lützow-Holm Complex in East Antarctica during the final phase of Gondwana assembly (Shiraishi et al., 1994). The WC, KC and VC domains are considered as Grenville-aged terranes of arc-related settings at the outer margin of the Rodinia supercontinent (Kehelpannala, 2003, 2004; Kröner et al., 2003, 2013; Willbold et al., 2004). Although Sri Lanka is a relatively small continental fragment, mimicking a pendant on the heart of Gondwana, the several distinct tectonic units in this island and their history of amalgamation offer important clues for evaluating Precambrian crustal evolution history.

In this study, we present results from our field investigations and petrologic, geochemical, zircon U–Pb and Lu–Hf isotopic studies on a suite of metamorphosed magmatic rocks from the Wanni, Kadugannawa and Highland Complexes. Our data reveal Neoproterozoic crustal growth through protracted arc magmatism derived from both juvenile and reworked sources, and lateral accretionary growth by the incorporation of oceanic and continental material. The subduction-accretion process culminated in continental collision and high-grade metamorphism during late Neoproterozoic-Cambrian.

2. Geological background

2.1. Overview of geology and petrology

The HC is dominantly composed of granulitic meta-quartzites, marbles, calc-silicates and metapelitic gneisses, in association with charnockites (Cooray, 1962, 1984, 1994; Perera, 1984; Mathavan et al., 1999; Mathavan and Fernando, 2001; Dharmapriya et al., 2014). The metasedimentary rocks such as marble and quartzite can be traced for more than 40 km in the central and northeastern part of the HC, whereas marble and quartzite are scarce in the southwestern part of this complex (Mathavan et al., 1999). Bands of wollastonite-scapolite, diopside- and scapolite-bearing calc-granulites and cordierite-bearing gneisses occur in the south and southwestern parts of the HC (Cooray, 1962, 1984; Hapuarachchi, 1968; Perera, 1984; Prame, 1991a; Mathavan et al., 1999; Mathavan and Fernando, 2001).

Metamorphism under granulite facies conditions has been well established in the HC from meta-basaltic and gabbroic to intermediate rocks (Sandiford et al., 1988; Schumacher et al., 1990; Schumacher and Faulhaber, 1994), charnockites (Prame, 1991b) and metamorphosed pelitic rocks (Perera, 1984, 1987; Prame,

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