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Ca. 820–640 Ma SIMS U-Pb age signal in the peripheral Vijayan Complex, Sri Lanka: Identifying magmatic pulses in the assembly of Gondwana

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ABSTRACT

Sri Lanka comprises three roughly north-south trending amphibolite- to granulite-facies lithotectonic complexes, from west to east the Highland Complex, the Wanni Complex, and the Vijayan Complex. These terranes were correlated with other East Gondwana continental terranes with similar lithologies forming at similar ages. The Wanni Complex and the Vijayan Complex have been interpreted as volcanic arc terranes brought together by a double-sided subduction. The Highland Complex represents the metamorphosed accretionary prism within the suture when the Wanni and Vijayan Complexes were juxtaposing against each other. In contrast to the Wanni and Highland Complexes, the Vijayan Complex has yielded only a few geochronological data with satisfactory precision. Previous studies suggested that the Vijayan Complex comprises ~1100–924 Ma granitic gneisses, which were metamorphosed during ~590–456 Ma. More recently, ~772–617 Ma mafic intrusions have been identified. This study divides the Vijayan granitic gneisses and the associated melt products geochemically into a low-Nb series and a more primitive high-Nb series. Our SIMS U-Pb zircon data suggested that both series have protolith magmatic ages of ~1062–935 Ma, and metamorphic ages of ~580–521 Ma, which is consistent with previous work. However, some of the Vijayan granitic gneisses and granitic anatectic melt products at the Highland-Vijayan tectonic mixed zone preserve an additional Tonian-Cryogenian (~820–630 Ma) age signal. This age signal suggested that felsic magmatism also occurred when mafic granulites were emplaced along the Highland-Vijayan boundary, which is broadly coeval with to the bimodal magmatism occurring along the Highland-Wanni boundary. This study also suggests that charnockitisation in the Vijayan Complex occurred at 562 ± 6 Ma during the Neoproterozoic regional metamorphism. The Tonian-Cryogenian signal preserved in the Highland-Vijayan tectonic mixed zone can also be found in the alkaline intrusion hosted by the Namuno Terrane and the Lurio Belt in Mozambique. This indicates a relationship between the Vijayan granitic gneisses and the Lurio foreland metagranitic basement, while the Namuno Terrane and the Lurio Belt are correlated with the Highland-Vijayan tectonic mixed zone. The ages and the isotope signatures of these granitic bodies further suggest a genetic relationship of these granitic bodies with various magmatic intrusions in East Antarctica.

1. Introduction

The tectonics and palaeogeographical location of Sri Lanka before the assembly of Gondwana remain controversial in reconstructions of late Precambrian geology. The island of Sri Lanka comprises three lithotectonic terranes, from west to east the Wanni Complex, the Highland Complex, and the Vijayan Complex (Figs. 1 and 2). They have similar metamorphic grade and structure to now removed terranes of southern India and eastern Antarctica, but the correlation between these regions has been based upon comparing the age spectra of the basement rocks and associated intrusive rocks (Baur et al., 1991; Hölzl et al., 1991, 1994; Black et al., 1992; Kröner and Williams, 1993; Kröner et al., 1994, 2003, 2013; Shiraishi et al., 1994; Paquette et al., 1994; Collins et al., 2007; Clark et al., 2009a,b; Sajeev et al., 2010; Brandt et al.,

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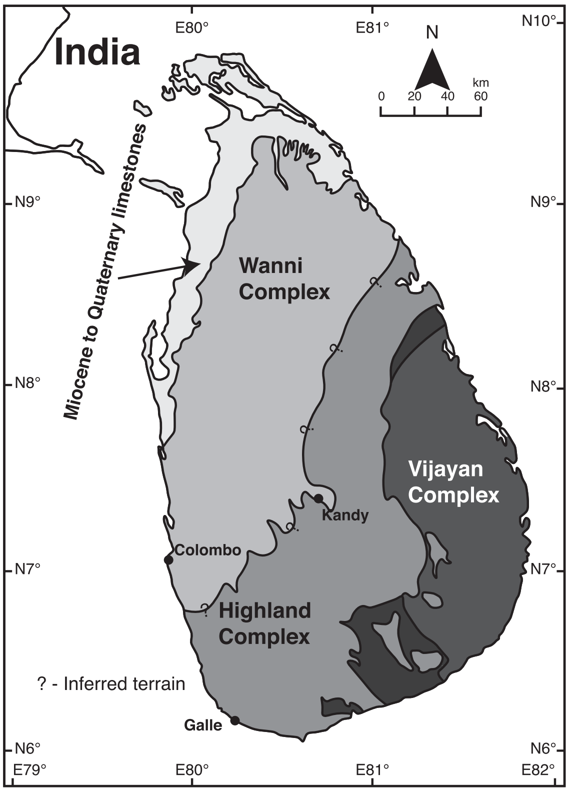

Fig. 1. Schematic geological map of Sri Lanka, after Kröner et al. (2013).

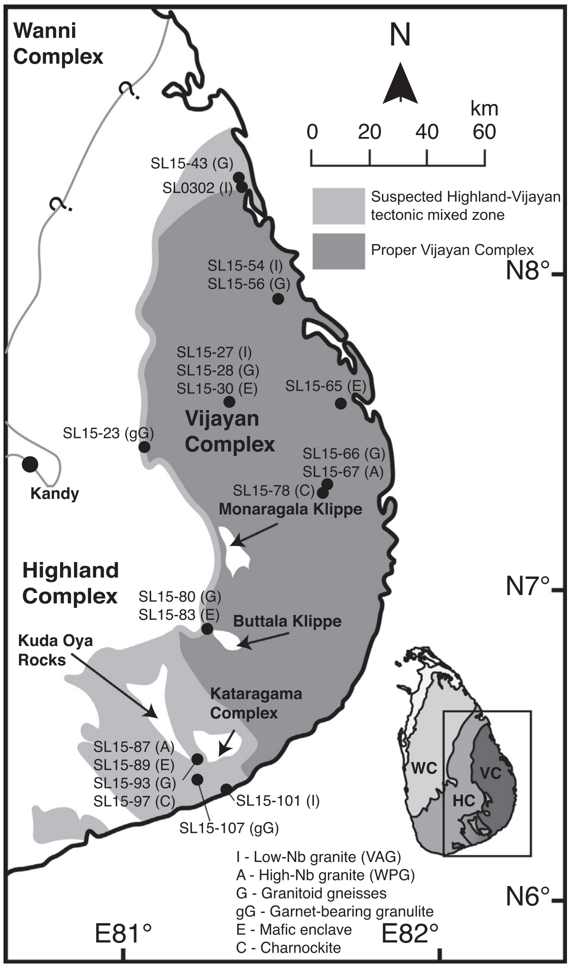

Fig. 2. Map of Vijayan Complex with locations of sampling, edited after Kröner et al. (2013). The tectonic mixed zone between the Highland Complex and the Vijayan Complex is highlighted as light-grey in colour.

2011; Malaviarachchi and Takasu, 2011; Collins et al., 2012; Santosh et al., 2014; He et al., 2015, 2016; Takamura et al., 2015, 2016; Tsunogae et al., 2015; Dharmapriya et al., 2016). From these previous works, it has become widely accepted that a single ~610–456 Ma metamorphic event is represented in all these terranes, and this period was interpreted by these workers as the collision time of Sri Lankan terranes, coeval to the assembly of Gondwana. Santosh et al. (2014) proposed that these Sri Lankan terranes were amalgamated by a double-sided subduction system, with the Wanni arc and the Vijayan arc juxtaposed against each other along sutures filled with metamorphosed Highland accretionary sediments. Previous works have focused on pressure-temperature metamorphic conditions of the Wanni and the Highland Complexes (Schenk et al., 1991; Raase and Schenk, 1994; Kriegsman and Schumacher, 1999; Sajeev and Osanai, 2004; Osanai et al., 2006; Sajeev et al., 2007; Dharmapriya et al., 2014; Santosh et al., 2014) and the geochronology of their basement rocks (Kröner et al., 1987, 1994, 2003; Milisenda et al., 1988, 1994; Burton and O'Nions, 1990; Baur et al., 1991; Hölzl et al., 1991, 1994; Kröner and Williams, 1993; Kröner and Jaeckel, 1994; Jaeckel et al., 1997; Sajeev et al., 2007, 2010; Amarasinghe and Collins, 2011; Malaviarachchi and Takasu, 2011; Santosh et al., 2014; Dharmapriya et al., 2015, 2016; He et al., 2015; Takamura et al., 2015, 2016). The Vijayan Complex is significantly less well-studied than the other two complexes due to political instability in the area. After the 1990s, the most extensive geochemical and geochronological study on the Vijayan rocks is presented by Kröner et al. (2013). This work suggested that the Vijayan Complex has rather simple zircon geochronology in contrast to the Wanni and the Highland Complexes, with ~1100–1000 Ma protolith magmatic ages, followed by a ~580 Ma regional metamorphism. However, many of these data were obtained by LA-ICP-MS U-Pb analyses with relatively poor precision. Recently, He et al. (2016) also presented U-Pb zircon geochronology of Vijayan mafic granulites and granitic gneisses, but these data are difficult to directly compare with previous work as they were obtained along the Highland-Vijayan boundary. Hence, this paper re-evaluates the geochronology of the entire Vijayan Complex using higher precision secondary ion mass spectrometry (SIMS) zircon U-Pb geochronology.

2. Geological background

The Highland Complex is the most well-studied lithotectonic complex in Sri Lanka. It is sandwiched by the Wanni Complex in the west and the Vijayan Complex in the east. Some Highland Complex rocks are found in Buttala, Kataragama, and Kuda Oya within the Vijayan Complex, and are interpreted as tectonic klippen (Fig. 2). The Highland Complex contains granulite-facies metamorphosed supracrustal lithologies, such as marbles, quartzites, metapelites, and calc-silicates that are characteristic of seafloor sediments; and metaigneous rocks such as charnockites and orthogneisses. The ε_{Nd} values obtained from the Highland rocks widely ranges from −25.1 to −7.3 with depleted mantle model age ranges from 2.0 to 3.4 Ga, suggesting the Complex was made of reworked old continental materials (Milisenda et al., 1994). The entire Highland Complex exhibits as a tilted metamorphic terrane with *P-T* gradient increases from 5 to 6 kbar and 700 °C in the northwest to 9–10 kbar and 830 °C in the southeast (Faulhaber and Raith, 1991; Raase and Schenk, 1994; Schumacher and Faulhaber, 1994; Dharmapriya et al., 2014). A clockwise *P-T* path has been drawn with extreme crustal metamorphism occurring at 9–12.5 kbar and 925–1150 °C (Kriegsman and Schumacher, 1999; Sajeev and Osanai, 2004; Osanai et al., 2006; Sajeev et al., 2007). The Highland Complex contains a wide age-range of detrital zircon U-Pb ages, ranging from 700 to 2800 Ma, with peaks reported at 2700, 2500, 2300–2000, 1700, and 1040–830 Ma (Kröner et al., 1987; Hölzl et al., 1991, 1994; Sajeev et al., 2010; Dharmapriya et al., 2015, 2016; Takamura et al., 2016). Orthogneisses yield a magmatic age of 2000–1800 Ma and 670–550 Ma (Kröner et al., 1987; Baur et al., 1991; Hölzl et al., 1991, 1994; Kröner and Williams, 1993; Dharmapriya et al., 2016). More recently, Dharmapriya et al. (2015) suggested the crystallisation age of sapphirine granulite in the Highland Complex is between 834 and 722 Ma. Granulite metamorphism occurred during 610–523 Ma (Kröner et al., 1987, 1994; Baur et al., 1991; Jaeckel et al., 1997; Sajeev et al., 2010; Santosh et al., 2014; He et al., 2015), with peak metamorphism and charnockitisation occurring during 580–530 Ma (Baur et al., 1991; Dharmapriya et al., 2015, 2016; Takamura et al., 2015, 2016). CHIME monazite dating however, suggested a wider metamorphic age range between 728 and 460 Ma (Malaviarachchi and Takasu, 2011). Magmatic core ages at ~576–550 Ma were obtained from mafic granulites and mafic enclaves, which is coeval to the latest granite emplacement in the Highland Complex (Santosh et al., 2014; He et al., 2015). Hence, bimodal magmatism occurred during the regional metamorphism of the Highland Complex.

The Wanni Complex comprises dominantly upper amphibolite- to granulite facies orthogneisses, with subordinate amount of metasediments in the east and southeast of the Complex. The orthogneisses are granitic, granodioritic, monzonitic, and tonalitic in composition while the metasediments include garnet-sillimanite gneisses, cordierite gneisses, quartzites, and calc-silicates (Pohl and Emmermann, 1991). The ε_{Nd} values obtained from the Wanni hornblende-biotite granitic gneisses range from −4.7 to +2.2 with depleted mantle model ages ranging from 1.1 to 2.0 Ga, suggesting reworked continental materials involved in the magmatism (Milisenda et al., 1994). Schenk et al. (1991) and Raase and Schenk (1994) estimated that peak metamorphism could reach 5–7 kbar and 700–830 °C. Reported detrital zircon ages extracted from Wanni metasediments are between 2745 Ma and 650 Ma, with peak recorded at 650, 1800 and 2700 Ma (Hölzl et al., 1991, 1994; Kröner et al., 1994; Amarasinghe and Collins, 2011;). Four episodes of magmatism have been identified in the Wanni Complex: ~1100–1000 Ma, ~980–894 Ma (derived from the former Kadugannawa Complex), ~790–750 Ma, and ~550 Ma (Milisenda et al., 1988, 1994; Hölzl et al., 1991, 1994; Kröner and Jaeckel, 1994; Kröner et al., 1994; Santosh et al., 2014). Ages for calc-alkaline magmatism range from ~1100–750 Ma (Kehelpannala, 1993, 2004; Kröner et al., 2003). Moreover, it was also shown that the sediments in the Wanni Complex resemble accretionary prism deposits (Santosh et al., 2014; He et al., 2016). Therefore, the Wanni Complex could well represent an Andean-type magmatic arc. During the latest magmatism at ~550 Ma, mafic dykes were emplaced at the same time (He et al., 2015). A separate terrane called the Kadugannawa Complex was defined near Kandy (Cooray, 1984). It was interpreted as a migmatised layered mafic-ultramafic complex, called the Kandy Layered Intrusion (KLI), with subordinate metasediments. This terrane was later combined into the Wanni Complex by Kröner et al. (2003) for two reasons: First, the available detrital zircon data of the "Kadugannawa" magmatism (~984–882 Ma) overlapped partly with the early-Neoproterozoic magmatism of the Wanni Complex. Second, the age and the geochemistry of the KLI indicated that the formation of the "Kadugannawa Complex" might be related to the plume activity leading to the breakup of Rodinia rather than representing a coherent tectonic block (Kröner et al., 2003). There is insufficient evidence to suggest that the "Complex" was an independent lithotectonic terrane. Several thermal events have been recorded in the Kadugannawa rocks at 832, 780, 721, 661–605 Ma (He et al., 2015). All these igneous and sedimentary rocks were then metamorphosed during 610–500 Ma, with charnockitisation occurred at 590–535 Ma (Baur et al., 1991; Hölzl et al., 1991; Kröner et al., 1994; Jaeckel et al., 1997; Amarasinghe and Collins, 2011; Santosh et al., 2014; He et al., 2015).

The Vijayan Complex is dominated by amphibolite-facies hornblende-biotite granitic gneisses. These orthogneisses are usually associated with charnockites and granitic melt products (Burton and O'Nions, 1990; Baur et al., 1991; Hölzl et al., 1991). Granulite-facies garnet-bearing orthogneisses are found near the boundary with the Highland Complex (Fig. 2) (Kröner et al., 2013; He et al., 2016). Whole complex was interpreted to have formed because of island-arc magmatism, similar to the tectonic environment that formed the Wanni Complex, followed by regional metamorphism and crustal anatexis (Milisenda, 1991; Pohl and Emmermann, 1991; Santosh et al., 2014; He et al., 2016). The ε_{Nd} values obtained from the Vijayan hornblende-biotite granitic gneisses range from −1.5 to +7.5 with depleted mantle model ages ranging from 1.0 to 1.8 Ga, suggesting a dominantly juvenile source involved in the magmatism in contrast to the Wanni Complex (Milisenda et al., 1994). In further contrast to the Highland and Wanni Complex, where extensive U-Pb zircon geochronology has been carried out, the age spectra of the Vijayan Complex were only reported in work conducted in the 1990s (Baur et al., 1991; Hölzl et al., 1991) before the extensive zircon U-Pb dating carried out by Kröner et al. (2013). These previous works suggested that the age spectrum of the Vijayan Complex is relatively simple and homogenous across the terrane. It was reported that this magmatism occurred during the early Neoproterozoic time (~1100–924 Ma), and the whole Complex was then metamorphosed with crustal anatexis at ~580–550 Ma (Kehelpannala, 2004; Kröner et al., 2003, 2013). Recently, He et al. (2016) reported additional U-Pb zircon ages obtained from the granitic gneisses, garnet-bearing mafic granulites, and clinopyroxenites collected along the Highland-Vijayan boundary. The latter two showed magmatic core ages of 617 ± 27 Ma and 772 ± 6 Ma respectively, suggesting mafic magmatism occurred before the regional metamorphism in the Vijayan Complex. They also showed ultramafic magmatism also occurred in the Ordovician at 485 ± 6 Ma, after the regional metamorphism.

Kröner et al. (2013) also re-evaluated the boundary of the Vijayan Complex. They found that around the villages of Mahawalatenna, Wellawaya, Embilipitiya, and Kirinda in southern Sri Lanka (Fig. 2), the Highland Complex overthrust the Vijayan Complex, leaving tectonic klippen called the Kuda Oya Rocks and the Kataragama Complex, and a mixed zone of rocks from both terranes in the area. Garnet-bearing granulites are apparently restricted to this tectonic mixed zone (Kröner et al., 2013; He et al., 2016). Kröner et al. (2013) also reported age spectra of zircons from this tectonic mixed zone, identifying three Tonian ages (~820–750 Ma) from zircon cores using U-Pb SIMS; these are not found in other parts of the Vijayan Complex. These few zircon-core ages do not have obvious affinities within the Highland Complex or the Vijayan Complex and were interpreted as an indicator of prolonged magmatism from Mesoproterozoic to Neoproterozoic without further discussion (Kröner et al., 2013). These authors argued that the zircons extracted from Vijayan rocks usually experienced Pb-loss, forming a discordant array with an upper intercept age of ~1100–1000 Ma as protolith age, and a lower intercept age of ~580 Ma as metamorphic age. This discordant array is close to the concordia curve, making Pb-loss difficult to quantify. They suggested that there are no significant concordant analyses between ~1100 and 1000 Ma and ~580 Ma, but rather discordant data lying close to concordia. However, as we illustrate in this study, the LA-ICP-MS U-Pb data are not precise enough to distinguish unambiguously between concordant analyses of intermediate age (which might represent a true Tonian event) from analyses that lie on a discordia line representing 1050 Ma zircon variably reset at 550 Ma, and are only useful when pooled in large numbers to yield a weighted average age. Hence, a dating technique with higher analytical precision is required to identify if there are any concordant signals between the reported upper and the lower intercept ages.

3. Field relationship and petrography

The Vijayan Complex basement is primarily hornblende-biotite granitoid gneisses, which were partly migmatised and charnockitised, and are hosting mafic enclaves. Garnet-bearing mafic granulites are usually found at the Highland-Vijayan tectonic mixed zone, associated with metasedimentary rocks with serpentinite and clinopyroxenite enclaves (He et al., 2016).

3.1. Granitoid gneisses in amphibolite facies

An outcrop in Verugal (N08°14′42.3″, E81°22′23.8″) shows the metamorphosed granitoid basement of the Vijayan Complex (Fig. 3A). These gneisses range from granitic to granodiorite in composition, and are highly deformed and metamorphosed into amphibolite facies. These gneisses contain hornblende, K-feldspar, plagioclase, quartz, biotite, ilmenite, apatite, magnetite, and zircon (Fig. 3B). Some of the gneisses are migmatised, forming leucosomic melt pockets (Fig. 3C). These melt pockets comprise mainly felsic minerals such as quartz, plagioclase, and K-feldspar. Mafic enclaves are occasionally found in the gneisses, for example in the outcrop exposed in Dambadeniya Mahaoya (N07°30′37.0″, E81°20′47.9″) (Fig. 3D). These enclaves contain mainly hornblende, pyroxene, and plagioclase.

3.2. Charnockite

Some of the basement granitoid gneisses of the Vijayan Complex are charnockitised with the appearance of garnet and orthopyroxene (hypersthene) in the mineral assemblage. These minerals made the charnockitised gneisses more brownish in colour. The physical boundary between the unaltered granitoid gneisses and the charnockites is usually wavy and gradual, and this can be seen at Damana (N07°11′44.8″, E81°39′59.7″) (Fig. 3E and F). These charnockites are associated with lens of feldspathic pegmatite.

3.3. Garnet-bearing mafic granulites

Mafic granulites in the Vijayan Complex usually contain coarse garnet grains (0.5–2 cm) in a fine-grained matrix dominated by pyroxene, hornblende, plagioclase and quartz. An outcrop of medium-pressure mafic granulite was exposed in dense vegetation located at a beach side at Ussangoda (N06°05′43.7″, E80°59′24.0″) (Fig. 3G). It shows gneissic bands and is adjacent to highly weathered serpentinised rocks, but without distinct contact in-between (Fig. 3H). Petrographic study of these samples indicate that they are mainly composed of porphyroblastic garnet, with equigranular clinopyroxene, orthopyroxene, plagioclase, quartz and hornblende (Fig. 3I). Inclusions of clinopyroxene, hornblende and quartz are commonly present in the garnet grains (Fig. 3J). Some of the garnet grains, which are inclusion-free or with a few inclusions, display euhedral crystals in contact with clinopyroxene, plagioclase and hornblende. Since there is no major reaction structure observed in the samples, garnet and matrix-type pyroxenes, hornblende, plagioclase and quartz are believed to be formed in equilibrium at a consistent stage.

4. Whole rock major and trace geochemistry

Fifty-six samples were collected for geochemical analyses throughout the Vijayan Complex, including not only the basement granitoid gneisses, but also the associated charnockites, anatectic melt products, and the hornblende-biotite mafic enclaves hosted by the melt products. Here we present basic geochemical background to the samples selected for U-Pb zircon geochronology (Table 1).

Samples were crushed and powdered by jaw crusher and corundum mill. They were then fused into glass beads in the Department of Earth Sciences, The University of Hong Kong. Major elements of samples were given by the X-Ray fluorescence (XRF) analytical results of these glass beads using the Rigaku ZSX 100e wavelength-dispersive XRF spectrometer in the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. The analytical procedures mentioned in Goto and Tatsumi (1996) were adopted in this paper, while the loss on ignition (LOI) was determined separately by routine procedures. The powdered samples were then divided into two batches of subsamples. The first batch of subsamples was digested with aqua regia and HF-HNO_3-$HClO_4$ in a graphite heating block. After cooling, the sample solution is diluted with deionised water, mixed and analyzed by inductively coupled plasma – atomic emission spectroscopy (ICP-AES), using a Varian VISTA, and followed by inductively coupled plasma – mass spectroscopy (ICP-MS), using an Agilent 7700x in ALS Chemex (Guangzhou) Co. Ltd. The second batch of the samples was digested with perchloric, nitric, hydrofluoric and hydrochloric acids, with the residue topped up with dilute hydrochloric acid. The sample solution is then analyzed by ICP-AES. The duplicate tolerance and standard tolerance are required to be controlled as <10% in the lab system. The comprehensive values are then released as the final results and presented in the Supplementary publication (Table S1).

The hornblende-biotite orthogneisses in the Vijayan Complex are predominantly alkalic to calc-alkalic, and metaluminous to weakly peraluminous. Nb and Ta negative anomalies are widely observed in all the granitic samples, suggesting a subduction-related tectonic environment. The geochemistry of the anatectic melt products resembles that of the hosting basement rocks (Fig. 4A). The granitic gneisses and the associated anatectic melt products can be divided into high-Nb series and low-Nb series at Y + Nb = 60 in Pearce et al. (1984) Rb vs. (Y + Nb) diagram (Fig. 4B). This is caused by the relative enrichment of Nb and other high field strength elements in some of these granitic gneisses and melt products. Although this diagram was designed to discriminate granites formed at different tectonic setting, it is worth noting that our samples are metamorphic rocks, such discrimination diagram do not give any tectonic implications to them. Here, only the geochemical trends of the samples are considered. The high-Nb series and the low-Nb series follow different fractionation paths. The fractionation path of the high-Nb series is steeper, and is extrapolated from a starting point of a mafic enclave sample (SL15-65) (Fig. 4C). The low-Nb series samples are metaluminous to weakly peraluminous, and could be derived from melting of mid-lower

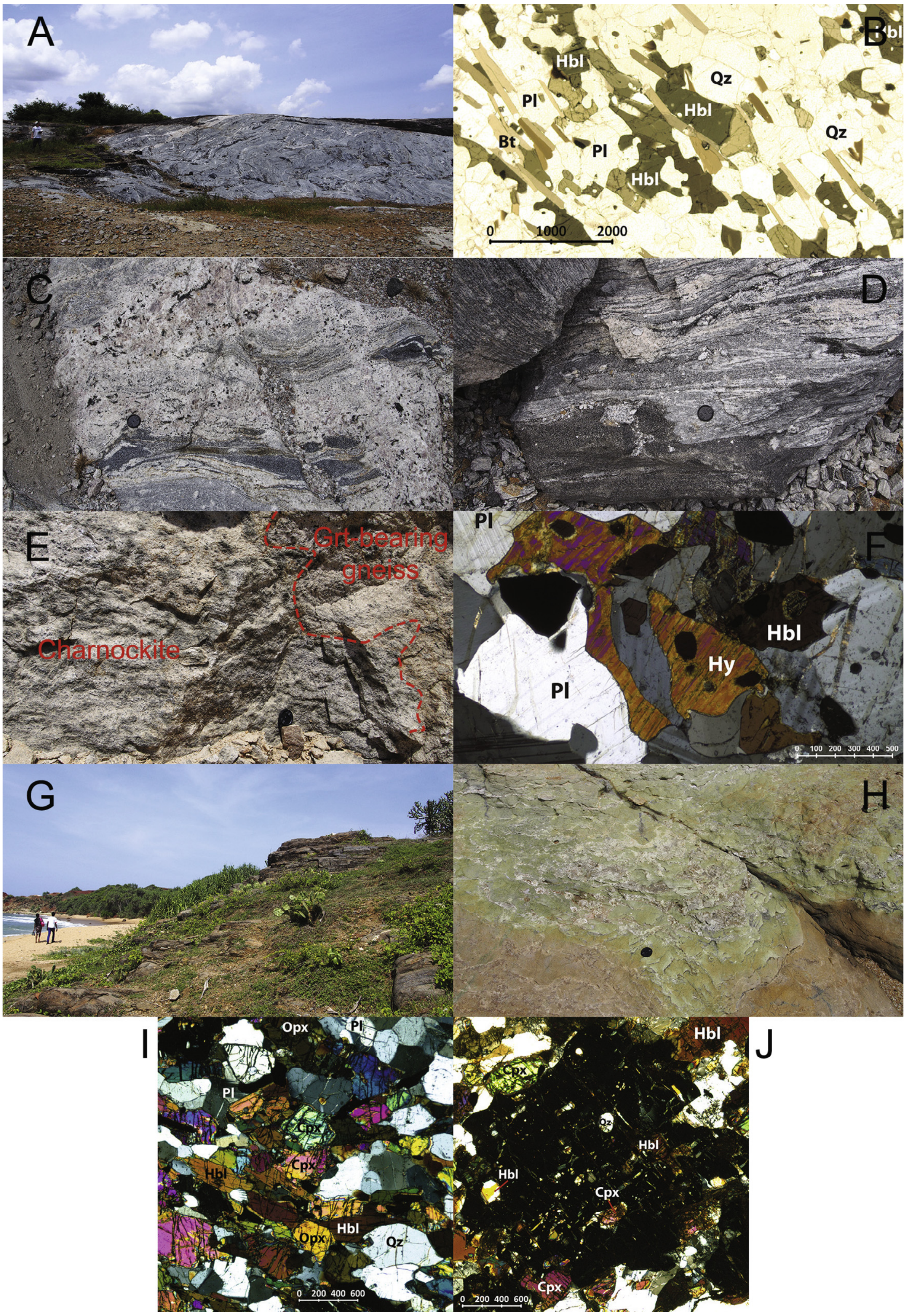

Fig. 3. (A) Field photo of Verugal, showing the granitoid gneisses basement in amphibolite facies of the Vijayan Complex; (B) A plane-polarised microscopic image showing the mineral assemblage of a Verugal biotite-hornblende gneiss (amphibolite facies) with plagioclase (Pl), quartz (Qz), hornblende (Hbl), and biotite (Bt) (scale unit in μm) (SL15-42); (C) The granitoid gneisses of the Vijayan Complex usually contain leucosomic granitic melt, photo was taken in Verugal; (D) An outcrop at Dambadeniya Mahaoya shows the mafic enclave in the basement granitoid gneiss; (E) Wavy contact of charnockitisation observed at Damana; (F) A cross-polarised microscopic image showing the mineral assemblage of a Damana charnockite (SL15-78) with plagioclase (Pl), hornblende (Hbl), and later developed hypersthene (Hy) (scale unit in μm); (G) Field photo of Ussangoda where an outcrop of garnet-bearing mafic granulite is exposed; (H) The mafic granulite is exposed adjacent to a highly weathered serpentinised rock; (I) A cross-polarised microscopic image showing the equigranular matrix-type of a garnet-bearing mafic granulite (SL15-109) with clinopyroxene (Cpx), orthopyroxene (Opx), plagioclase (Pl), hornblende (Hbl) and quartz (Qz) (scale unit in μm); (J) Euhedral garnet (Grt) grain with a few inclusions of quartz (Qz) and hornblende (Hbl), in contact with clinopyroxene (Cpx), quartz (Qz) and hornblende (Hbl) in the garnet-bearing mafic granulite matrix (SL15-109) displayed in a microscopic image under cross-polarized light (scale unit in μm).

Table 1
Samples collected from the vijayan complex.

Sample	Locality	Latitude	Longitude	Rock type	Assemblage
SL15-21	Serana 48 mi. Post	N07°20′43.5″	E81°02′14.4″	Grt-bearing gneiss	Pl, Hbl, Cpx, Opx, Qz, Grt, Zrn
SL15-22	Serana 48 mi. Post	N07°20′43.5″	E81°02′14.4″	Grt-bearing gneiss	Pl, Hbl, Cpx, Opx, Qz, Grt, Zrn
SL15-23	Serana 48 mi. Post	N07°20′43.5″	E81°02′14.4″	Grt-bearing gneiss	Pl, Hbl, Cpx, Opx, Qz, Grt, Zrn
SL15-25	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-27	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-28	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-30	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Mafic enclave	Pl, Hbl, Cpx, Opx, Bt, Mag, Zrn
SL15-31	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-32	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-33	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-34	Dambadeniya Mahaora 66 mi. Post	N07°30′37.0″	E81°20′47.9″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-39	Urukamam	N07°38′28.8″	E81°29′41.1″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-40	Urukamam	N07°38′28.8″	E81°29′41.1″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-41	Urukamam	N07°38′28.8″	E81°29′41.1″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-42	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granitic gneiss)	Hbl, Pl, Kfs, Qz, Bt, Ap, Mag, Ilm, Zrn
SL15-43	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granitic gneiss)	Hbl, Pl, Kfs, Qz, Bt, Ap, Mag, Ilm, Zrn
SL15-44	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granodioritic gneiss)	Hbl, Pl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-45	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granodioritic gneiss)	Hbl, Pl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-46	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granodioritic gneiss)	Hbl, Pl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-47	Verugal	N08°14′42.3″	E81°22′23.8″	Amphibolite (Granodioritic gneiss)	Hbl, Pl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-49	Kadiraweli	N08°13′12.5″	E81°22′46.5″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-50	Kadiraweli	N08°13′12.5″	E81°22′46.5″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-51	Kadiraweli	N08°13′12.5″	E81°22′46.5″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-52	Kadiraweli	N08°13′12.5″	E81°22′46.5″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-54	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-55	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-56	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-57	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-58	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-59	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-60	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-61	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-62	Korawali, Kiran	N07°50′59.5″	E81°30′16.6″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-65	Viwekanadapura	N07°30′07.7″	E81°42′48.6″	Mafic enclave	Pl, Hbl, Cpx, Opx, Bt, Mag, Zrn
SL15-66	Hingurana	N07°14′12.3″	E81°40′02.4″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-67	Hingurana	N07°14′12.3″	E81°40′02.4″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-68	Hingurana	N07°14′12.3″	E81°40′02.4″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-69	Hingurana	N07°14′12.3″	E81°40′02.4″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-70	Hingurana	N07°14′12.3″	E81°40′02.4″	Amphibolite(Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-72	Hingurana	N07°14′12.3″	E81°40′02.4″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-73	Hingurana	N07°14′12.3″	E81°40′02.4″	Amphibolite (Granodioritic gneiss)	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-78	Damana	N07°11′44.8″	E81°39′59.7″	Charnockite	Pl, Hbl, Hy, Qz, Kfs, Bt, Ap, Ilm, Zrn
SL15-80	Karawilakotuwa, Buttala	N06°44′15.3″	E81°15′33.6″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-81	Karawilakotuwa, Buttala	N06°44′15.3″	E81°15′33.6″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-83	Karawilakotuwa, Buttala	N06°44′15.3″	E81°15′33.6″	Mafic enclave	Pl, Hbl, Cpx, Opx, Bt, Mag, Zrn
SL15-87	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-88	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Granodioritic melt	Pl, Hbl, Qz, Kfs, Bt, Ap, Mag, Ilm, Zrn
SL15-89	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Mafic enclave	Pl, Hbl, Cpx, Opx, Bt, Mag, Zrn
SL15-93	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-97	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Charnockite	Pl, Hbl, Hy, Qz, Kfs, Bt, Ap, Ilm, Zrn
SL15-98	Angaligala, Bannegamuwa	N06°19′20.9″	E81°14′20.2″	Amphibolite (Granitic gneiss)	Pl, Kfs, Qz, Hbl, Bt, Ap, Mag, Ilm, Zrn
SL15-100	Kirinda	N06°12′36.4″	E81°19′46.9″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-101	Kirinda	N06°12′36.4″	E81°19′46.9″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-103	Kirinda	N06°12′36.4″	E81°19′46.9″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn
SL15-107	Uduwila, Weerawila	N06°15′53.9″	E81°14′11.7″	Grt-bearing gneiss	Pl, Hbl, Cpx, Opx, Qz, Grt, Zrn
SL0302	Kadiraweli	N08°13′12.5″	E81°22′46.5″	Granitic melt	Pl, Kfs, Qz, Bt, Hbl, Ap, Mag, Ilm, Zrn

Ap – Apatite, Bt – Biotite, Cpx – Clinopyroxene, Grt – Garnet, Hbl – Hornblende, Ilm – Ilmenite, Kfs – K-feldspar, Mag – Magnetite, Opx – Orthopyroxene, Pl – Plagioclase, Qz – Quartz, Zrn – Zircon.

crustal metaigneous materials. The high-Nb series samples are solely metaluminous (Fig. 4D) and are enriched in HFSE.

5. SIMS zircon U-Pb geochronology

SIMS with a beam diameter of 15–20 μm was used here to analyze the U-Pb isotopic composition of the zircons from the Vijayan rocks. This allows better spatial resolution than the zircon analysis in Kröner et al. (2013), in which the beam diameter of the LA-ICP-MS is up to 30–40 μm. Furthermore, the SIMS method (both in this paper and the SHRIMP analyses of Kröner et al., 2013) measures the ^{204}Pb isotope free of interference, permitting precise and accurate common Pb correction of Pb isotope ratios. U-Pb isotope ratios were measured using a CAMECA IMS1280 ion microprobe at the NordSIMS Laboratory in the Swedish Museum of Natural History, Stockholm. Protocols described by Whitehouse et al. (1999) and Whitehouse and Kamber (2005) were followed. Instrument configuration details and full analytical data are given in the Supplementary publication. All ages in this article are presented at 2σ (or, where appropriate, 95% confidence level), with decay constant errors, and the MSWD value, which represents that of both concordance and equivalence, following Ludwig (1998). Decay constants follow Steiger and Jäger (1977). Given the ubiquitous presence of post-crystallisation, possibly recent, Pb-loss causing skewed age

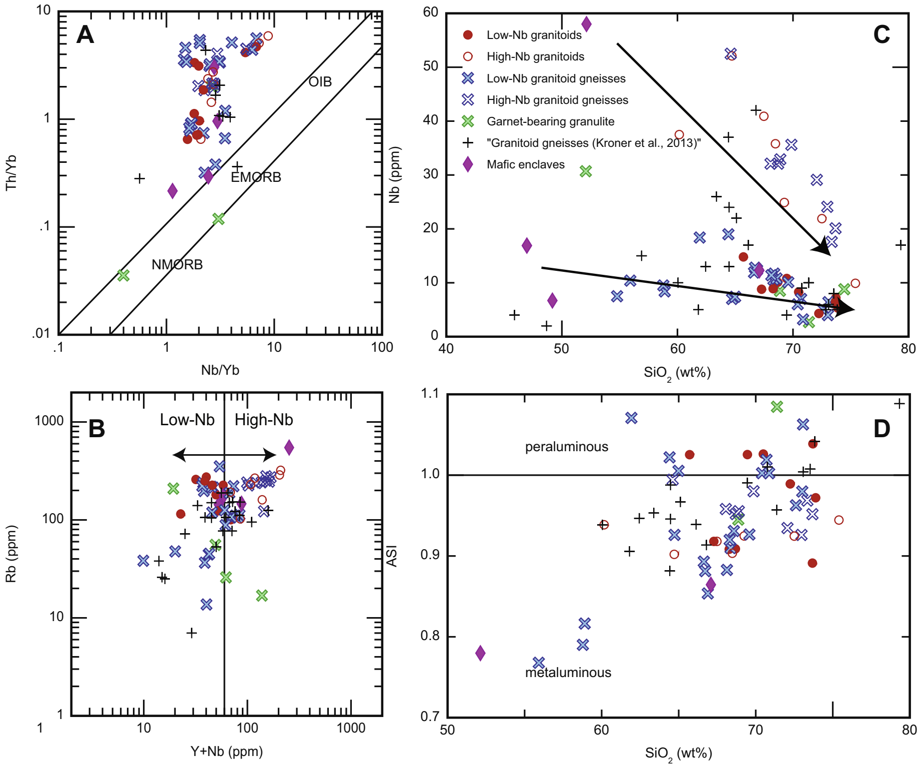

Fig. 4. Geochemical plots of the Vijayan Complex: (A) The Th/Yb vs. Nb/Yb plot (Pearce, 2008) shows that the granitic gneisses and the associated anatectic melt products were derived from the same source; (B) The Rb vs. (Y + Nb) plot (Pearce et al., 1984) shows that the anatectic melt products in the Vijayan Complex can be divided into Low-Nb series (empty circle), and high Nb-series (solid circle) at Y + Nb = 60; (C) The Nb vs SiO_2 plot shows that these two geochemical series of anatectic melt follow different fractionation trend; (D) The aluminum saturation index (ASI) vs SiO_2 plot shows that the High-Nb series is solely metaluminous, while the Low-Nb series is metaluminous to weakly peraluminous.

dispersion towards apparently younger ages, as well as the presence in some zircons of clear inherited cores, a consistent filtering approach was used to extract the probable magmatic crystallisation age and metamorphic age. This involved first excluding any obvious older cores, then rejecting the youngest analyses ($^{238}U/^{206}Pb$ age) interpreted based on CL images, which most likely reflect Pb-loss. This procedure is repeated until the remaining group of ages yielded a concordia age, *sensu* Ludwig (1998).

Two populations of zircon grains have been identified in the Vijayan samples as shown in the scanning electron microscope images (Fig. 5). The extracted magmatic zircons are 50–300 μm euhedral prisms with an aspect ratio ranging from 2:1 to 4:1. Cathodoluminescence imaging reveals oscillatory zoning and typically CL-dark to CL-medium magmatic cores, surrounded by CL-light metamorphic rims. Some cores are xenocrystic, which provides an inherited signal. The U concentration of the magmatic cores is between 20 and 1150 ppm, while the Th/U ratio lies in the range from 0.08 to 1.02. The metamorphic zircons extracted are usually more equant, with an aspect ratio of 1:1–1.5:1 and are smaller, with sizes ranging from 50 to 100 μm. In CL, some of them have homogeneous internal textures, but others have irregular concentric zoning towards the core. The metamorphic growth

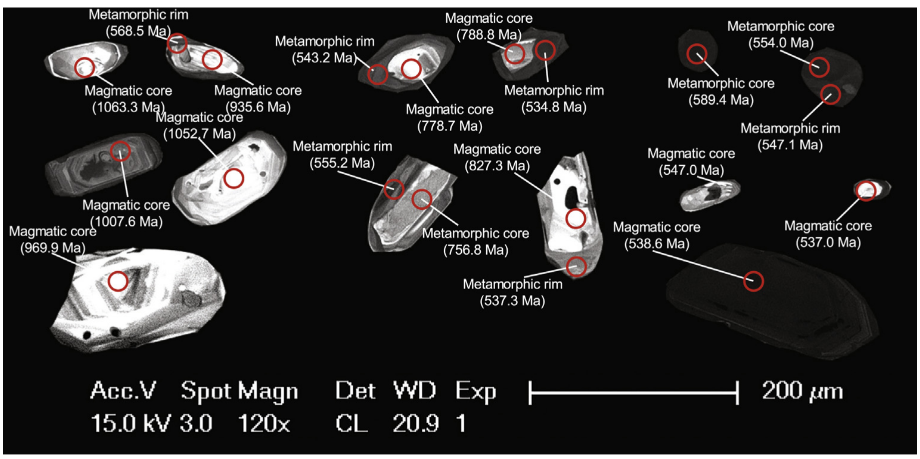

Fig. 5. Scanning electron microscope (SEM) images of representative zircon grains extracted from the Vijayan Complex.

of the zircon usually has U concentration ranging between 15 and 4900 ppm, while the Th/U ratios range between 0 and 0.5. The average Th/U ratio of the metamorphic zircons is 0.06, which is significantly less than that of the magmatic zircon (average Th/U ratio = 0.40).

Tera-Wasserburg diagrams of individual samples are shown in the Supplementary publication. Composite U-Pb Terra-Wasserburg diagrams combining the individual Tera-Wasserburg diagrams (Figs. S1 and S2) of the proper Vijayan Complex samples and those diagrams (Figs. S3 and S4) of the Highland-Vijayan boundary samples are shown in Fig. 6. Most of the Vijayan rocks, both basement gneisses and melt products, have an age signal at ~1062–935 Ma, predominantly from magmatic zircon, and some of the metamorphic rims. This reflects the formation time of the Vijayan Complex. The whole Complex was then metamorphosed at ~580–521 Ma as indicated by the metamorphic zircons and the metamorphic rims on magmatic grains (Fig. 7A). These two age signals agree with those reported by previous workers (Kröner et al., 1987, 2013; Hölzl et al., 1991, 1994; Willbold et al., 2001; He et al., 2016). Considerable numbers of magmatic zircons dated to ~580–550 Ma was also extracted, suggesting crustal anatexis also occurred during the metamorphism. The exceptions came from the Highland-Vijayan tectonic mixed zone (SL15-87, SL15-89, SL15-93, and SL15-107) in southern Sri Lanka, and at the boundary between the Highland Complex and the Vijayan Complex in central Sri Lanka (SL15-23 and SL0302). At least one additional magmatic zircon core age population has been

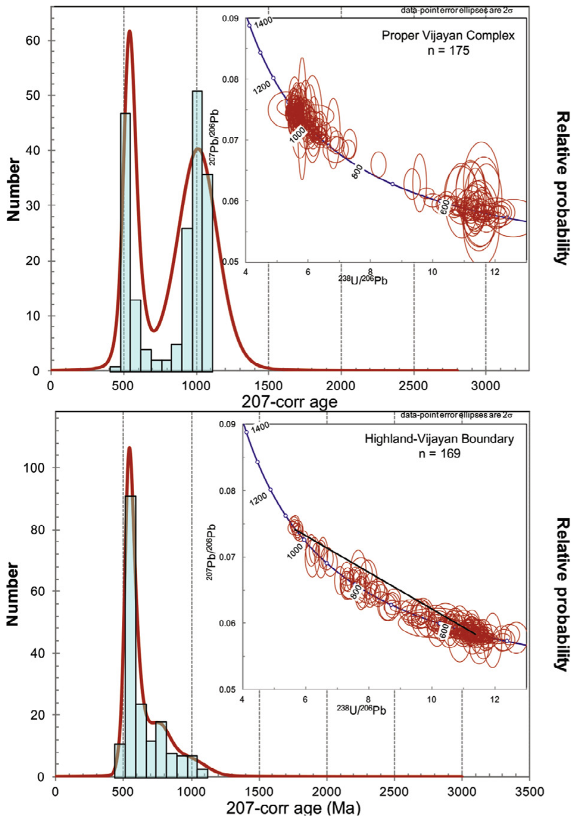

Fig. 6. Combined histograms and Tera-Wasserburg diagrams of the samples collected from the proper Vijayan Complex (SL15-27, 28, 30, 54, 56, 66, 67, 78, 80, and 83) and those collected from the tectonic mixed zone along the Highland-Vijayan boundary (SL15-23, 43, 87, 89, 93, 97, 101, 107 and SL0302), showing the age distribution, showing the Tonian-Cryogenian signals are truly concordant, and do lie on the solid line indicating the discordant array from 1050 Ma to 550 Ma.

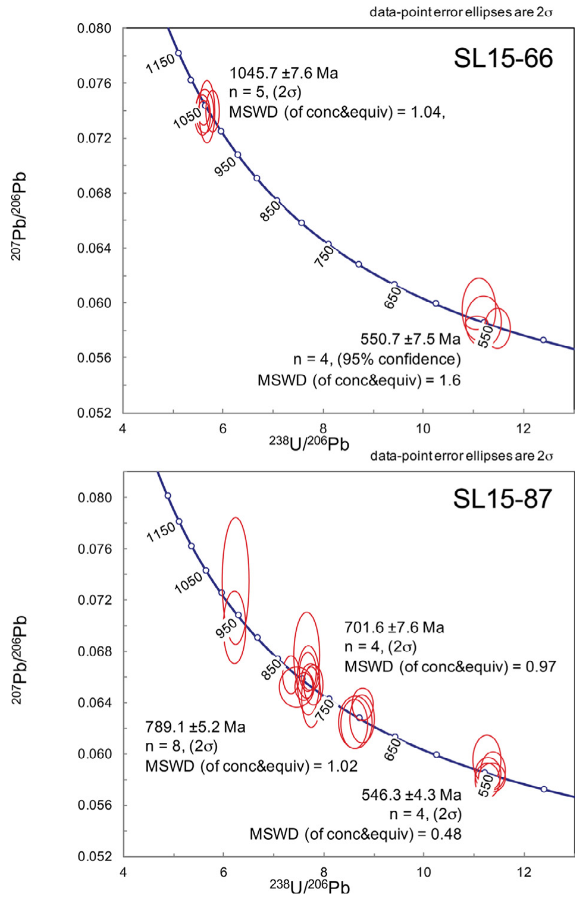

Fig. 7. Representative Tera-Wasserburg diagram yielded from samples collected from the proper Vijayan Complex (SL15-66) and in the Highland-Vijayan tectonic mixed zone (SL15-87) respectively.

recorded between the ~1062–935 Ma protolith age and the ~580–521 Ma metamorphic age. Magmatism is recorded in the zircons extracted from the Highland-Vijayan tectonic mixed zone (SL15-87 and SL15-93) at Tonian time (~820–750 Ma) (Fig. 7B). A slightly younger and less prominent Cryogenian signal (~700–640 Ma) was also recorded in some of our Vijayan rocks collected near the terrane boundary (SL15-23, SL15-89, SL15-107, and SL0302). From the data collected in this work, with over 400 zircon grains dated (Supplementary publication), our composite data shows that protolith magmatism in the proper Vijayan Complex could be continuous until 850 Ma. However, there is a relatively quiet period during ~900–840 Ma at the Highland-Vijayan tectonic mixed zone, which renders the Tonian-Cryogenian event distinct from the early Neoproterozoic age population, with magmatism indicated by age population peaks recorded at ~820–750 Ma and ~700–640 Ma (Fig. 6).

6. Discussion

6.1. Geochronological significance in the Sri Lankan tectonic framework

All the previous geochronological works and the SIMS U-Pb zircon ages presented in this paper are summarised in Fig. 8. The geochemical data and U-Pb zircon ages of the Vijayan Complex indicates that the protoliths of the metamorphic basement probably represent a magmatic arc forming at ~1062–935 Ma. The whole Complex was then metamorphosed to amphibolite to granulite facies during the overthrust of the Highland Complex in the Ediacaran (~580–521 Ma). Tonian-Cryogenian magmatic events (~820–750 and ~700–640 Ma) were widely recorded in samples collected from the Highland-Vijayan tectonic mixed zone as shown by the composite U-Pb zircon ages (Fig. 5). Kröner et al. (2013) suggested that there is no meaningful age data between the ~1100–1000 Ma protolith magmatic ages and the ~580–550 metamorphic ages because the 1100–550 Ma discordant array observed from the LA-ICP-MS data is sub-parallel to the concordia curve. However, these LA-ICP-MS zircon U-Pb data were presented at the 1σ uncertainty level, further obscuring possible discrete age signals. In this study, we present SIMS zircon U-Pb data with higher precision and accuracy. The Tonian-Cryogenian 2σ uncertainty ellipses in the Tera-Wasserburg diagrams (Figs. 6, 7 and in the Supplementary publication Figs. S1 and S2) on the concordia curve are distinct from the aforementioned 1050–550 Ma discordant array. It can be argued that the composite data presented in Fig. 6 may still represent composite Pb-loss, especially in the ^{204}Pb-direction in the Tera-Wasserburg diagrams. However, it is worth noting that the data clustered as coherent age groups in individual samples. For

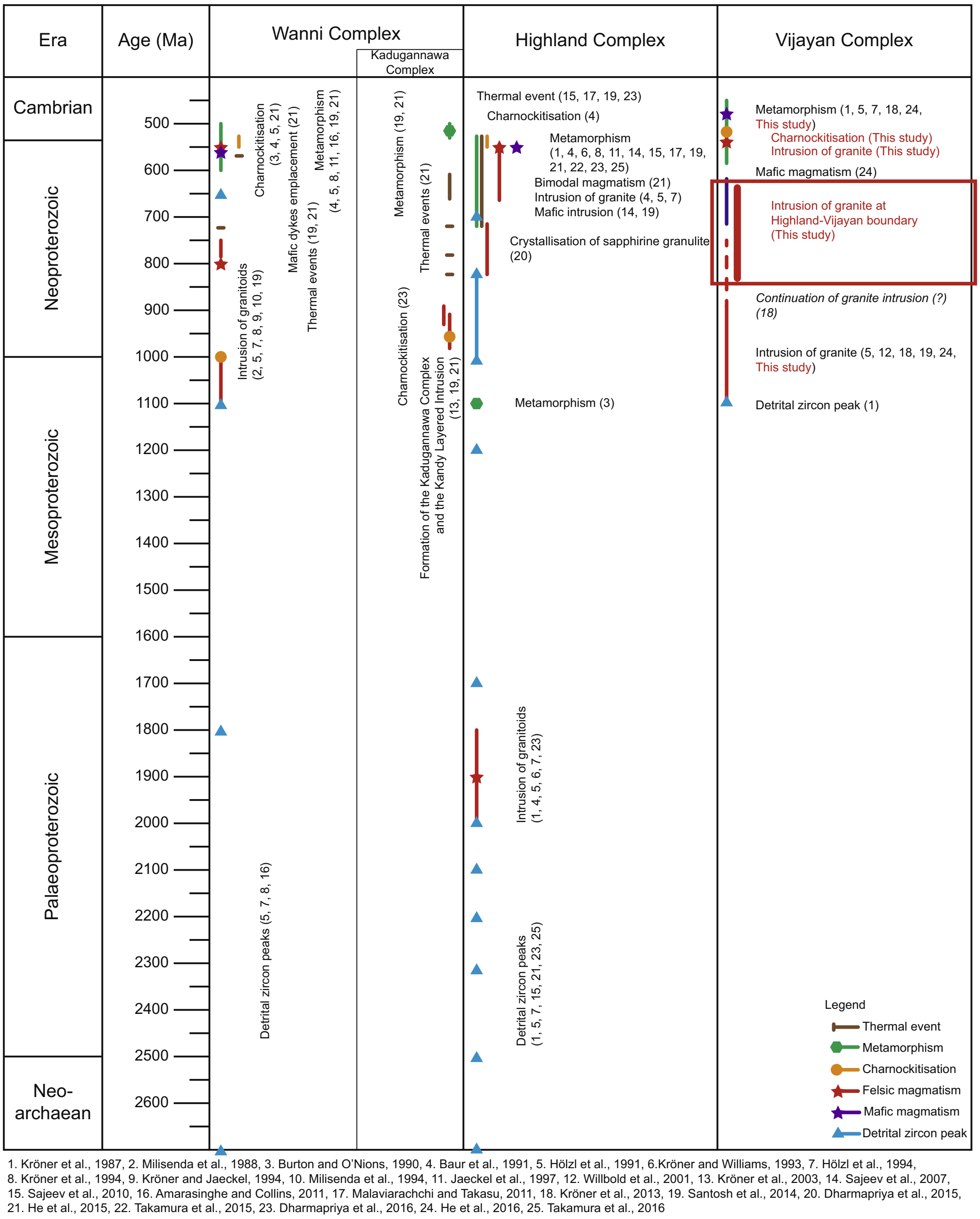

Fig. 8. Summary of geochronological works conducted in Sri Lanka.

instance, in SL15-87, the Tonian-Cryogenian signals were given by data clustered at 789 ± 5 and 702 ± 8 Ma (Fig. 7). No resolvable Pb-loss array is observed in individual samples. Comparison of our composite data with the LA-ICP-MS U-Pb data of Kröner et al. (2013) is shown in Fig. 9. Even though the LA-ICP-MS U-Pb data presented by Kröner et al. (2013) might be interpreted as a discordant array, with sufficient precision, a Tonian-Cryogenian concordant age population can be resolved. Hence, this age population represents a particular magmatic event, spatially constrained at the Highland-Vijayan boundary. The ~1100–1000 Ma zircon age peak also becomes less prominent in the Highland-Vijayan tectonic mixed zone (Fig. 6), suggesting the magmatic centre might have shifted to the tectonic boundary since Tonian time. Such Tonian-Cryogenian granitic magmatism is also supported by the coeval mafic enclaves collected from some of the granitic melt products, which indicate a significant heating from mafic intrusions dated at 617 ± 27 Ma (mafic granulite) and 772 ± 6 Ma (clinopyroxenite) by He et al. (2016). In the meantime, these enclaves may well represent fragments of the basement brought up by the melt. In fact, this Tonian-Cryogenian event has been observed in the Wanni Complex in Sri Lanka (Dharmapriya et al., 2015) and in the Highland Complex (Milisenda et al., 1988, 1994; Kröner and Jaeckel, 1994; Santosh et al., 2014). The collision between the Wanni Complex and the Highland Complex was broadly coeval with, or shortly before the Highland-Vijayan collision (He et al., 2016).

6.2. Geochronological significance in the Gondwana tectonic framework

The identification of Tonian-Cryogenian (~820–640 Ma) granitic magmatism in the Highland-Vijayan mixed zone is also significant to the understanding of Gondwana assembly. The origin of the Vijayan Complex remains unclear, but from the tight-fit reconstruction of Lawver et al. (1998), the Vijayan Complex was sandwiched by the Lurio foreland in Mozambique on the present west, and the Dronning Maud Land in East Antarctica on the present east (Fig. 10). The correlation of the Vijayan granitic gneisses with these terranes is supported by the ~1100–1000 Ma magmatic ages, and ~580–550 Ma metamorphic ages yielded from the granitoids (Sacchi et al., 1984, 2000; Costa et al., 1992; Moyes et al., 1993; Grantham et al., 1995; Jacobs et al., 1996, 1998, 2003a,b, 2015; Kröner et al., 1997; Collins and Windley, 2002; Bauer et al., 2003; Paulsson and Austrheim, 2003; Ravikant et al., 2004; Collins and Pisarevsky, 2005; Grantham et al., 2011). The Tonian-Cryogenian age signal (~820–640 Ma) presented in this paper was also observed in the granites and syenites in the Namuno Terrane (Unango and Marrupa Complexes), at the north-western side of the Lurio Belt (Bingen et al., 2009). If the Vijayan Complex is correlated to the foreland granitic basement on the south-eastern side of the Lurio Belt (Collins and Windley, 2002; Collins and Pisarevsky, 2005), the Namuno Terrane and the Lurio Belt in Mozambique could be directly correlated to the Highland-Vijayan tectonic mixed zone on the western side of the Vijayan Complex. In the meantime, the Namuno Terrane has been correlated to the Sør Rondane Mountain in the eastern Dronning Maud Land of East Antarctica, and is supported by the presence of Tonian-Cryogenian metacarbonates in both terranes (Grantham et al., 2013; Otsuji et al., 2013). Such metacarbonates are intimately associated with the gabbro-trondhjemite-tonalite-granodiorite (GTTG) intrusions in the Sør Rondane Mountain (Jacobs et al., 2015). However, no Tonian-Cryogenian signal has been found in these intrusions, just as in the proper Vijayan Complex. More recently, ca. 850 Ma arc magmatism was identified at the Akarui Point in the Lützow-Holm Complex of East Antarctica, which could be correlated to the "Kadugannawa magmatism" in Sri Lanka (~1006–881 Ma) (Kazami et al., 2016). Yet the magmatic event recorded at the

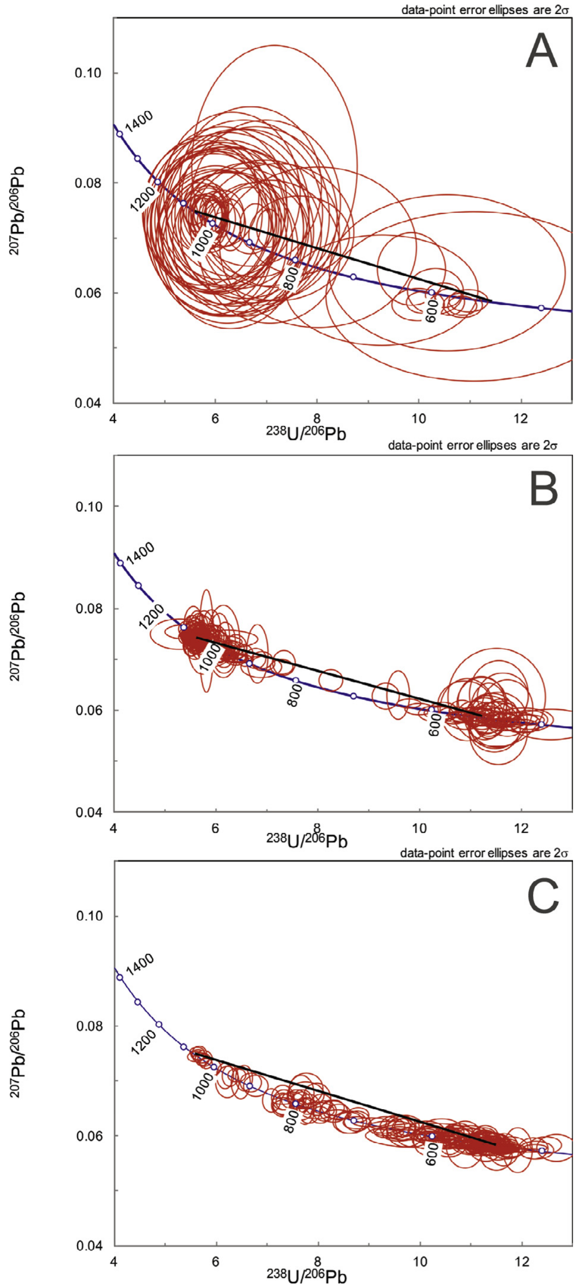

Fig. 9. (A) Tera-Wasserburg concordia diagram showing all LA-ICP-MS analytical data reported by Kröner et al. (2013). Age data were interpreted as lying on a discordant array from 1050 Ma to 550 Ma (black line), but are insufficiently precise to distinguish between this and possible true concordance; (B) Combined Tera-Wasserburg diagrams of the samples collected from the proper Vijayan Complex (SL15-27, 28, 30, 54, 56, 66, 67, 78, 80, and 83), and (C) those collected from the tectonic mixed zone along the Highland-Vijayan boundary (SL15-23, 43, 87, 89, 93, 97, 101, 107 and SL0302), showing the age distribution, showing the Tonian-Cryogenian signals are truly concordant, and do lie on the solid line indicating the discordant array from 1050 Ma to 550 Ma.

Akarui Point is slightly younger and more comparable to the Tonian-Cryogenian event recorded at the Highland-Vijayan tectonic mixed zone. These age data show that the Vijayan Complex in Sri Lanka has a fundamental relationship with the Lurio foreland basement in Mozambique, and might also have a genetic relationship with various magmatic intrusions in East Antarctica.

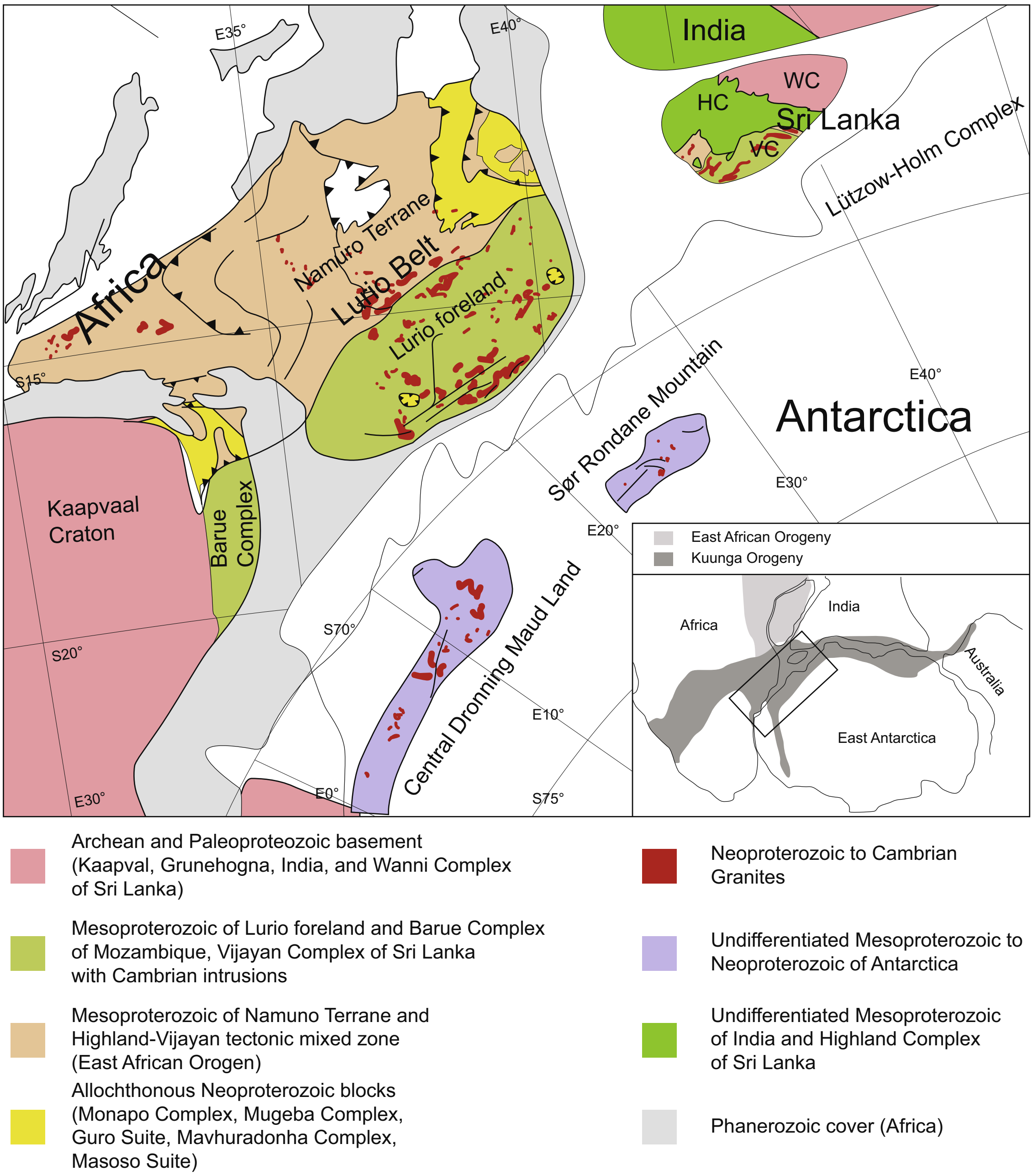

Fig. 10. Gondwana reconstruction after Lawver et al. (1998), and map after Grantham et al. (2013) showing the proximity of the Vijayan Complex (VC) and the Lurio foreland. The Namuno Terrane and the Lurio Belt is correlated with the tectonic mixed zone, which separates the Vijayan Complex (VC) and Highland Complex (HC) of Sri Lanka. The correlation between the Highland Complex (HC) and the Wanni Complex (WC) with the southern Indian terranes is supported by the works of Sajeev et al. (2007, 2010), Malaviarachchi and Takasu (2011), Santosh et al. (2014), He et al. (2015), Dharmapriya et al. (2015), and Takamura et al. (2015).

The linkage between Sri Lankan basement and the southern Indian basement have been discussed in Teale et al. (2011), Santosh et al. (2012), and Yellappa et al. (2016). These works suggest that Manamedu ophiolite in the Madurai Block of southern India was formed at ~820–730 Ma at suprasubduction setting during the closure of the Neoproterozoic Mozambique Ocean. Coeval arc-related granites (~820–766 Ma) were emplaced in the Madurai Block, which were interpreted as the products of an extensive arc extending from central Madagasacar, through southern India to the Wanni Complex of Sri Lanka. This arc is coeval, but probably not related to the Tonian-Cryogenian magmatism recorded in the Highland-Vijayan tectonic mixed zone, as it does not fit into the tectonic reconstruction made by Lawver et al. (1998).

6.3. Geochemical evolution of Vijayan granitic gneisses and granitic melt products

The SIMS U-Pb zircon magmatic ages yielded from the Vijayan Complex suggested that the prolonged subduction and volcanic-arc magmatism occurred in the Complex in four episodes,

~1062–935, ~820–750, ~700–640, and ~580–521 Ma. The geochemical data suggested that the Vijayan granitic gneisses and the associated melt products can be broadly divided into high-Nb series, and low-Nb series. Both contribute to positive ε_{Nd} values, indicating only primitive magmatic sources involved. The ultramafic intrusion (He et al., 2016) associated with the magmatic centre of the Vijayan Complex moved towards the Highland-Vijayan tectonic mixed zone at the later stage of subduction (~772–617 Ma) before the amalgamation of Sri Lanka. All these observations indicate that mantle wedge flux was considerably involved. This can be accounted by terrane extension under prolonged subduction. The Vijayan Complex comprises juvenile granitic gneisses and granitic melt products. The Mocuba Complex representing the basement of the Lurio foreland, were also sourced by juvenile crust, with average initial $^{87}Sr/^{86}Sr$ ratio at 0.7066 (Costa et al., 1992; Kröner et al., 1997; Sacchi et al., 2000). In addition, in the case of the Sør Rondane Mountain, the GTTG was also sourced by juvenile protoliths with ε_{Nd} values ranging from +2 to +4 (Jacobs et al., 2015). Mantle flux was involved in these igneous intrusions, which supported the interpretation of a similar magmatic environment in their formation.

7. Conclusion

- The Vijayan Complex comprises ~1062–935 Ma granitic gneisses, which were metamorphosed during ~580–521 Ma. A Tonian-Cryogenian age signal of ~820–640 Ma is prominent and restricted in the Vijayan rocks to the Highland-Vijayan tectonic mixed zone along the tectonic boundary.
- The Vijayan granitic gneisses and the associated melt products can be divided into a high-Nb series and a low-Nb series suggesting significant mantle input in the parental melt. There is no geochronological pattern to their formation.
- The U-Pb zircon geochronology and the geochemistry of the granitic gneisses and granitic intrusions allow correlation of the Vijayan Complex in Sri Lanka with the Lurio foreland granitic basement in Mozambique, these terranes might be genetically related to various magmatic intrusions in East Antarctica.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.precamres.2017.03.013.

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