THE UNIVERSITY OF ADELAIDE, AUSTRALIA

A geochronological U-Pb zircon La-ICPMS age and provenance study of Wanni, Highland and Vijayan Complexes of Sri Lanka and Proterozoic Pranhita Godavari Purana basin of India unveils origin of Sri Lanka.

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Submitted- 30th January 2017

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Chapter 3 –Leucosomes of Migmatitic Gneisses of Wanni Complex of Sri Lanka Indicate Metasedimentary Origin and Correlation with Southern Madurai Block of India and Molo Group of Madagascar whilst Paleosomes show metaigneous origin: LA-ICPMS U-Pb Zircon Geochronology

Abstract

The island of Sri Lanka is the focus of Neoproterozoic super continent Gondwana. But the geological origin and paleotectonic position of Sri Lanka are least understood without knowing age and provenance of the four main crustal units, the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC) and the Kadugannawa Complex (KC). The study of age and provenance of metaquartzites of the WC and HC, leucosomes and paleosomes of migmatites of the WC, and charnockites of the HC and VC of Sri Lanka and sedimentary rocks of neighboring Proterozoic rift basins like Pranhita-Godavari basin of central India is significant in research on origin of Sri Lanka and also continental evolution to unravel the paleotectonic position of Sri Lanka before Gondwana being amalgamated in the Neoproterozoic. This study examined age of detrital zircon cores and metamorphic rims of metaquartzite, migmatite and charnockite samples along two west to east transects across the island of Sri Lanka as well as sedimentary rock samples from the Pranhita-Godavari rift basin of India using the LA-ICPMS method.

The U-Pb zircon isotopic data from metaquartzites of WC (near WC-HC boundary) and HC demonstrate dominant Mesoarchaean to Paleoproterozoic (2.0-2.8 Ga) detrital input into the metasedimentary make up and near boundary WC and HC metaquartzites were deposited between 2000 Ma and ~550 Ma with a maximum age of deposition ~ 2000 Ma, however a sample from the western WC was deposited in early Neoproterozpoic and mixed with Paleoproterozoic to Neoarchaean detritus indicating WC and HC terranes existed adjacent to each other since early Neoproterozoic and current WC-HC boundary is inaccurate and to be shifted westwards.

This study reveals that parent materials of leucosomes of WC migmatitic gneisses are metasedimentary and showing late Mesoproterozoic to Neoproterozoic provenance (0.70-1.15 Ga) with maximum age of deposition at ~700 Ma. But paleosomes of WC migmatites show metaigneous origin with older Mesoarchaean ages (2.85-3.0 Ga) and have been identified in this study as the Mesoarchaean reworked continental basement material of WC. The HC charnockites clearly show metaigneous origin and primary intrusion ages of ~1.82 to 1.85 Ga. whilst a sample from the VC shows metasedimentary origin. A weighted mean of all rim data of WC and HC yields an age of 545.1 ± 9.7 Ma, supporting the age of

Ediacaran-Cambrian metamorphism. Metaquartzite rocks of the HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metaquartzites of the western WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar and Sri Lankan metaquartzites were most probably sourced from east African igneous protolith sources. These differences in sedimentary provenance and maximum age of deposition prove and confirm that WC was a different crustal domain from the HC terrane.

All this strongly supports a double subduction and collisional geological origin for the island of Sri Lanka with 'HC orogeny' occurred when the Southern Madurai Block of India (SMB)-WC and VC Mesoarchaean continental blocks collided with the HC orogenic belt and the oceanic crust of deeper basin of HC had subducted underneath the SMB-WC and VC continental blocks when ancient south Mozambique ocean closed along WC-HC boundary and HC-VC boundary sutures. This study reveals that Sri Lanka's paleotectonic position could be south east of south India connecting Trivandrum Block to the HC and WC to the Southern Madurai Block. The study also reveals that the Pranhita-Godavari Basin was sourced from Eastern Ghats and Antarctica unlike Sri Lankan terranes were sourced from East Africa indicating Southern Granulite Terrane of India and Sri Lanka were not parts of mainland cratonic India until Ediacaran-Cambrian times.

Acknowledgements

I am very pleased to thank and pay my deepest gratitude to my PhD supervisor, Professor Alan.S Collins for excellent guidance and advice throughout my PhD research project with constant encouragements. I also thank Professor Martin Hand for guidance and serving as the co-supervisor of my research project.

I also wish to thank the Government of Australia for awarding me a Full PhD scholarship and the University of Adelaide for the providing me adequate laboratory facilities for sample preparation and U-Pb zircon dating. I pay my deep gratitude to the University of Peradeniya, Sri Lanka and the Government of Sri Lanka for granting me overseas PhD study leave to read for the Doctor of Philosophy degree at the University of Adelaide. Professor John Foden is also thanked for encouragements. Dr. Benjamin Wade of Adelaide Microscopy is especially thanked for assistance during LA-ICPMS analysis. My PhD colleagues, Diana Plavsa, Jade Anderson, Ben McGee, Frank Robinson, Thomas Raimondo of the Department of Geology are also thanked for their encouragements. My teacher, Professor Kapila Dahanayake is paid my gratitude for encouraging me to achieve this PhD degree. Mr.Prassana. Dharmapriya is thanked for improving figures in Corel draw and Mr. Moditha Kodikaraarachchi of the Department of Geology, University of Peradeniya is thanked for his assistance in petrographic photography. Dasith Bandara Wewegama, a second year undergraduate in Medicine, the University of Adelaide is thanked for all the encouragements and helps. Mr. Thusitha Wimalasiri is thanked for assistance in computer formatting work. Finally, I wish to dedicate my PhD thesis to my beloved Appachchi (Dad, Wewegama Rajapakse Mudiyanselage Udagedera Amarasinghe), Ammi (Mum, Rajapakse Wasala Mudiyanselage Kumburegedera Anula Yasomenike Amarasinghe), my two sons (Dasith Bandara Wewegama and Hirusha Bandara Wewegama).

Thesis Declaration

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Chapter 1

1.1 Introduction

The Island of Sri Lanka is located in a very interesting and important position in the process of amalgamating Neoproterozoic supercontinent Gondwana. Sri Lanka forms a small but important jigsaw piece of the supercontinent, Gondwana, and has been the focus of intense research in the late 1980's and early 1990's (Mathavan et al., 1999). According to present geographic coordinates, Sri Lanka is near to the Southern Granulite Terrane of South India but the island is understood to be a crustal block which was also connected to other neighbouring/adjacent land blocks such as Madagascar, East Africa and Antarctica when the supercontinent Gondwana was assembled during Ediacaran to Cambrian along numerous orogenic belts. The Ediacaran (~635-541 Ma; Gradstein et al., 2012) to Cambrian assembly of Gondwana took place by the collision and amalgamation of numerous continental blocks along a number of disparate orogenic belts (see Collins and Pisarevsky et al., 2005). But Sri Lanka's geological origin and exact paleotectonic position or how the island crustal block was connected to her neighbouring land masses are not yet confidently understood and still remains as a knowledge gap. Although the geological origin and continental evolution of the island of Sri Lanka most probably had taken place during the assembly of the Gondwana supercontinent in the Ediacaran-Cambrian, there exists still a basic difficulty to understand the geological origin of the island of Sri Lanka due to lack of clear understanding on age, provenance, maximum age of deposition and geological origin of island's four main crustal units, the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC) and Kadugannawa Complex (KC) and also on how the central mountains of Sri Lanka was originated as an uplifted land of about 3000 m above mean sea level. This lack of complete understanding on the geological origin of four different crustal units is mainly caused by not yet carrying out sedimentary provenance studies on detrital mineral grains of metasedimentary rocks belonging to four different crustal units of Sri Lanka to trace locations of protolith sources and also no adequate attempts have been made to understand the geological origin of predominant rock types such as metaquartzites of the Highland Complex (HC) and Wanni Complex (WC), leucosomes and paleosomes of migmatites of the Wanni Complex (WC) and charnockites of the Highland Complex (HC) and the Vijayan Complex (VC). As an example, the U-Pb LA-ICPMS zircon concordia plots drawn for cores of zircons and also probability density plots can most probably indicate either metaigneous or metasedimentary geological origin for a given rock. A metaigneous rock characteristically produces a concordia plot in which age points of zircon cores are concentrated or clustered at one point on the concordia curve whilst a metasedimentary rock characteristically produces a concordia plot in which detrital points of zircon cores occur in a wide range along the concordia curve. This is here applied as a 'geochronological' method to discriminate between igneous and sedimentary protoliths of high grade metamorphic rocks. The ages of detrital zircons in the metasedimentary rocks of WC, HC and VC could be used to constrain the possible provenance that supplied the detritus. The most appropriate way of addressing this research problem is by tracing the origins of protolith sources or provenance of highgrade metasedimentary rocks belonging to different crustal units of Sri Lanka as well as those of other neighbouring contemporary / coeval sedimentary rift basins such as Pranhita-Godavari rift basin of central southeast India and attempting to correlate whether other neighbouring Gondwana crustal blocks such as Trivandrum Block, Southern Madurai Block and Northern Madurai Block of Southern Granulite Terrane of India, Madagascar and East Africa have similar age and provenance to that of the different geologic/tectonic terranes of Sri Lanka and contemporary sedimentary basins such as Pranhita-Godavari rift basin of India. The Pranhita-Godavari rift basin of India preserved unmetamorphosed rocks and studying such rocks would be an advantage in tracing origins of protolith sources in the region. On the other hand the tiny island landmass of Sri Lanka is geologically unique with respect to its four major disparate crustal units and understanding geology of Sri Lanka is considered basically significant in proceeding towards tracing the geological origin and tectonic evolution of the island of Sri Lanka.

1.1.1 Geological setting of Sri Lanka

About ninety percent of the island of Sri Lanka is understood to be underlain by Mesoarchaean to Neoproterozoic highgrade basement rocks and the rest is mainly of Miocene limestone and scattered Jurassic, Quarternary and recent deposits (Fig.2.1). The high-grade metamorphic basement of Sri Lanka consists mainly of Mesoarchaean to Neoproterozoic orthogneiss and paragneiss rocks and four major crustal units named as the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC), and Kadugannawa Complex (KC) (Fig.2.1) defined traditionally based on rock type, metamorphic grade (Kröner et al., 1991), and Nd model ages (Milisenda et al., 1988; 1994; Sajeev et al., 2010). The basement was metamorphosed to upper amphibolite and or granulite grade in the Neoproterozoic, each complex having a discrete metamorphic history (Sajeev et al., 2010).

Many workers still consider that the oldest rocks are in the Highland complex (Sajeev and Osanai, 2004; and Sajeev et al., 2010) which lies in the centre of the island consisting of granulite grade major supracrustal meta-sedimentary rocks, charnockites and concordant to discordant metaigneous rocks. The major meta-sedimentary rocks are garnet sillimanite gneisses, marbles, calc silicates, garnetiferous granulites, and metaquartzites. Kröner et al. (1991) suggested that more than 50% of the HC rocks are of granitoid origin. The age of the HC was interpreted as 3.2 to 2.0 Ga based on Nd model ages (Milisenda et al., 1988; Kröner and Williams, 1993). Igneous intrusions within the HC were reported to have taken place around 1850-1990 Ma (Kröner and Williams, 1993; Schumacher et al., 1990). The high-grade metamorphism had taken place as a part of the Ediacaran-Cambrian metamorphism and orogeny at ~ca. 550Ma (Kröner et al., 1991) and the rocks were subjected to peak metamorphic PT conditions of 900°C and 9 K bars. The regional metamorphism was followed by slow cooling and uplifting of the HC into higher crustal levels (Kröner et al., 1991; Jayawardane and Carswell, 1976; Kröner and Williams, 1993; Faulhaber and Raith, 1991). The boundary between the HC and the VC is well defined as a tectonic boundary marked by thrust and shear zones, mafic to ultramafic intrusions, and a belt of hot water springs. But the boundary between the Wanni Complex (WC) and the Highland Complex (HC) is not yet clearly identified without precise geochronological data.

The Mesoproterozoic to Neoproterozoic (Milisenda et al., 1988, 1994, Sajeev et al., 2010) Vijayan Complex (VC) lies to the east of the central HC (Fig.2.1) and consists mainly of granitic gneisses, migmatites, hornblende gneisses, and isolated bands of metaquartzite and calc gneiss (Dahanayake and Jayasena, 1983). The VC represents upper amphibolite grade metamorphic rocks. Among the other prominent geological formations of the VC are the occurrence of granitic intrusions and acidic charnockites close to the eastern coast (Milisenda et al., 1991) and the NW trending suite of dolerite dykes in the VC. It was described that the gneissose granitoids of the Vijayan Complex as having compositions ranging from tonalite to leucogranite (Milisenda, et al., 1988; Corfu et al., 2003).

The Mesoproterozoic to Neoproterozoic (Milisenda et al., 1988, 1994, Sajeev et al., 2010) Wanni Complex lies in the west of the HC. The WC consists mainly of granitic gneisses, migmatitic gneisses, granitic intrusions, cordierite gneisses, and minor abundance of supracrustal metaquartzites, and metapelites. But the predominant rock type in the WC is migmatitic gneiss or migmatite. These migmatitic gneisses and cordierite-bearing migmatitic gneisses could be either partially melted metasedimentary paragneisses or igneous orthogneisses or mixtures of those two types but sufficient research studies have not yet been conducted in the past to understand the origin of WC migmatitic gneisses. The migmatitic gneisses mainly consist of probably older paleosome parts and younger leucosome parts but there is still no any knowledge about the ages of these two portions and also about the parent materials of these two parts. In the WC of Sri Lanka, metasedimentary metaquartzites are subordinately abundant compared to greater abundance of metaquartzites in the HC. WC metaquartzites are found to occur generally close to the current tentative WC-HC boundary but there are isolated metaquartzite bands occurring in the western WC terrane. It is significant and yet to understand whether WC and HC metaquartzites have similar sedimentary provenance or not. The current geological boundary between the WC and the HC is still tentative and the exact boundary is to be re-established based on further geological field work and geochronological studies. There are diverse views on the recognition of WC as a separate crustal domain different from the HC. There have been several workers attempted to describe the supracrusral rocks of WC and HC of Sri Lanka. Kehelpannala (1991) reported that most of the metasediments of the WC occur close to the assumed boundary with the HC. Voll and Kleinschrodt et al. (1991) also rejected the establishment of WC as it is not clearly confined, no precise definitions for its delineation can be given and proposed that common history is represented by HC and WC rocks with HC represents a deeper crustal level than the WC. Willbold et al. (2004) also stated that though the Nd model ages and zircon age spectra suggest different origins for the WC and the HC, this division is difficult to substantiate with lithological and petrological data. There is also no any research work carried out to understand the nature and age of possible basement rock materials of the WC, HC and VC terranes of Sri Lanka.

1.1.2 Previous geochronological studies in Sri Lanka

Although the dating of basement rocks of Sri Lanka is reported for a long period of time, sedimentary provenance studies have never been carried out in the past to trace protolith sources of sedimentary detritus. But the dating history of the Sri Lankan basement rocks goes back to beginnings of the twentieth century when Boltwood (1907) published work on thorianite containing rocks from Galle in the Highland Complex and reported ages ~2.2 and 0.9 Ga. In 1950s and 1960s geochronological dating methods in Sri Lanka were based on U-Pb and K-Ar methods on minerals of pegmatite intrusions. These results were described by Holmes (1955), Vitanage (1959) and Cooray (1969).

Although those dating work yielded relatively young ages for the Sri Lankan basement rocks many geologists speculated that Sri Lankan rocks were to be as old as Paleoproterozoic to Mesoproterozoic when comparing ages of Indian rocks such as rocks of Eastern Ghats. This comparison was based on the lithologic and geological similarity of Sri Lankan rocks with those of the Indian subcontinent (Holzl et al., 1994). First Precambrian ages were reported by Crawford and Oliver, (1969) on highgrade gneisses using Rb-Sr and K-Ar methods on whole rock and mineral samples. The whole rock results showed that HC supracrustal rocks were of Archaean age and highgrade metamorphism had taken place ~ 2.0 Ga. The results of rocks of WC and VC (then western Vijayan series and eastern Vijayan Series) suggested that granite intrusion and retrogressive amphibolite facies metamorphism occurred throughout the entire region ~ 1.1 Ga ago. They also reported mineral ages between 650 and 450 Ma, and interpreted them as indicating a separate and widespread thermal event. Wickramasinghe (1969) had also suggested ~2.0 Ga highgrade metamorphism from Rb-Sr whole rock data for widely displaced HC and Kataragama Klippe samples. It seems that above interpretations were confirmed by further whole-rock Rb-Sr data of Cordani and Cooray (1989) and they described a “Vijayan orogeny” 1100-1000 Ma ago, and by a Rb-Sr whole rock isochron of 1930Ma which De Maesschalck et al. (1990) interpreted as the age of high-grade metamorphism in the Highland Complex. Later Holzl et al . (1994) suggested that in the light of extensive new U-Pb data on zircons and other minerals, this interpretation of whole rock isotope data is no longer tenable. Instead, the new data show that the ~2.0 Ga events dated by the Rb-Sr whole rock data represent the approximate age of either primary magmatic intrusion or maximum age of sedimentation, where as the main granulite facies metamorphic event occurred much later, generally between ~600 and 550 Ma ago.

Detrital grains from the Highland Complex metasediments were analysed by Kröner et al. (1987) and reported late Archaean to Paleoproterozoic near concordant ages (3.2-2.4 Ga). Their discordant data indicated considerable scatter, which Kröner et al. (1987) originally thought to be consistent with lead loss ~1.1 Ga ago, caused by granulite grade metamorphism. Later, this explanation has since been withdrawn (Baur et al., 1991) in favour of a Neoproterozoic age of metamorphism. A pink granite close to Kandy (probably from the Kadugannawa Complex) produced U-Pb ages extending from an inferred upper concordia intercept near 1100 Ma for zircon cores to an inferred lower intercept near 550 Ma for new zircon growth. Kröner et al. (1987) interpreted these results as indicating an intrusion age of 1100 Ma. The maximum ages for zircons from a metaquartzite xenoliths in a Vijayan orthogneiss were found to be ~ 1.1 Ga, suggesting that the Vijayan Complex is significantly younger than the Highland Complex.

Milisenda et al. (1988,1994) carried out a Sm-Nd study and reported Sm-Nd model ages and identified three distinct age provinces: the Highland Complex produced model ages of 3.4 to 2.2 Ga, indicating derivation from late Archaean sources. It is bounded to the west and east by Wanni Complex and Vijayan Complex with model ages of 2.0 to 1.0 Ga. These results were confirmed by Pb isotope data (Lew et al., 1991 a, b, 1994) who first showed that the primary ages of the three crustal blocks contrasted sharply with each other, and that the Vijayan and Wanni Complexes are not simply “overprinted “ or retrograded Highland Complex material but represent much younger additions to the continental crust.

Orthogneisses from the Highland Complex and Wanni Complex were studied by Baur et al. (1991) and reported that U-Pb data showing primary crystallization ages around 1940 Ma, 770 Ma and 660 Ma. They found severe Pb loss ~ 550Ma ago in all the samples thus constraining the time of high-grade metamorphism to the range between 660 Ma (the age of youngest primary crystallization event) and 550Ma (the age of lead loss). Holzl et al. (1991) presented preliminary data on Rb-Sr in whole rocks, Rb-Sr in biotites, Sm-Nd in garnets and U-Pb in zircons and monazites. These results showed primary ages of ~2.0 Ga for the Highland Complex and ~1.0 Ga for the Vijayan and Wanni complexes, whereas high-grade metamorphism occurred 610-550 Ma ago and was followed by slow cooling.

Burton and O’Nions, (1990b) studied the late, small scale or local, in-situ charnockititation process using rock samples collected near Kurunegala in the WC. They obtained Rb-Sr and Sm-Nd whole rock ages around 535 Ma for a sequence of small slices from an amphibolites-granulite transition zone, and Sm-Nd, Pb and Rb-Sr mineral data from 524 to 486 Ma, and suggested these as cooling ages. These results are consistent with those of Baur et al. (1991), they found a lower intercept for U-Pb ages of zircons 563 -26 +22 Ma for very similar, charnockitized rocks also near Kurunegala. However, the upper intercept of Baur's zircon discordia lies at 771 -14+17 Ma, which is significantly different from an U-Pb age of 1094 ±8Ma and a Pb-Pb age of 1058 ± 100 Ma reported by Burton and O'Nions (1990a) for illmenites from their Kurunegala samples.

Kagami et al. (1990) reported Sm-Nd and Rb-Sr whole rock data. One sample of these, taken from the Highland Complex gneisses near Gampola, yielded a four point Sm-Nd isochron of 2330 ± 30.

Kröner et al. (1994) presented zircon SHRIMP and single grain evaporation data for the Vavuniya Charnockite Prrovince, which indicate primary ages of 1000-1100 Ma and Pb loss as well as new zircon growth 550—560 Ma ago. They concluded that this extensive northern charnockite province should be regarded as part of the Wanni (rather than Highland) Complex.

Sajeev et al. (2010) studied ultrahigh-temperature metamorphism in the central Highland Complex terrane and dated detrital cores and found ages in the range of 2.5 – 0.83 Ga. The LaICPMS U-Pb zircon dating was carried out by Amarasinghe and Collins, (2011) on metaquartzites of WC and HC of Sri Lanka and suggested that both WC and HC show derivation of detritus predominantly from Mesoarchaean and Paleoproterozoic sources (1.9-2.9) Ga but as an exception one western WC metaquartzite sample from Maradankadawela reported Neoproterozoic detrital grains at ~ 813 Ma and ~960Ma. Further, Teale et al. (2011) also described using (Amarasinghe et al., unpublished data) and showed that metaquartzites within the Wanni Complex have Paleoproterozoic sources in addition to those previously reported. He et al. (2015) carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of charnockites and metagabbro rocks (HC), hornblende biotite gneisses and charnockites of (KC) and charnockites (WC) and reported Early Neoproterozoic to Late Neoproterozoic ages (525 Ma to 950 Ma). He et al. (2015) also suggested about convergent margin magmatism in the WC and the KC during assembly of the Gondwana. He et al. (2016) also carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of metamorphosed acidic, mafic and ultra mafic igneous plutonic rocks of the Vijayan Complex (VC) of Sri Lanka and reported Early to Late Neoproterozoic ages (542 Ma to 966 Ma) and suggested an eastern suture along the boundary between the HC and the VC of Sri Lanka with arc accretion and subduction in the Neoproterozoic.

1.1.3 Geological setting of Pranhita-Godavari basin of India

The pre-Gondwana 'Purāna' basin of the Pranhita-Godavari Valley is preserved in, and may well have developed as, a major rift extending for about 450 km, from the Eastern Ghats Belt in the southeast to the Central Indian Tectonic Zone (CITZ) in the northwest (Fig.5.1). Although previous workers had suggested that the Proterozoic sedimentary rocks in the basin were likely to be the preserved relics of a much larger basin (Ramakrishnan and Vaidyanathan, 2008), sedimentological studies by Chaudhuri et al. (2012) demonstrated that the rocks were deposited largely within the present rift boundaries. The rift developed along the NW–SE trending Karimnagar Orogenic Belt, which delineates a Neoarchaean granulite belt between the Dharwar and Bastar cratonic nuclei. The Pranhita-Godavari Valley preserves records of multiple Proterozoic rifts, as well as a Gondwana rift, opening and closing along the same zone where Purāna formations occur as several structural inliers within the younger Gondwana rift system. The Gondwana outcrops occur primarily as a linear belt along the axial part of the Valley, separating Purāna outcrops into two belts (Fig.5. 2). Both Purāna and Gondwana outcrop belts maintain similar depositional and structural trends (Chaudhuri et al., 2012), and Purāna formations can be lithostratigraphically correlated across the valley into several unconformity-bound sequences (Chaudhuri, 2003 and Chaudhuri et al., 2012). The sequences, by turn, can be classified into at least three 1st or 2nd order depositional cycles (Fig.5. 3), each bounded by regional unconformities. The unconformity–bound cycles, representing major basin formation events, are stacked one above, generating a megasequence where basins are considered as genetic units rather than simply as a geographical unit (Whittaker et al., 1991). The cycles are characterized by very distinctive sets of lithologic attributes indicating deposition under highly variable modes and tempos of sediment generation, sediment supply and creation of accommodation space.

1.1.3.1. Cycle I

The Cycle I, or the basal cycle, comprises two smaller order unconformity–bound sequences, defined as groups, namely, the Mallampalli Group, which unconformably rests over crystalline basement, and the overlying Mulug Group. Equivalent Groups occur spatially separated on the east-side of the Valley, these are named the Devalmari and Somanpalli Groups (Fig.5. 2 and Fig.5. 3). The sedimentation age of the basal sandstone formation in these groups was constrained by $^{40}Ar/^{39}Ar$ dating of early authigenic glauconite grains by incremental heating technique on single grains (Conrad et al., 2011). Glauconites from Mallampalli sandstones yielded a plateau age of 1686 ± 6 Ma, whereas those from the Mulug and Somanpalli Groups yielded ages of 1565 ± 6 Ma and 1620 ± 6 Ma, respectively. The Mulug and Somanpalli Groups have been interpreted, on the basis of regional stratigraphic considerations, to have developed as two parallel belts within a protracted rift system. The former developed as a shallow tidal shelf deposit and the latter was deposited in a genetically related deep water slope and continental rise environment (Chaudhuri et al., 2012). Sedimentation in the shallow water–deep water couplet was terminated by contractional deformation , termed the Somanpalli orogenic belt by Chaudhuri et al.,(2012). The age of basin inversion is not well constrained, but we consider that it coincides with the closure of Mulug–Somanpalli basin, and pre-dates deposition of the Penganga Group that overlies the Mulug Group above a major erosional unconformity.

The Mallampalli, Devalmari, Somanpalli and Mulug Groups are all characterized by mixed carbonate-siliciclastic assemblages, and the combined succession has been designated as the Pakhal Supergroup. The Pakhal Supergroup crops out primarily in the central and southwestern part of the Pranhita-Godavari Valley.

1.1.3.2. Cycle II

Cycle II comprises a major unconformity-bound sequence of mixed carbonate-siliciclastic rocks, designated the Penganga Group. The Penganga Group crops out mainly in the central and northern part of the Pranhita-Godavari Valley, and the basin had a northwesterly to northerly palaeoslope (Mukhopadhyay and Chaudhuri, 2003), contrasting with the underlying Pakhal Supergroup. The lower part of the Penganga succession comprises a thick fining-up succession of alluvial conglomerate-pebbly sandstone-coarse grained sandstone that grades upward into a succession of limestone and shale through a zone of quartz-arenite that was deposited in a tidal shelf environment. The outcrops of the carbonate-shale succession have been covered up by the Deccan volcanics (Fig.5. 2) in the northern part of the outcrop belt. However, it appears most likely that the outcrops extended further north–northwest beneath the volcanics, and connected down palaeoslope with open ocean situated along the present Central Indian Tectonic Zone.

The $^{40}Ar/^{39}Ar$ analysis of glauconites from a submarine-fan complex (Patranabis-Deb and Fukuoka, 1998) at the basal part of the carbonate assemblage did not yield any plateau age, but provided a provisional minimum age of c. 1200 Ma for initiation of carbonate sedimentation (Conrad et al., 2011), suggesting a much older age for opening of the Penganga Basin. The Penganga Group has been lithostratigraphically correlated with the combined succession of the c. 1400 to c. 1000 Ma Chandarpur and Raipur groups of the Chhattisgarh Basin (Mukhopadhyay et al., 2006 and Conrad et al., 2011), which is consistent with the provisional glauconite age.

1.1.3.3. Cycle III

The red sandstones of the Sullavai Group, along with the Albaka and Usur groups, constitute Cycle III. Sullavai sandstones unconformably overlie different formations of the Penganga Group, the Mulug Group and the Mallampalli Group in different parts of the Pranhita-Godavari Valley, attesting to the variable degree of uplift of fault blocks and erosion during the sub-Sullavai hiatus, exceeding several thousand metres at places. The stratigraphic relationship attests to deposition of the Sullavai Group in fault controlled basins, representing a probable Neoproterozoic rift cycle. The Sullavai red beds comprise different types of feldspathic and sub-feldspathic sandstones and were deposited in extensive fluvial and erg environments (Chakraborty, 1991, Chakraborty, 1999 and Chakraborty and Chaudhuri, 1993).

The stratigraphic position of the combined succession of the Albaka Group and the unconformably overlying Usur Group could not be uniquely constrained though field mapping. The siliciclastic assemblage unconformably overlies the folded succession of the Somanpalli Group, and are here considered to either be lateral equivalents of, or stratigraphic younger than, the Sullavai Group. The Albaka and Usur successions comprise extensive quartz-arenites and shales deposited in tide- and storm-dominated inner shelf environments. Though the stratigraphic position of the Albaka and Usur groups is uncertain, along with the Sullavai Group, the sequences collectively constitute a siliciclastic depositional system that was fundamentally different from the system represented by the carbonate-dominated, mixed carbonate-siliciclastic Pakhal or Penganga successions of late Palaeoproterozoic and Mesoproterozoic age.

1.2 The scope of the research study

The literature study clearly reveals that though metasedimentary rocks predominantly occur in the Highland Complex (HC) as well as subordinately occur in the Wanni Complex and the Vijayan Complex (VC) terranes no age and sedimentary provenance studies have been conducted on the predominant metasedimentary rocks of those major crustal units to trace the origins of protolith detrital cores. On the other hand no adequate attempts have been made to understand age, provenance and geological origin of predominant rock types such as metaquartzites of Highland Complex (HC) and Wanni Complex (WC), leucosomes and paleosomes of migmatites of the Wanni Complex (WC) and charnockites of the Highland Complex (HC) and the Vijayan Complex (VC). As an example, the U-Pb LA-ICPMS zircon concordia plots drawn for cores of zircons and also probability density plots can most probably indicate either metaigneous or metasedimentary geological origin for a given rock. It is here applied as a 'geochronological' method to discriminate between igneous and sedimentary protoliths of high grade metamorphic rocks. Further, geochronological information is needed to know the maximum age of deposition of WC and HC tarraines to understand whether the WC and HC metasediments deposited in a single basin of orogenic belt or two different younger and older basins of orogenic belts or one of the terraines represents a continental block and other represents a basin of an orogenic belt. Therefore, such knowledge or research gaps remaining to be filled to understand the geological origin and the most probable Paleotectonic position of the island of Sri Lanka in the supercontinent Gondwana.

In the past many believed that WC migmatitic gneisses to be mainly metaigneous/orthogneisses based on only the mineralogical composition but it was not well understood for a long period of time due to unavailability of precise geochronological data. In addition to that on the basis of Sm-Nd model ages and differences in mineralogy and lithology, the Wanni Complex (WC) and Highland Complex (HC) of Sri Lanka have long been thought to form two distinct terranes or crustal domains, exotic to one another, with different tectonic histories. The Highland Complex is traditionally thought to be dominated by Paleoproterozoic to Neoarchaean matasedimentary rocks whilst the Wanni Complex was thought to be largely composed of Mesoproterozoic to Neoproterozoic metaigneous rocks. But some geologists still debate that WC and HC represent a single crustal domain. However, this research question has not yet been well answered and there exist debates because only a limited and a small number of true metasedimentary rock samples have been reliably dated in the past. This necessitates a further verification based on applying modern and precise geochronological methods such as LaICPMS U-Pb zircon dating to examine the provenance of metasedimentary rocks of the two terranes and also to address their tectonic relationship. Further, charnockites of granulite facies form one of the predominant rocks of the Highland Complex (HC) of Sri Lanka. Minor charnockite occurrences are also found in the adjacent Wanni Complex (WC) and Vijayan Complex (VC) terranes. These rocks are found conformable with other supracrustal rocks of the HC, WC and VC. In order to further understand the age and geological origin of the HC and VC terranes, it is significant to date charnockites of these two terranes to better understand the geological origin of the island of Sri Lanka. In the past many believed that Sri Lankan charnockites to be mainly metaigneous/orthogneisses but it was not yet well understood for a long period of time due to unavailability of precise geochronological data. On the other hand in order to understand the paleotectonic position of Sri Lanka before Gondwana super continent amalgamated in Ediacaran-Cambrian, it is significant to understand the protolith sources of metasedimentary charnockites as well as primary intrusive ages of charnockites of igneous origin.

As far as provenance of highgrade metasedimentary rocks is concerned precise age information of sedimentary detritus would be a primary requirement. In the process of attempting to understand the paleotectonic position of the island of Sri Lanka not only it is important to understand age of protolith sources/provenance of metasedimentary rocks of Highland Complex (HC) and Wanni Complex (WC) and also primary intrusive ages of metaigneous charnockites of the Highland Complex (HC) and Vijayan Complex of Sri Lanka but also it is significant to understand age and sedimentary provenance of rocks of other neighboring coeval sedimentary basins of deposition which existed during Paleoproterozoic to Neoproterozoic periods such as the Pranhita-Godavari ‘Purana” basin of India.

In the past several geochronological studies were carried out in the island of Sri Lanka by several workers but those were not formulated as sedimentary provenance studies but just attempting to date rock samples which were collected randomly. In this context , Holzl et al. (1994) had established a general geochronological framework for the crystalline basement of Sri Lanka based on U-Pb ages of zircons and monazites from ortho – and paragneisses representing the major crystalline basement units of Sri Lanka. Previously, a geochronological framework for the island was put forward using Sm-Nd model ages (Milisenda et.al., 1988, 1994). Such Sm-Nd model ages are considered as less reliable as average ages of all possible ages of protolith sources are also taken into account in calculating the average age of a given rock resulting in errors in ages. In both the above studies rock samples were collected arbitrarily or in scattered manner from the four main geologic/tectonic provinces of Sri Lanka rather than collecting rock samples along west to east traverse lines or transects which are approximately perpendicular to the strike of rock layerings/foliation or trend lines of the terranes. Collecting rock samples along transects perpendicular to strike direction is considered to be the best to study age relationships. On the one hand this shortcoming of not collecting along traverse lines has resulted in creating uncertainities about the exact/accurate boundaries between four major tectonic provinces, the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC) and Kadugannawa Complex (KC) of Sri Lanka. In those previous geochronological studies on the Sri Lankan basement rocks, sampling and dating were not done on metamorphosed definite sediments such as metaquartzites but other suspected paragneisses and orthogneisses and also the detrital cores and their metamorphic rims were not also dated after imaging under cathodoluminescence (CL). Under these circumstances, a fresh and methodical geochronological research study has become a necessity to fill the knowledge and research gaps and overcome the remaining shortcomings in the current geochronological framework of Sri Lanka and also to verify whether the Wanni Complex and Highland Complex of Sri Lanka have derived sedimentary detritus from similar protolith sources or not as well as the current tentative boundary between the Wanni Complex and the Highland Complex is to be re-established or not.

But Sri Lanka's exact paleotectonic position and how the island crustal block was connected to neighboring land masses is not yet confidently understood and it is still a puzzle and a research gap. The most appropriate way of addressing this research problem is by finding the origins of protolith sources/ provenance of highgrade metasedimentary rocks of Sri Lanka as well as those of other neighboring contemporary sedimentary basins such as Pranhita-Godavari rift basin of central southeast India and attempting to correlate whether other neighboring crustal blocks such as Southern granulite terrane of India, Madagascar, East Africa and Antarctica have similar age and provenance to that of the different geologic/tectonic terranes of Sri Lanka and Pranhita-Godavari basin of India. The present research study is mainly aimed at addressing above research gaps as well as tracing the links of the Sri Lankan crustal blocks to her neighboring crustal blocks such as South India, Madagascar and East Africa in the process of amalgamation of the Neoproterozoic supercontinent Gondwana based on a geochronological provenance study. Though there were attempts in the past to link and correlate WC and HC of Sri Lanka to the Southern Granulite Terrane of south India without based on a sedimentary provenance study but on just limited age data of rocks and which had become mostly speculations when not knowing Sri Lankan crustal blocks and South Indian crustal blocks have similar provenance or not. In the Paleoproterozoic to late Neoproterozoic there existed probable continental blocks or orogenic belt basins such as Trivandrum Block, Southern Madurai Block, Northern Madurai Block of the Southern Granulite Terrane of South India as well as WC, HC, VC, and KC terranes of Sri Lanka and also Pranhita-Godavari 'Purana' rift basin of India which became sandwiched between Archean Dharwar and Bastar cratons of India. So it is probable that Sri Lankan and Indian sedimentary basins may have received sedimentary detritus from Dharwar and Bastar cratons as well as non Indian protolith sources. So a research question still remains to be answered and research gap is to be filled based on a geochronological provenance study on where was the probable paleotectonic position of the island of Sri Lanka? So it is necessary to focus on a sedimentary provenance study of both probable three main crustal units WC, HC and VC which had produced the land mass of the island of Sri Lanka as well as neighbouring contemporary /coeval unmetamorphosed rift basins such as "Purana" Pranhita Godavari basin of India. The added significance of studying sedimentary provenance of rocks of Pranhita-Godawari 'Purana' rift basin of India is these rocks are unmetamorphosed and zircon detrital grains could probably produce better geochronological data compared to zircons of highgrade metamorphic rocks.

Among the minerals which contain radioactive isotopic elements to date rocks in geochronology ,the zircon is recognised as the best and the recorder or pathfinder of the past geological events because zircon is an extremely long lasting, rugged, robust, and resistant mineral against melting, weathering, transportation and highgrade regional and thermal metamorphism. So that zircon can survive well in geological and tectonothermal events and can be found in current highgrade metasedimentary rocks containing geochronological information about the nature and age of protolith sources , extent of transportation, impact of magma intrusions, events of regional metamorphism and so on.

So the zircon has become the best tracer or pathfinder of the original protolith sources. Latest developments in sector field inductively coupled plasma-mass spectrometry (ICPMS) have enabled precise measurements of this isotopic systems in zircons by laser ablation (Plavsa,et.al., 2014; Griffin et. al., 2000; Iizuka and Hirata, 2005). This method called LaICPMS is particularly useful as it allows for specific textural and age domains within zircon to be targeted during the analysis (Plavsa et al., 2014). It is here applied the LaICPMS method as an analytical technique to the high-grade terranes of the Wanni Complex (WC) , Vijayan Complex (VC) and Highland Complex (HC) of Sri Lanka and Pranhita-Godavari 'Purana' rift basin of India to unravel the source of the protoliths of high-grade metasedimentary metaquartzite, migmatites, and charnockite rocks of Sri Lanka which were collected systematically along two west to east transects across the island of Sri Lanka and Proterozoic unmetamorphosed sedimentary rocks of Pranhita-Godavari rift basin of India that assist elucidate the Neoproterozoic paleogeography of the region.

1.3 Objectives of the study

- Constrain the ages of cores of detrital zircon grains of metaquartzite rocks of the Wanni Complex (WC) and the Highland Complex (HC) of Sri Lanka.
- Constrain the metamorphic ages of rims of detrital zircon grains of metaquartzite rocks of the Wanni Complex (WC) and the Highland Complex (HC) of Sri Lanka.
- Determine whether migmatites of the Wanni Complex (WC) of Sri Lanka could have metasedimentary or metaigneous origin based on the study of U-Pb zircon concordia plots and probability density plots.
- Constrain the ages of cores of zircon grains of paleosome and leucosome portions of migmatites of the Wanni Complex (WC) of Sri Lanka.
- Determine whether charnockites of the Highland Complex (HC) and the Vijayan Complex (VC) of Sri Lanka could have metasedimentary or metaigneous origin based on the study of U-Pb zircon concordia plots and probability density plots.
- Investigate the time span of detrital zircons of mataquartzites , migmatites, and charnockites of Wanni Complex (WC), Highland Complex (HC), and Vijayan Complex (VC) of Sri Lanka.

- Determine possible provenance of detrital zircons of mataquartzites , migmatites, and charnockites of Wanni Complex (WC), Highland Complex (HC), and Vijayan Complex (VC) of Sri Lanka.
- Investigate the possible linkage between different crustal units of Sri Lanka and the Southern Granulite Terrane of South India.
- Constrain the ages of cores of detrital zircon grains of sedimentary rocks of the Pranhita-Godavari 'Purana' basin rift valley of India.
- Determine possible sedimentary provenance of sedimentary rocks of the Pranhita-Godavari 'Purana' basin rift valley of India and to find any possible relationships to basins of Sri Lankan crustal units.
- Address the possible geological origin in a tectonic model and paleotectonic position of the island of Sri Lanka during the assembly of the Gondwana supercontinent .

Thesis Outline

The island of Sri Lanka is the focus of Neoproterozoic super continent Gondwana. But the geological origin and paleotectonic position of Sri Lanka are least understood without knowing age and provenance of the four main crustal units, the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC) and the Kadugannawa Complex (KC). The study of age and provenance of metaquartzites of the WC and HC, leucosomes and paleosomes of migmatites of the WC, and charnockites of the HC and VC of Sri Lanka and sedimentary rocks of neighboring Proterozoic rift basins like Pranhita-Godavari basin of central India is significant in research on origin of Sri Lanka and also continental evolution to unravel the paleotectonic position of Sri Lanka before Gondwana being amalgamated in the Neoproterozoic. This study examined age of detrital zircon cores and metamorphic rims of metaquartzite, migmatite and charnockite samples along two west to east transects across the island of Sri Lanka as well as sedimentary rock samples from the Pranhita-Godavari rift basin of India using the LA-ICPMS method.

The U-Pb zircon isotopic data from metaquartzites of WC (near WC-HC boundary) and HC demonstrate dominant Mesoarchaean to Paleoproterozoic (2.0-2.8 Ga) detrital input into the metasedimentary make up and near boundary WC and HC metaquartzites were deposited between 2000 Ma and ~550 Ma with a maximum age of deposition ~ 2000 Ma, however a sample from the western WC was deposited in early Neoproterozpoic and mixed with Paleoproterozoic to Neoarchaean detritus indicating WC and HC terranes existed adjacent to each other since early Neoproterozoic and current WC-HC boundary is inaccurate and to be shifted westwards.

This study reveals that parent materials of leucosomes of WC migmatitic gneisses are metasedimentary and showing late Mesoproterozoic to Neoproterozoic provenance (0.70-1.15 Ga) with maximum age of deposition at ~700 Ma. But paleosomes of WC migmatites show metaigneous origin with older Mesoarchaean ages (2.85-3.0 Ga) and have been identified in this study as the Mesoarchaean reworked continental basement material of WC. The HC charnockites clearly show metaigneous origin and primary intrusion ages of ~1.82 to 1.85 Ga. whilst a sample from the VC shows metasedimentary origin. A weighted mean of all rim data of WC and HC yields an age of 545.1 ± 9.7 Ma, supporting the age of Ediacaran-Cambrian metamorphism.

Metaquartzite rocks of the HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metaquartzites of the western WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar and Sri Lankan metaquartzites were most probably sourced from east African igneous protolith sources. These differences in sedimentary provenance and maximum age of deposition prove and confirm that WC was a different crustal domain from the HC terrane.

All this strongly supports a double subduction and collisional geological origin for the island of Sri Lanka with 'HC orogeny' occurred when the Southern Madurai Block of India (SMB)-WC and VC Mesoarchaean continental blocks collided with the HC orogenic belt and the oceanic crust of deeper basin of HC had subducted underneath the SMB-WC and VC continental blocks when ancient south Mozambique ocean closed along WC-HC boundary and HC-VC boundary sutures. This study reveals that Sri Lanka's paleotectonic position could be south east of south India connecting Trivandrum Block to the HC and WC to the Southern Madurai Block. The study also reveals that the Pranhita-Godavari Basin was sourced from Eastern Ghats and Antarctica unlike Sri Lankan terranes were sourced from East Africa indicating Southern Granulite Terrane of India and Sri Lanka were not parts of mainland cratonic India until Ediacaran-Cambrian times.

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Chapter 2 – Age and Sedimentary Provenance of Metaquartzites of Highland Complex and Wanni Complex of Sri Lanka show correlation with Southern Granulite Terrane of India and Madagascar: LaICPMS U-Pb Geochronology of Zircons

ABSTRACT

The Island of Sri Lanka as a crustal fragment, crustal block or micro continent is considered as the mid-point or focus of the Neoproterozoic super continent Gondwana. The study of age and provenance of metaquartzites of the central granulite belt or the Highland complex and also the Wanni Complex of Sri Lanka is considered extremely significant in research on continental evolution to unravel the paleotectonic position of Sri Lanka before Gondwana supercontinent amalgamated in the Neoproterozoic. In this study, it is examined age distribution of detrital zircon cores and later metamorphic rims of nine metaquartzite samples along two west to east transects across the island in the Highland Complex (HC) and Wanni Complex (WC) of Sri Lanka using Laser Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS).

The LaICPMS U-Pb zircon isotopic data from three WC metaquartzites and five HC metaquartzites demonstrate dominant Mesoarchaean to Neoarchaean to Paleoproterozoic detrital input into the metasedimentary make up and original sediments to the WC and HC metaquartzites were deposited between ~ 2000 Ma and 515 Ma, whereas a sample from the western WC collected at Maradankadawela (S814) was deposited in Neoproterozoic times. This rock contains detritus with >90% concordant Neoproterozoic detrital peaks at 813.5 ± 11 Ma, 964 ±14 Ma and mixed with Paleoproterozoic to Neoarchaean detrital grains up to 2700 Ma indicating WC and HC basins of continental blocks or orogenic belts existed adjacent to each other since early Neoproterozoic . This study reveals that WC and HC are two different crustal domains and WC represents a continental block with shallow basins of sediments welded/merged to

Southern Madurai Block of South India and supracrustal HC represents an orogenic belt deep basin connected to the Trivandrum Block of South India.

This study yields correlations of the WC and HC of Sri Lanka to Southern Granulite Terrane of India and reveals that the metaquartzite rocks of the HC of Sri Lanka are correlated with the Trivandrum Block, Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metasedimentary rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. The detrital peaks indicate that Sri Lankan metaquartzites were most probably sourced from the east African igneous protolith sources. It is here suggested that metasedimentary sequences of WC and HC of Sri Lanka, Trivandrum Block and Southern Indian Madurai Block sequences, and Malagasy sequences represent different parts of basins of continental blocks or sedimentary orogenic belts. Sri Lanka's paleotectonic position could be south east of south India before Gondwana being amalgamated in Ediacaran-Cambrian and the HC of Sri Lanka, Trivandrum Block of South India and Itremo Group of Madagascar formed as a part of the micro continent Azania that lay above a south/west (present directions) dipping Cryogenian-Ediacaran subduction zone in a collisional orogeny when final consumption of the south Mozambique ocean occurred as double subduction of HC oceanic crust along two suture zones at WC-HC and HC-VC boundaries during the assembly of Gondwana in the Ediacaran-Cambrian. The HC of Sri Lanka was formed during this collisional "HC orogeny' with the Trivandrum Block. The results of this study suggests that HC of Sri Lanka could be the South Eastern continuation of the Trivandrum Block of South India.

The U-Pb ages of metamorphic rims of zircon grains from both WC and HC are found to be between ~ 600 Ma and 550 Ma. A weighted mean of all rim data yields an age of 545.1 ± 9.7 Ma, supporting an age of Ediacaran-Cambrian metamorphism similar to that found in adjacent areas of Southern India.

Key words: LA-ICPMS, U-Pb ages, Detrital peaks, Maximum age of deposition, Highland Complex, Wanni Complex, Sri Lanka

2.1 Introduction

The Island of Sri Lanka is located in a key position in the process of amalgamating Neoproterozoic supercontinent Gondwana. Sri Lanka forms a small but important jigsaw piece of the supercontinent, Gondwana. Sri Lanka’s exact paleotectonic position and how the island crustal block was connected to neighbouring land masses is not yet confidently understood and it is still a puzzle and a knowledge gap. The most appropriate way of addressing this research problem is by finding the origins of protolith sources/ provenance of highgrade metasedimentary rocks of Sri Lanka and attempting whether other adjacent crustal blocks have similar age and provenance to that of the different geologic/tectonic terranes of Sri Lanka. It is more appropriate in attempting to locate probable protolith sources with respect to ages of detrital zircon cores in metaquartzites like definite metasedimentary rocks . In addition to that on the basis of Sm-Nd model ages the Wanni Complex (WC) and Highland Complex (HC) of Sri Lanka have long been thought to form two distinct terranes or crustal domains, exotic to one another, with different tectonic histories while some others still argue that WC and HC represent one crustal domain. The Highland Complex is traditionally thought to be dominated by Paleoproterozoic to Neoarchaean matasedimentary rocks whilst the Wanni Complex was thought to be largely composed of Mesoproterozoic to Neoproterozoic metaigneous rocks. However, this research question also has not yet been well answered and there exist debates because only a limited and a small number of true metasedimentary rock samples have been reliably dated in the past. This necessitates a further verification based on applying modern and precise geochronological methods such as LaICPMS U-Pb zircon dating to examine the provenance of metasedimentary rocks of the two terranes and also to address their tectonic relationship.

As far as provenance of highgrade metasedimentary rocks is concerned precise age information of sedimentary detritus would be a primary requirement. In the past several geochronological studies were carried out in the island of Sri Lanka by several workers but those were not structured as sedimentary provenance studies. In those previous studies rock samples were collected arbitrarily or in scattered manner from the four main geologic/tectonic provinces of Sri Lanka rather than collecting rock samples as much as possible to be perpendicular to the general trend lines or strike of rock layers along west to east traverse lines or transects. On the one hand this shortcoming has resulted in creating uncertainties about the exact/accurate boundaries between four major tectonic provinces, the Wanni Complex (WC), Highland Complex (HC), Vijayan Complex (VC) and Kadugannawa Complex (KC) of Sri Lanka. In those previous geochronological studies on the Sri Lankan basement rocks, sampling and dating were not done on metamorphosed definite sediments such as metaquartzites but other suspected paragneisses and orthogneisses and also the detrital cores and their metamorphic rims were not also dated after imaging under cathodoluminescence (CL). Under these circumstances, a fresh and methodical geochronological research study has become a necessity to fill the research gap and overcome the remaining shortcomings in the current geochronological framework of Sri Lanka and also to verify whether the Wanni Complex and Highland Complex of Sri Lanka have derived sedimentary detritus from similar protolith sources or not as well as the current tentative boundary between the Wanni Complex and the Highland Complex is to be re-established or not.

The present research study is mainly aimed at addressing above research gaps as well as tracing the links of the Sri Lankan crustal block to her adjacent crustal blocks such as South India, Madagascar and East Africa, in the process of amalgamation of the Neoproterozoic supercontinent Gondwana based on a geochronological provenance study.

Latest developments in sector field inductively coupled plasma-mass spectrometry (ICPMS) have enabled precise measurements of isotopic systems in zircons by laser ablation (Plavsa,et.al., 2014; Griffin et. al., 2000; Iizuka and Hirata, 2005). This method called LaICPMS is particularly useful as it allows for specific textural and age domains within zircon to be targeted during the analysis (Plavsa et al., 2014). I here apply the LaICPMS method as an analytical technique to the high-grade terranes of the Wanni Complex (WC) and Highland Complex (HC) of Sri Lanka to unravel the source of the protoliths of high-grade metasedimentary metaquartzite rocks of Sri Lanka which were collected systematically along two west to east transects across the island of Sri Lanka that assist elucidate the Neoproterozoic paleogeography of the region.

2.2 Geological background

More than two thirds of the island of Sri Lanka is underlain by Precambrian highgrade metamorphic rocks and the rest is mainly of Miocene sedimentary rocks and isolated Jurassic, Quarternary sedimentary rocks (Fig.2.1). The high-grade metamorphic basement of Sri Lanka comprised mainly of Mesoarchaean to Neoproterozoic orthogneiss and paragneiss rocks and sub-divided into four major crustal units named as the Highland Complex (HC), Vijayan Complex (VC), and Wanni Complex (WC) and Kadugannawa Complex (KC) (Fig.2.1) traditionally based on lithology, mineralogical composition, metamorphic grade (Kröner et al., 1991), and Nd model ages (Milisenda et al., 1988; 1994, Sajeev et al., 2010). The oldest rocks are in the Highland complex (Sajeev and Osanai, 2004, and Sajeev et al., 2010) which is centrally located and consisting of granulite grade major supracrustal meta-sedimentary rocks, charnockites and concordant to discordant metaigneous rocks. The major meta-sedimentary rocks are garnet sillimanite gneisses (also known as khondalites), marbles, calc silicates, garnetiferous granulites, and metaquartzites. Kröner et al., (1991) described that more than half of the HC rocks are of granitoid origin. Field mapping in several parts of the HC showed a close association of charnockites and other metasedimentary paragneisses on local as well as regional scale (Cooray, 1962, 1984). The metasedimentary rocks of HC could be traced for more than 40 km. In the southwestern parts of the HC, thick bands of marble and quartzite are rare and instead, mappable bands of wollastonite-scapolite, diopside-scapolite rocks and cordierite bearing gneisses are observed. The age of HC was approximately found as 3.2 to 2.0 Ga based on Nd model ages (Milisenda et al., 1988; Kröner, and Williams, 1993). Intermittent intrusions of granites to the HC succession of metasediments were emplaced at around 2.0 and 0.65 Ga (Kroner et al., 1987, Holzl et al., 1991, 1994). Field studies show that the granites, the precursor to the charnockitic rocks, were intruded as a large number of basaltic sills and /or dikes, varying in thickness from about a centimetre to about a metre. The intrusions predated the deformation and metamorphism of the sedimentary pile (Voll and Kleinschrodt, 1991, Kehelpannala et al., 1994). These basaltic rocks have been transformed into metabasites and brought into parallelism with S surfaces in the host rocks during the intense deformation and metamorphism and now those occur as conformable bands or layers within the host rocks. Many of these bands have undergone partial or complete retrogression. Igneous intrusions to HC was reported to have taken place around 1850-1990Ma (Kröner and Williams, 1993; Schumacher et al., 1990). The high-grade metamorphism had taken place as a part of the Ediacaran-Cambrian metamorphism and orogeny at ca. 550 Ma (Kröner et al., 1991) and the rocks were subjected to peak metamorphic PT conditions of 900°C and 9 K bars. The regional metamorphism was followed by slow isobaric cooling and uplifting of the HC into higher crustal levels (Kröner et al., 1991; Jayawardane, and Carswell, 1976; Kröner, and Williams, 1993; Faulhaber, and Raith, 1991). The boundary between HC and VC is well defined as a tectonic boundary marked by thrust and shear zones, tectonic breccia, mafic to ultramafic intrusions, and a belt of hot water springs.

The Vijayan Complex (VC) lies to the east of the central HC (Fig.2.1) and consists mainly of granitic gneisses, migmatites, hornblend gneisses, and minor abundance of isolated bands of metaquartzite and calc gneisses (Dahanayake and Jayasena, 1983) of Mesoproterozoic to Neoproterozoic age (Milisenda et al., 1988, 1994; Sajeev et al., 2010).. It was described that the gneissose granitoids of the Vijayan Complex as having compositions ranging from tonalite to leucogranite (Milisenda, et al., 1988; Corfu et al., 2003). The major structural trends in the VC are discontinuous and rather complexly oriented, forming several circular or dome like structures. Geochemical and isotopic data broadly identify the precursor to the VC rocks as I type calc-alkaline granitoids (Pohl and Emmermann, 1991, Milisenda, 1991). This characterisation lead to the interpretation that the VC rocks originated at a subduction related tectonic environment (Milisenda, 1991).

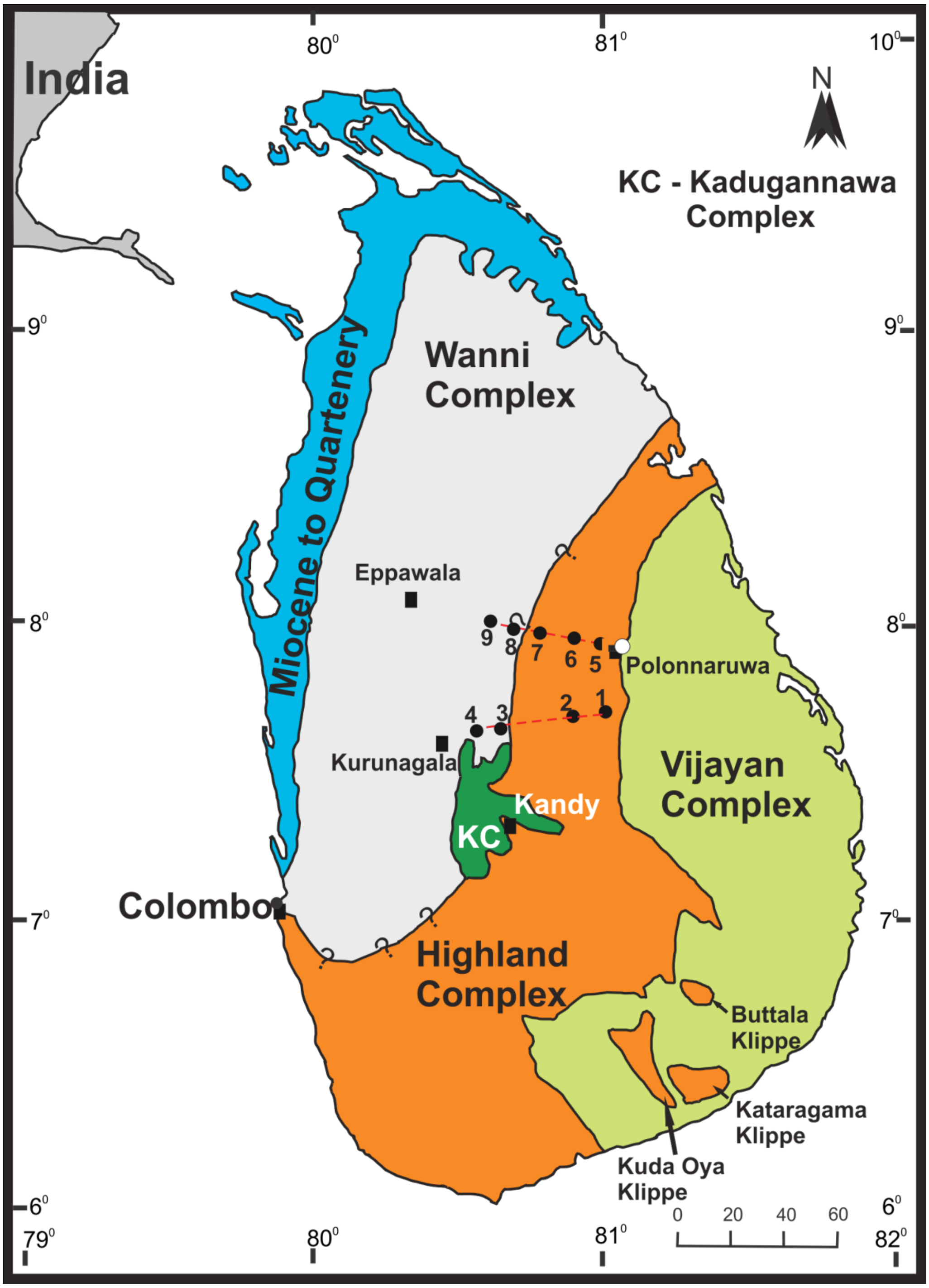

Fig. 2.1. Generalized geological and tectonic framework of Sri Lanka showing major crustal blocks and their boundaries (after Cooray, 1994). The study area is shown along two west-east transects. Sample locations of metaquartzites are shown by black circles. Sample locations; 1-Midlands (S911), 2- Rattota(S821), 3- Dodangaslanda(S094), 4-Batalagoda (S097), 5-Giritale (S0922), 6- Minneriya (S088), 7-Habarana-Minneriya (S0917), 8-Palugaswewa (S0813), and 9- Maradankadawela (S0814).

The Wanni Complex defined on the basis of Nd model ages (1.1-1.8 Ga) lies in the west of the HC (Milisenda et al., 1988, 1994; Sajeev et al., 2010). The WC consists mainly of leucocratic gneisses, granitic gneisses, migmatitic gneisses, migmatites, granitic intrusions, cordierite gneisses, charnockitic gneisses and minor abundance of supracrustal metaquartzites, and metapelites. Metasediments are relatively less abundant but cordierite bearing gneisses and migmatites are ubiquitous in the Colombo and Gampaha areas. Charnockitic gneisses are dominant in the northern lowlands, particularly around Vavniya, referred to as the 'Vavniya' charnockite province by Kroner et al., (1994). Arrested charnockites too occur in several locations (e.g., Kurunegala and Anamaduwa). Late microcline bearing alkaline rocks are relatively more common than in the other two complexes. But the predominant rock type in the WC is migmatitic gneiss or migmatite. These migmatitic gneisses and cordierite bearing migmatitic gneisses could be either metasedimentary paragneisses or igneous orthogneisses but sufficient research studies have not yet been conducted in the past to understand the origin of WC migmatitic gneisses.

The structural geology of the WC is not well understood, but the works of many show a similar history between the WC and the HC, partly because a large part of the WC represents former HC rocks as well as WC and HC underwent a single event of regional metamorphism. The prominent, major upright Taprabonian folds in the HC are continuous into the eastern WC (Kehelpannala, 1991). Even the early pre-Taprabonian structures such as, tight to isoclinals folds and strong stretching lineations are similar and have similar orientation in the two complexes (Kriegsman, 1991; Voll and Kleinschrodt 1991).

In the WC of Sri Lanka, metasedimentary metaquartzites are subordinately abundant compared to greater abundance of metaquartzites in the HC. WC metaquartzites are found to occur generally close to the current tentative WC-HC boundary but there are isolated metaquartzite bands occurring in the western WC terrane. It is significant to understand whether WC and HC metaquartzites have similar age and sedimentary provenance or not. There is still no adequate geological and geochronological evidence to precisely mark a clear boundary between the HC and the WC.

There are diverse views on the recognition of WC as a separate crustal domain different from the HC. There have been several workers attempted to describe the supracrusral rocks of WC and HC of Sri Lanka. Kehelpannala (1991) reported that most of the metasediments of the WC occur close to the assumed boundary with the HC. Voll and Kleinschrodt (1991) also rejected the establishment of WC as it is not clearly confined, no precise definitions for its delineation can be given and proposed that common history is represented by HC and WC rocks with HC represents a deeper crustal level than the WC. Willbold et al. (2004) also stated that though the Nd model ages and zircon age spectra suggest different origins for the WC and the HC, this division is difficult to substantiate with lithological and petrological data.

The Mesoproterozoic to Neoproterozoic Kadugannawa Complex (KC) exists in the west HC terrane close to the currently tentative WC-HC boundary as the smallest geological unit of Sri Lanka. The KC consists of highly deformed several doubly plunging synform structures or 'arenas' comprising of Hornblend Biotite Gneisses, Metagabbros, and metabasites with granitoid and charnockites.

2.2.1 Recent geochronological studies in Sri Lanka

Zircon detrital grains from the HC metasediments were dated by Kröner et al. (1987) and reported late Archaean to Paleoproterozoic near concordant ages (3.2-2.4 Ga). There were dispersed detrital points in the concordia plots due to high discordancy, which Kröner et al., (1987) initially understood to be due to lead loss ~1.1 Ga ago, caused by granulite grade metamorphism. Later, this explanation has since been withdrawn (Baur et al., 1991) in favour of a Neoproterozoic age of metamorphism. Single zircon studies (SHRIMP and single grain evaporation techniques) indicated two phases of emplacements of granitoid plutonic structures in the WC, at 750-790 Ma and 1000-1050 Ma (Kroner and Jaeckel, 1994). A pink granite close to Kandy (probably from Kadugannawa Complex) produced U-Pb ages extending from an inferred upper concordia intercept near 1100 Ma for zircon cores to an inferred lower intercept near 550 Ma for new zircon growth. Kröner et al. (1987) interpreted these results as showing an intrusion age of 1100 Ma. The maximum ages for zircons from a metaquartzite xenoliths in a Vijayan orthogneiss were found to be ~ 1.1 Ga, suggesting that the Vijayan Complex is significantly younger than the Highland Complex.

Milisenda et al. (1988, 1994) carried out a Sm-Nd dating of the Precambrian basement of Sri Lanka and reported Sm-Nd model ages and identified three distinct age zones: the Highland Complex produced model ages of 3.4 to 2.2 Ga, indicating derivation from late Archaean protolith sources. It is bounded to the West and East by Wanni Complex and Vijayan Complex with model ages of 2.0 to 1.0 Ga. These results were consistant with Pb isotope data (Lew et al., 1991 a, b, 1994) first showed that the primary ages of the three crustal blocks contrasted sharply with each other, and that the Vijayan and Wanni Complexes are not simply "overprinted " or retrograded Highland Complex material but represent much younger additions to the continental crust.

Orthogneisses from the Highland Complex and Wanni Complex were dated by Baur et al. (1991) and reported that U-Pb data showing primary crystallization ages around 1940 Ma, 770 Ma and 660 Ma. They found severe Pb loss ~ 550Ma ago in all the samples thus constraining the time of high-grade metamorphism to the range between 660 Ma (the age of youngest primary crystallization event) and 550Ma (the age of lead loss). Holzl et al. (1991) presented preliminary data on Rb-Sr in whole rocks, Rb-Sr in biotites, Sm-Nd in garnets and U-Pb in zircons and monazites. These results showed primary ages of ~2.0 Ga for the Highland Complex and ~1.0 Ga for the Vijayan and Wanni complexes.

Burton and O'Nions (1990b) studied the late, small scale or local, in-situ charnockititation phenomenon using rock samples collected near Kurunegala in the WC. They obtained Rb-Sr and Sm-Nd whole rock ages around 535 Ma for a sequence of small slices from an amphibolites-granulite transition zone, and Sm-Nd, Pb and Rb-Sr mineral data from 524 to 486 Ma, and suggested these as cooling ages. These results are consistent with those of Baur et al. (1991), they found a lower intercept for U-Pb ages of zircons 563 -26 +22 Ma for very similar, charnockitized rocks also near Kurunegala. However, the upper intercept of Baur's zircon Discordia lies at 771 -14+17 Ma, which is significantly different from an U-Pb age of 1094 ±8Ma and a Pb-Pb age of 1058 ± 100 Ma reported by Burton and O'Nions (1990a) for illmenites from their Kurunegala samples.

Kagami et al. (1990) reported Sm-Nd and Rb-Sr whole rock data. One sample of these, taken from the Highland Complex gneisses near Gampola, yielded a four point Sm-Nd isochron of 2330 ± 30.

Kröner et al. (1994) presented zircon SHRIMP and single grain evaporation data for the Vavuniya Charnockite Province, which indicate primary ages of 1000-1100 Ma and Pb loss as well as new zircon growth 550—560 Ma ago. They concluded that this extensive northern charnockite province should be regarded as part of the Wanni (rather than Highland) Complex.

Sajeev et al. (2010) studied ultrahigh-temperature metamorphism in the central Highland Complex terrane and dated detrital cores and found ages in the range of 2.5 – 0.83 Ga. The LaICPMS U-Pb zircon dating was carried out by Amarasinghe and Collins (2011) on metaquartzites of WC and HC of Sri Lanka and suggested that both WC and HC show derivation of detritus predominantly from Mesoarchean and Paleoproterozoic sources (1.9 – 2.9) Ga but as an exception one western WC metaquartzite sample reported Neoproterozoic detrital grains at ~ 813 Ma and ~960Ma. Further, Teale et al. (2011) also described using (Amarasinghe et al., unpublished data) and showed that metaquartzites within the Wanni Complex have Paleoproterozoic sources in addition to those previously reported. He et al. (2015) carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of charnockites and metagabbro rocks (HC), hornblende biotite gneisses and charnockites of (KC) and charnockites (WC) and reported early Neoproterozoic to late Neoproterozoic ages (525 Ma to 950 Ma). He et al. (2015) also suggested about convergent margin magmatism in the WC and the KC during assembly of the Gondwana. He et al. (2016) also carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of metamorphosed acidic, mafic and ultra mafic igneous plutonic rocks of the Vijayan Complex (VC) of Sri Lanka and reported early to late Neoproterozoic ages (542 Ma to 966 Ma) and suggested an eastern suture along the boundary between the HC and the VC of Sri Lanka with arc accretion and subduction in the Neoproterozoic. On the basis of the outcome of the literature review this present study focuses on a sedimentary age and provenance study of metaquartzites of the WC and HC of Sri Lanka to address above knowledge gaps and research questions.

2.3. Analytical Methods

2.3.1 Sample selection and preparation

Sample collection was carried out during field geological mapping along two west-east transects (Fig.2.1) as northern transect (between Eppawela and Polonnaruwa via Habarana) and southern transect (between Kurunegala and Riverstone via Matale) running right across the island from near current WC-HC tentative boundary in the WC to HC terranes. Three WC mataquartzite samples were collected near the current WC-HC tentative boundary. One WC metaquartzite sample was collected in the western WC about 30 km far away from the current WC-HC tentative boundary. All the five HC metaquartzite samples were collected within the HC terrane.

Particular emphasis was paid to select metamorphosed definite sedimentary rocks for the study of provenance of WC and HC. As a result of that nine metaquartzite samples representing both the WC and HC were used for laboratory investigation. Each sample was crushed, milled, and sieved to produce a 79-400 micro meter fraction. This fraction was panned. Then all the magnetic minerals were removed using the magnetic separator as well as using a hand magnet. Then the grains were separated in the methylene iodide heavy liquid to separate zircon grains. The zircon grains were hand- picked selecting zircon grains of all sizes, shapes and colours in order to avoid bias and mounted using epoxy resin material discs. When the mounts were hardened, the exposed surface was polished and carbon coated. The mounted zircon grains were subsequently imaged using the Cathodoluminescenece (CL) apparatus, Phillips XL 20 scanning electron microscope with attached Gatan CL at the Adelaide Microscopy of Medical School of the University of Adelaide. The zircon grains have been imaged using ~16 mm working distance and accelerating voltage of 12 kV.

2.3.2 LAICPMS U-Pb zircon dating

The mounts of zircon minerals were placed in the Laser Ablation Inductively Coupled Plasma – Mass Spectrometer (La-ICPMS) of the University of Adelaide and each zircon grain was analysed on a new wave 213 mm Nd-YAG laser coupled plasma-mass spectrometer (ICP-MS) subjected to a laser beam with 30 micro meter spot size was used with a standard spot depth of 30-50 micro meter to obtain U-Pb age data. A particular emphasis was paid to target cores of the detrital zircon grains as well as the metamorphic rims. The isotopic ratios were observed and corrected for drift and within-run U-Pb fractionation by repeated analysis of GEMOC GJ-1 (a Sri Lankan pegmatitic zircon crystal) as the standard zircon (published thermal ionization mass spectrometry normalizing ages of $^{207}Pb/^{206}Pb$ =607 ± 4.3 Ma, $^{206}Pb/^{238}U$ = 600.7 ± 1.1 Ma and $^{207}Pb/^{235}U$ =602.0 ± 1.0 Ma, Jackson et al., 2004). The data were analysed using computer software to produce U-Pb concordia plots. During the process of analytical sessions, a total of 358 analyses of the GJ-1 external standard yielded a weighted average $^{207}Pb/^{206}Pb$ age of 610 ± 3.9 Ma (2 sigma, mean square of weighted deviates (MSWD) = 0.58) and $^{206}Pb/^{238}U$ = 600.02 ± 0.88 Ma (2 sigma MSWD = 0.54). Analysis of the Plesovice zircon standard (TIMS $^{206}Pb/^{238}U$ age = 337.13± 0.37 Ma, 95 % of confidence limits; Slama et al., 2008) was performed to check for validity of the applied method during the analysis of unknowns. A total of 110 analyses of the Plesovice internal standard yielded weighted average ages of $^{206}Pb/^{238}U$= 337.84± 0.94 Ma (2 sigma, MSWD = 1.07) and $^{207}Pb/^{206}Pb$ = 340.6 ± 7.1 Ma (2 sigma, MSWD = 0.8), demonstrating the accuracy of the operating conditions.

2.4. Results

2.4.1 Sample descriptions and U-Pb Geochronology

LAICPMS U-Pb age data presented in the Appendix B available from the on-line version of this paper, geochronological interpretations are presented in Figs 2.4-2.8.
The Fig. 2.2 and 2.3 indicate the Cl images of zircons in the WC and the HC respectively. The Fig.2.4 and Fig.2.5 show that the concordia plots of all the nine samples have got a large number of scattered and strayed discordant points due to considerable and partial lead loss during highgrade metamorphism. These scattered discordant points have caused a difficulty to draw a best fit line to determine the upper and lower intercepts to find the maximum and minimum ages of deposition of sedimentary detrital grains. That means there is no any linear lead loss in all the nine concordia plots. Under these conditions the maximum and minimum ages of deposition of all the nine metaquartzite samples have been determined with respect to concordant or near concordant (< 10 % discordant) points occur on the concordia plot as well as using the major and minor peaks found in the probability density plot (which is drawn using < 10% discordant points).

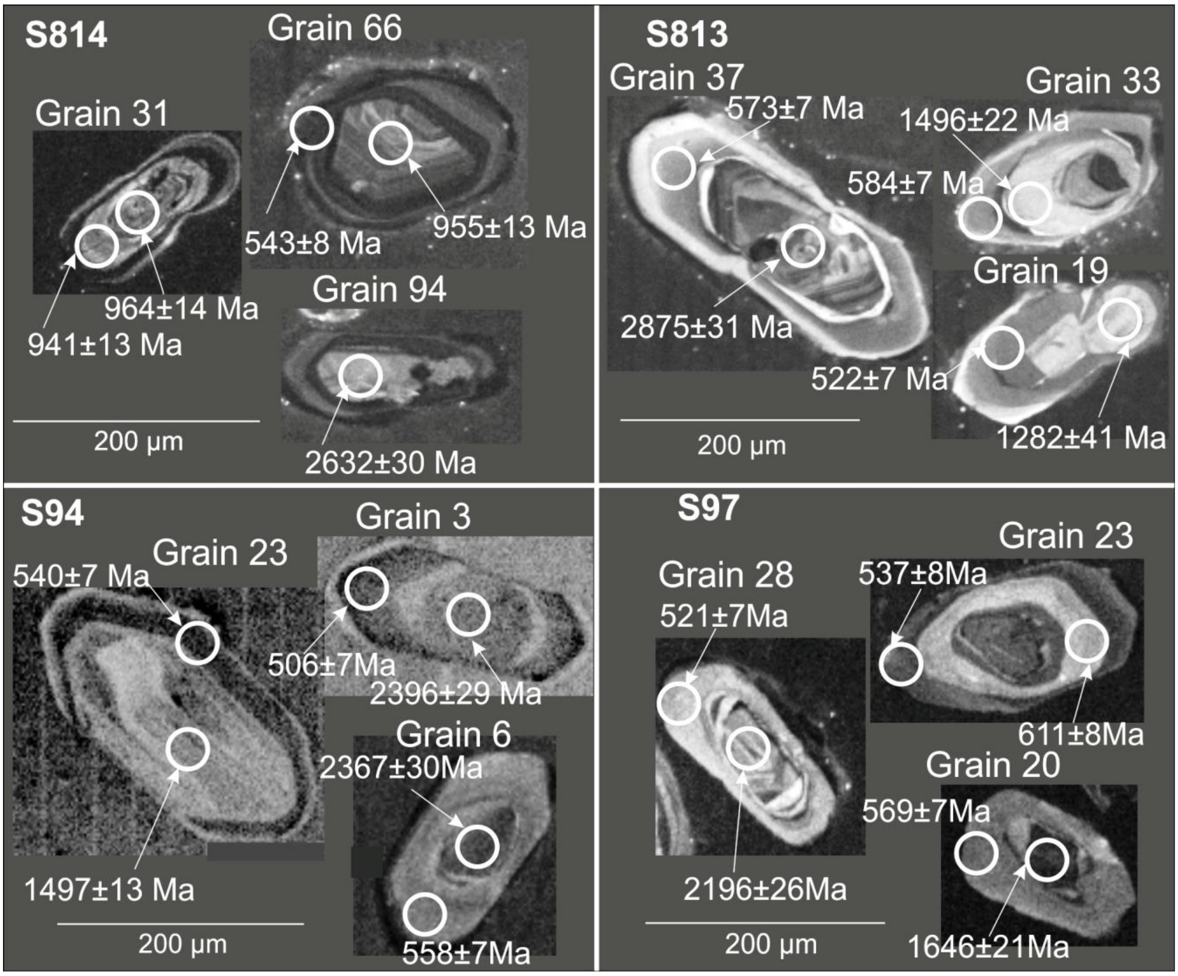

Fig. 2.2. Cathodoluminescence (CL) images and the U-Pb zircon ages of analysed detrital zircons of metaquartzites of Wanni Complex (WC) of Sri Lanka (discordance < 10%).

2.4.2. Wanni Complex Metaquartzites

2.4.2.1. Sample S-814 from Maradankadawela (WC)

The sample is a metaquartzite collected at Maradankadawela in the Wanni Complex This location is in the western WC about 30 Km west of the tentative WC-HC boundary. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under cathodoluminescent images (CL) the zircon grains generally show a diverse range of morphologies with subhedral (Fig.2.2) long tetragonal prism and pyramid combination forms. Some zircon grains are nearly equant and squat anhedral ovoids. The cores of some zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The zircon grains also show a diverse range of luminescence responses. The cores are generally dark but occasionally light coloured and luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. When the zircon cores show oscillatory zoning it will indicate zircon crystallization from a melt (Corfu et al., 2003). In this sample also some zircon cores show oscillatory zoning indicating crystallization from an igneous melt. As shown in the Fig.2.2, to represent the rock sample S814, three zircon grains, grain-31, grain-66 and grain 94 have been selected. The grain-31 shows that its core is long prismatic but sub-rounded to rounded due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with faint oscillatory zoning.

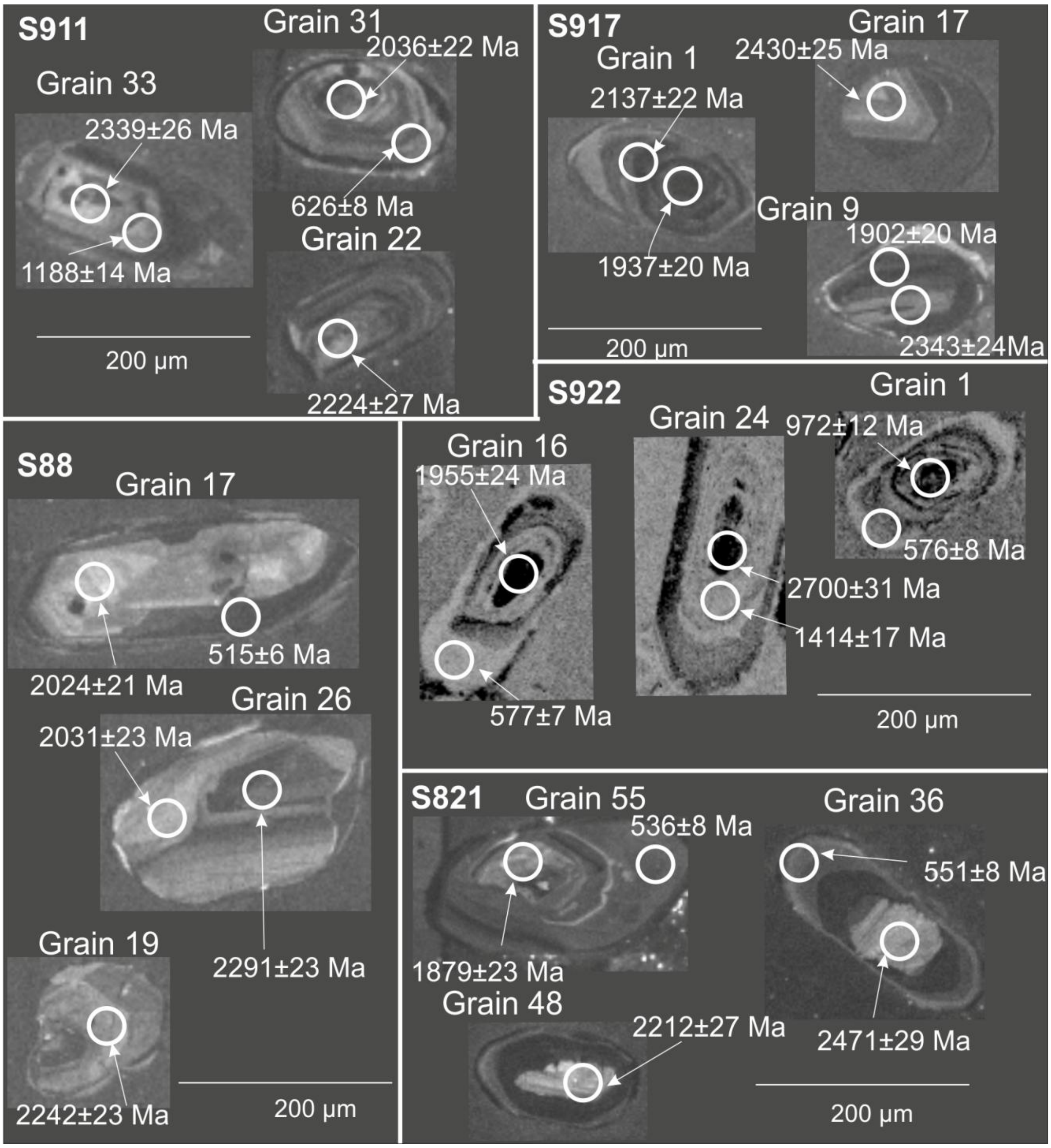

Fig. 2.3. Cathodoluminescence (CL) images and the U-Pb zircon ages of analysed detrital zircons of metaquartzites of Highland Complex (HC) of Sri Lanka (discordance < 10%).

The rims of the zircon grains are generally bright to low luminescent with concentric zones. The rims were formed during regional metamorphism. This grain is Neoproterozoic with a $^{206}Pb/^{238}U$ age of 964±14 Ma. The grain-66 is short prismatic. This grain clearly shows distinct oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a relatively thicker homogeneous and bright metamorphic rim. This is also a Neoproterozoic grain showing $^{206}Pb/^{238}U$ age of 955 ± 13 Ma. The grain-94 is subhedral and long prismatic. The core of this grain is bright luminescent and its truncated surface is also interpreted here as resulting from sedimentary abrasion during transportation. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2632± 30 Ma. The thicker metamorphic rim of the grain-66 shows an age of 543 ± 8 Ma. This shows that a mixture of detritus from Paleoproterozoic to Neoproterozoic protolith sources are found in this rock.

Sixty zircon grains were analysed from the sample S-814. Fifteen analyses were < 10% discordant. The Fig.2.4 (concordia plot) and Fig.2.6 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S814 sample is found to be ~820 Ma and the minimum age of deposition is found to be ~540 Ma and major detrital peaks occur at 820 Ma, 960 Ma, 1050 Ma, 1900 Ma, 2300 Ma, 2450 Ma, 2600 Ma, 2700 Ma, The Fig.2.4 and Fig.2.6 also show that younger Neoproterozoic detrital peaks occur at 813.5 ±11 Ma (92 % concordant) and 964 ± 14Ma (97% concordant). It is interesting to note that such Neoproterozoic detrital cores were first time reported in this study from the western WC about 30km far away from the WC-HC boundary (not a near boundary sample) and these Neoproterozoic detrital grains are found in one rock of metaquartzite as age mixtures with the typical HC older Mesoarchaean and Paleoproterozoic grains. This result is consistent with the reported Neoproterozoic detrirus from the South Indian metasediments (Collins et al., 2007). Also the maximum age of deposition of this WC metaquartzites at Maradankadawela can be constrained at ~820Ma based on >90% concordant point in Fig.2.4 –S-814 and a major peak in the probability density plot (Fig.2.6). The rims of the sample show a metamorphic age about 547 Ma and this indicates Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Maradankadawela metaquartzite received detritus from several sources of Neoproterozoic to Mesoarchean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for metaquartzites had taken place in the western WC terrane from about 820 Ma to 540 Ma.

Wanni Complex Metasedimentary Rocks

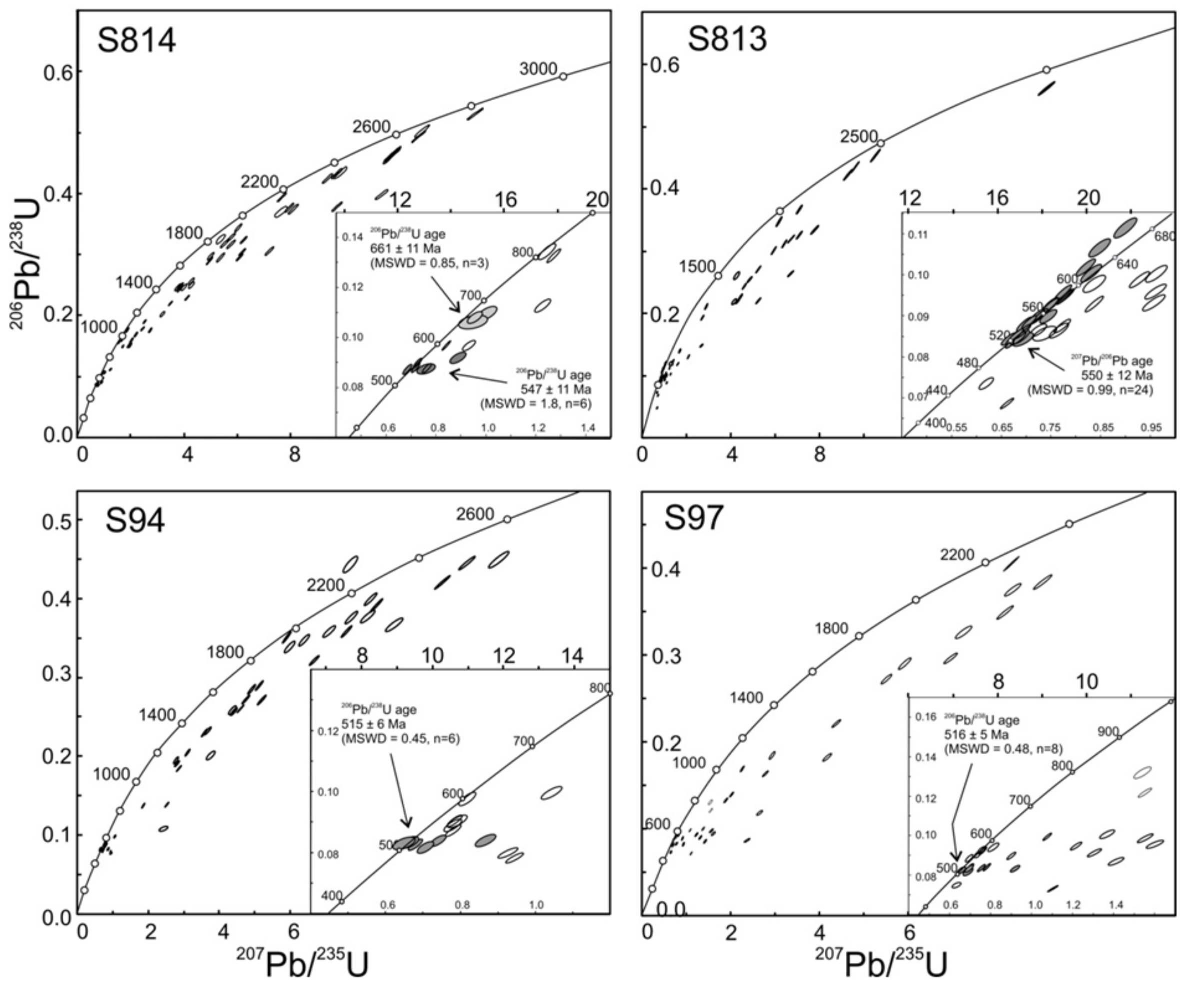

Fig. 2.4 U-Pb Concordia plots of analysed metaquartzies of Wanni Complex (WC) of Sri Lanka (MSWD- mean square of weighted deviates). Upper and lower intercepts were not calculated as there is no linear lead loss. Inset figures show weighted mean of regional metamorphism.

2.4.2.2. Sample S813 from Palugaswewa (WC)

The sample is a metaquartzite collected from a road cutting at Palugaswewa in the Wanni Complex. This location is about 12 Km west of the tentative WC-HC boundary. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.2-S813) typical long tetragonal prism and pyramid forms with occasional subhedral to anhedral forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally bright to low luminescent and concentric zones. The zircon cores frequently show oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.2 to represent the rock sample S813 three zircon grains three zircon grains have been selected as, grain-37, grain-33 and grain 19. The grain-37 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing ^{207}Pb/ ^{206}Pb age 2875 ± 31. The grain-33 is short prismatic and subhedral. The core of this grain shows three dark to bright luminescence sector zones with different U contents. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a relatively thicker metamorphic rim. This is a Mesoproterozoic detritus showing ^{207}Pb/^{206}Pb age 1496 ± 22 Ma. The grain-19 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Mesoproterozoic ^{207}Pb/ ^{206}Pb age of 1282 ± 41 Ma. The thicker metamorphic rim of the grain-33 shows an age of 584±7 Ma. This shows that a mixture of detritus from Mesoarchean to Mesoproterozoic protolith sources are found in this rock.

Fig. 2.4 U-Pb concordia plots of analysed metaquartzies of Wanni Complex (WC) of Sri Lanka (MSWD- mean square of weighted deviates). Upper and lower intercepts were not calculated as there is no linear lead loss. Inset figures show weighted mean of regional metamorphism.

Seventy two zircon grains were analysed from the sample S-813 collected at Palugaswewa in the WC. Nineteen analyses were < 10% discordant. The Fig.2.4 (concordia plot) and Fig 2.6 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S813 sample is found to be ~ 2000 Ma and the minimum age of deposition is found to be 530 Ma and major detrital peaks occur at 530 Ma, 590 Ma, 2000 Ma, 2300 Ma, 2900 Ma, Also the maximum age of deposition of this WC metaquartzite can be constrained at ~2000 Ma based on >90% concordant point in Fig.2.4 –S-813.The rims of the sample show a metamorphic age about 547 Ma and this is indicating Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Palugaswewa metaquartzite received detritus from several sources of Mesoproterozoic to Mesoarchaean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It also indicates that this sample collected at Palugaswewa is a true HC sample and the tentative WC-HC boundary is to be corrected. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 2000 Ma to 530 Ma.

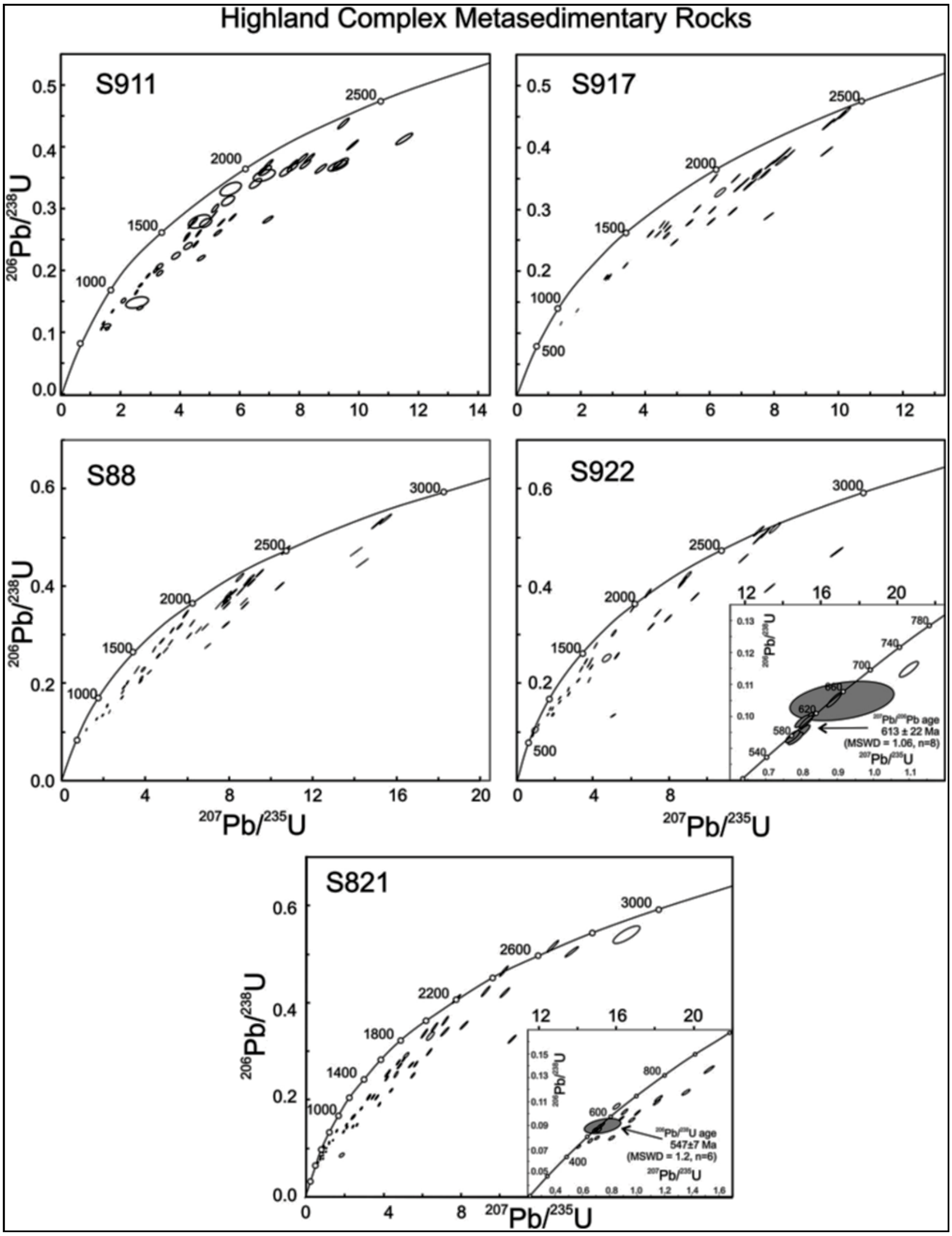

Fig. 2.5. U-Pb Concordia plots of analysed metaquartzies of Highland Complex (HC) of Sri Lanka (MSWD - mean square of weighted deviates). Upper and lower intercepts were not calculated as there is no linear lead loss. Inset figures show weighted mean of regional metamorphism.

2.4.2.3. Sample S- 94 from Dodangaslanda (WC)

The sample is a metaquartzite collected from Dodangaslanda in the Wanni Complex This location is about 10 Km west of the tentative WC-HC boundary. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.2-S-94) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. In some cores, fine luminescent zones tend to transgress rim boundaries (e.g. "ghost" zoning passing from bright inner rim to dark outer rim as shown by the three representative grains in Fig.2.2). Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.2 to represent the rock sample S-94 ,three zircon grains , grain-23, grain-3 and grain 6, have been selected. The zircon grains of this sample frequently show morphology of euhedral to subhedral prismatic crystals. The grain-23 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with faint oscillatory zoning. This grain is a Paleoproterozoic detritus showing ^{207}Pb/ ^{206}Pb age of 2131±25 Ma. The grain-3 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a relatively thicker metamorphic rim. This is a Paleoproterozoic detritus showing ^{207}Pb/ ^{206}Pb age of 2396 ± 29 Ma. The grain-6 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Paleoproterozoic ^{207}Pb/^{206}Pb age of 2367 ± 30 Ma. The thicker metamorphic rim of the grain-33 shows an age of 540±7 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Forty six zircon grains were analysed from the sample S-94 collected at Dodangaslanda in the WC. Eight analyses were < 10% discordant. The Fig.2.4 (concordia plot) and Fig.2.6 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S94 sample is found to be ~ 1900 Ma and the minimum age of deposition is found to be 515 Ma and major detrital peaks occur at 515 Ma, 600 Ma, 1900 Ma, 2200 Ma, 2400 Ma, Also the maximum age of deposition of this WC metaquartzite can be constrained at ~1900 Ma based on a >90% concordant point in Fig.2.4 –S-94.The rims of the sample show a metamorphic age about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Dodangaslanda metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchaean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It also indicates that this sample collected at Dodangaslanda is a true HC sample and the tentative WC-HC boundary is to be corrected. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 1900 Ma to 515 Ma.

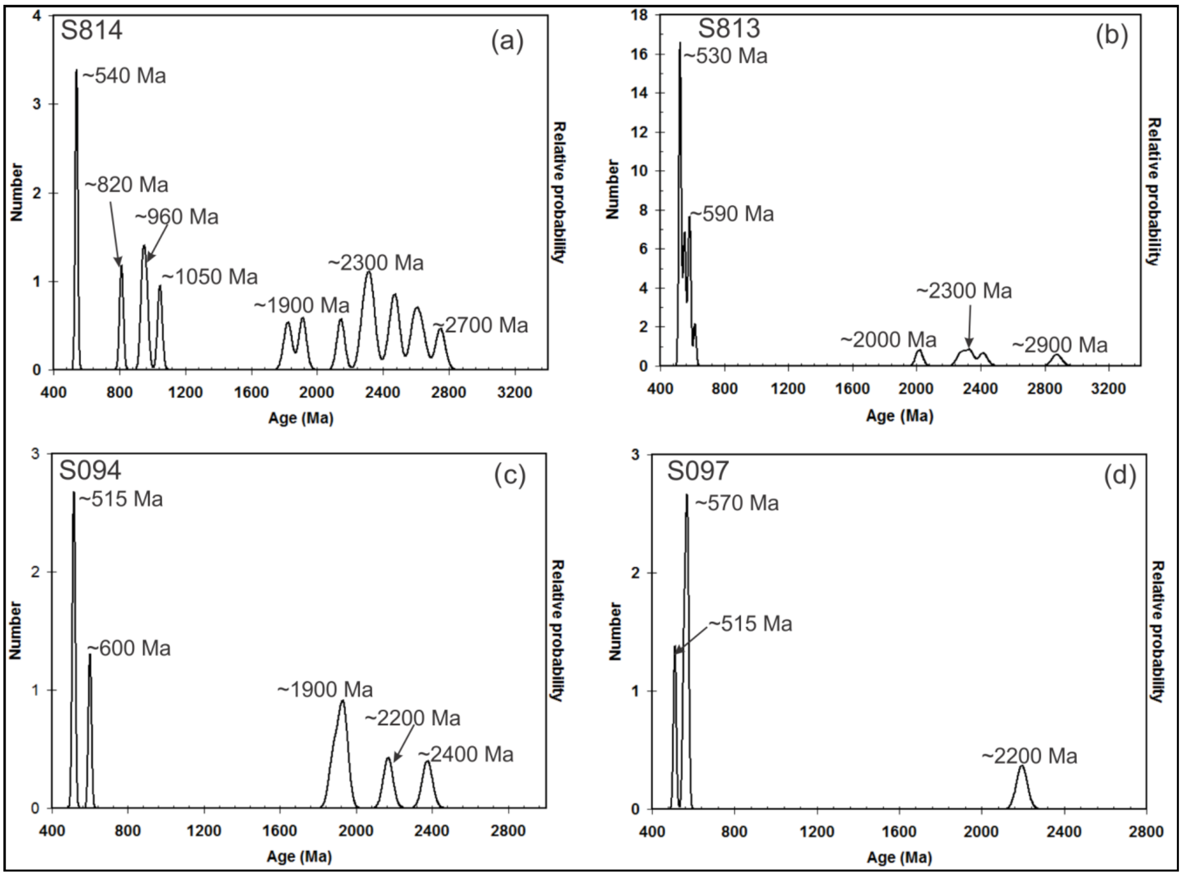

Fig. 2.6. Probability density distribution plots of individual metaquartzite samples from the Wanni Complex (WC) of Sri Lanka. Bin size of 25 was used for the histogram calculation and 10% discordance was used as a cut-off for the concordant zircon populations.

2.4.2.4. Sample S-97 from Batalagoda (WC)

The sample is a metaquartzite collected from a rock outcrop close to the Batalagoda tank area (Fig.2.1) in the WC. This location is about 10 Km far and west of the tentative WC-HC boundary. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the

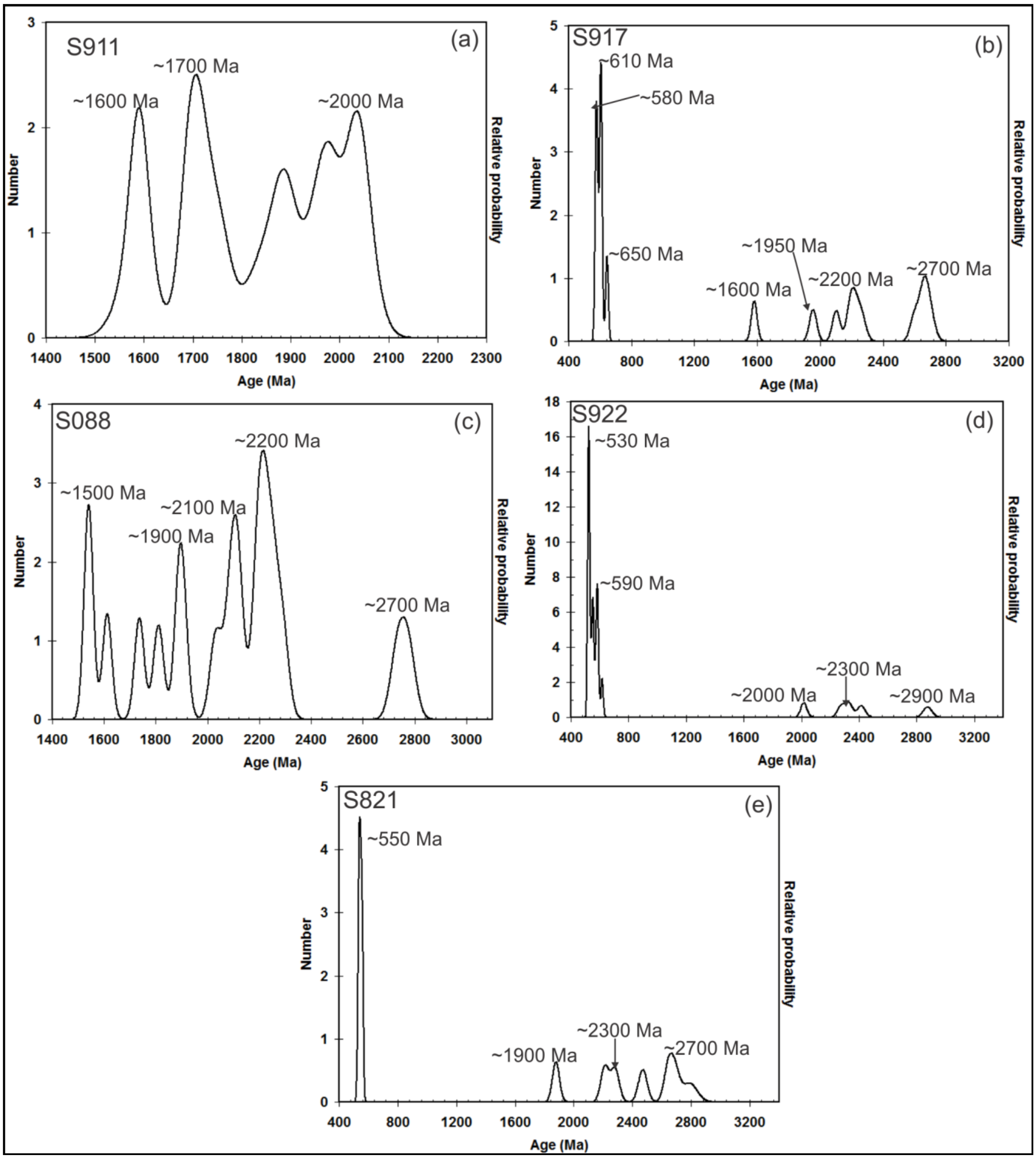

Fig. 2.7. Probability density distribution plots of individual metaquartzite samples from the Highland Complex (HC) of Sri Lanka. Bin size of 25 was used for the histogram calculation and 10% discordance was used as a cut-off for the concordant zircon populations.

zircon grains generally show (Fig.2.2-S-97) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.2 to represent the rock sample S-97 ,three zircon grains, grain-28, grain-23 and grain 20 have been selected. The grain-28 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing $^{207}Pb/^{206}Pb$ age of 2196 ±26. The grain-23 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Neoproterozoic $^{206}Pb/^{238}U$ age of 611± 8 Ma This grain shows a relatively thicker metamorphic rim. The grain-20 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoned with faint oscillatory zoning. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 1646 ± 21 Ma. The thicker metamorphic rim of the grain-33 shows an age of 540± 7 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Forty three zircon grains were analysed from the sample S-97 collected at Btalagodaa in the WC. Five analyses were < 10% discordant. The Fig.2.4 (concordia plot) and Fig.2.6 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S97 sample is found to be ~ 2200 Ma and the minimum age of deposition is found to be 515 Ma and major detrital peaks occur at 515 Ma, 570 Ma, 2200 Ma. Also the maximum age of deposition of this WC metaquartzite can be constrained at ~2200 Ma based on >90% concordant point in Fig 2.4 –S-97. The rims of the sample show a metamorphic age about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Batalagoda metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchaean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It also indicates that this sample collected at Batalagoda is a true HC sample and the tentative WC-HC boundary is to be corrected. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 2200 Ma to 515 Ma.

2.4.3. Highland Complex (HC)

2.4.3.1. Sample S8-21 from Rattota-Pallagama (HC)

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The sample is a metaquartzite collected from Rattota-Pallegama in the Highland Complex. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.3-S-821) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The zircon grains of this rock show a variety of morphologies ranging from subhedral prismatic crystals to anhedral equant rounded grains. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.3, to represent the rock sample S-821, three zircon grains, grain-55, grain-36 and grain 48 have been selected. The grain-55 shows that its core is long prismatic but sub-rounded to rounded, truncated and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing $^{207}Pb/^{206}Pb$ age of 1879 ± 23. The grain-36 is long prismatic and subhedral. This grain clearly shows an inner core of bright luminescence and an outer core of dark luminescence. It also has got concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2471 ± 29 Ma This grain shows a relatively thicker metamorphic rim. The grain-48 is subhedral to anhedraland long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2212 ± 27 Ma. The thicker metamorphic rim of the grain-36 shows an age of 551±8 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Sixty one zircon grains were analysed from the sample S-821 collected at Rattota-Pallegama in the HC. 14 analyses were < 10% discordant. The Fig.2.5 (concordia plot) and Fig 2.7 (probability density plot drawn for <10% discordant grains) show that the maximum age of deposition of the S821 sample is found to be ~ 1900 Ma and the minimum age of deposition is found to be 515 Ma and major detrital peaks occur at 550 Ma, 1900 Ma, 2300 Ma and 2700 Ma. Also the maximum age of deposition of this HC metaquartzite can be constrained at ~1900 Ma based on a >90% concordant point in Fig.2.5 –S-821.The rims of the sample show a metamorphic age of about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Rattota-Pallegama metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 1900 Ma to 515 Ma (as the minimum age of deposition tends to direct towards the 515 Ma).
The rims of the sample show about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism.

The Fig. 2.6-S-821 shows deposition of sediments had taken place in the HC terrane from about 1900 Ma (as the maximum age of deposition is about 1900 Ma based on a near concordant point in the concordia plot) to 515 Ma.

2.4.3.2. Sample S-911 from Midlands (HC)

The sample is a metaquartzite collected from Midlands in the Highland Complex . The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.3-S-911) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.3, to represent the rock sample S-911, three zircon grains, grain-33, grain-31 and grain 22 have been selected. The grain-33 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing age 2339 ± 26 Ma. The grain-31 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2036 ± 22 Ma This grain shows a relatively thicker metamorphic rim. The grain-22 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2224 ± 27 Ma. The thicker metamorphic rim of the grain-31 shows an age of 626±27 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Sixty seven zircon grains were analysed from the sample S-911 collected at Midlands in the HC. Three analyses were < 10% discordant. The Fig.2.5 (concordia plot) and Fig.2.7 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S911 sample is found to be ~ 1600 Ma and major detrital peaks occur at 1600 Ma, 1700 Ma and 2000 Ma. Also the maximum age of deposition of this HC metaquartzite can be constrained at ~1600 Ma based on >90% concordant point in Fig.2.5 –S-911. This suggests that the premetamorphic materials of the Midlands metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 1600 Ma to 515 Ma.

The rims of the sample show about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism.

The probability density plot, Fig.2.6-S-911 shows deposition of sediments had taken place in the HC terrane from about 1600 Ma (as the maximum age of deposition is about 1600Ma based on a near concordant point in the concordia plot) to 515 Ma.

2.4.3.3. Sample S-917 from Habarana-Minneriya (HC)

The sample is a metaquartzite collected from a road side rock cutting at Habarana-Minneriya (Fig.2.1) in the HC. The rock is light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.3-S-917) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.3, to represent the rock sample S-917, three zircon grains , grain-1, grain-17 and grain 9 have been selected. The grain-1 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic and showing $^{207}Pb/^{206}Pb$ age of 2137 ± 22 Ma. The grain-17 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2430 ± 25 Ma This grain shows a relatively thicker metamorphic rim. The grain-9 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2343 ± 24 Ma. This shows that a mixture of detritus from Paleoproterozoic to Neoarchaen protolith sources are found in this rock.

Forty three zircon grains were analysed from the sample S-917 collected at Habarana-Minneriya in the HC. Four analyses were < 10% discordant. The Fig.2.5. shows that the concordia plot of the sample has got a large number of scattered discordant points due to considerable lead loss during highgrade metamorphism. This scattered discordant points have caused a difficulty to draw a best fit line to determine the upper and lower intercepts to find the maximum and minimum ages of deposition of sedimentary detrital grains. Under these conditions the maximum and minimum ages of deposition are possible to determine with respect to concordant or near concordant (< 10 % discordant) points occur on the concordia plot as well as using the major and minor peaks found in the probability density plot. The Fig.2.5 (concordia plot) and Fig.2.7 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S917 sample is found to be ~ 1600 Ma and major detrital peaks occur at 580 Ma, 610 Ma, 650 Ma, 1600 Ma, 1950 Ma, 2200 Ma and 2700 Ma. Also the maximum age of deposition of this HC metaquartzite can be constrained at ~1600 Ma based on >90% concordant point in Fig.2.5 –S-917. This suggests that the premetamorphic materials of the Habarana-Minneriya metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchaean sources as well as detritus were well mixed during transportation and deposition as shown by above ages.. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 1600 Ma to 580 Ma.

The rims of the sample show about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism.

The Fig.2.6-S-917 shows deposition of sediments had taken place in the HC terrane from about 1600 Ma (as the maximum age of deposition is about 1600 Ma based on a near concordant point in the concordia plot) to 515 Ma.

2.4.3.4. Sample S-88 from Minneriya (HC)

The sample is a metaquartzite collected from Minneriya in the Highland Complex . The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.3-S-88) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.3, to represent the rock sample S-88, three zircon grains, grain-17, grain-26 and grain 19 have been selected. The grain-17 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing $^{207}Pb/^{206}Pb$ age of 2024 ± 21 Ma. The grain-26 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2291 ± 23 Ma. This grain shows a relatively thicker metamorphic rim. The grain-19 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoned with faint oscillatory zoning. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2242±23 Ma. The thicker metamorphic rim of the grain- shows an age of 515 ± 6 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Fifty five zircon grains were analysed from the sample S-88 collected at Minneriya in the HC. Nine analyses were < 10% discordant. The Fig.2.5 (concordia plot) and Fig.2.7 (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S88 sample is found to be ~ 1500 Ma and major detrital peaks occur at 1500 Ma, 1900 Ma, 2100 Ma, 2200 Ma, and 2700 Ma. Also the maximum age of deposition of this HC metaquartzite can be constrained at ~1500 Ma based on >90% concordant point in Fig.2.5 –S-88. This suggests that the premetamorphic materials of the Minneriya metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchaean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 1500 Ma to 580 Ma.

The rims of the sample show about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism. The Fig.2.6-S-88 shows deposition of sediments had taken place in the HC terrane from about 1500 Ma (as the maximum age of deposition is about 1500 Ma based on a near concordant point in the concordia plot) to 515 Ma (as the minimum age of deposition tends to direct towards the 515 Ma.

2.4.3.5. Sample S-922 from Giritale (HC)

The sample is a metaquartzite collected from a rock outcrop at a road cutting at Giritale area (Fig.2.1) in the HC. The rock is white to light coloured and consists of quartz as the major mineral. The rock shows coarse to very coarse grained granoblastic texture. Under CL the zircon grains generally show (Fig.2.3-S-922) typical long tetragonal prism and pyramid forms. The cores of zircon grains show porphyritic to idiomorphic outlines indicating a protolith source of an intrusive igneous rock. The cores are generally dark but occasionally light coloured and brightly luminescent depending on the U content. Some cores show oscillatory zoning indicating crystallization from an igneous melt. The rims of the zircon grains are generally luminescent and sometimes showing oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003). The rims were formed during regional metamorphism. As shown in the Fig.2.3, to represent the rock sample S-922, three zircon grains, grain-16, grain-24 and grain 1 have been selected. The grain-16 shows that its core is long prismatic but sub-rounded to rounded and subhedral due to long distance transportation. This grain shows concentric zoning and diverse luminescence responses with oscillatory zoning. This grain is a Paleoproterozoic detritus showing $^{207}Pb/^{206}Pb$ age of 1955± 24 Ma. The grain-24 is short prismatic and subhedral. This grain clearly shows concentric and faint oscillatory zoning. The variation of luminescence is shown with low to moderate brightness. This grain shows a Paleoproterozoic $^{207}Pb/^{206}Pb$ age of 2700 ± 31 Ma This grain shows a relatively thicker metamorphic rim. The grain-1 is subhedral and long prismatic. The core of this grain is bright luminescent and sector zoning with faint oscillatory zoning. This grain shows a Neoproterozoic $^{206}Pb/^{238}U$ age of 972 ± 12 Ma. The thicker metamorphic rim of the grain 1- shows an age of 576±8 Ma. This shows that a mixture of detritus from Paleoproterozoic to Mesoproterozoic protolith sources are found in this rock.

Forty six zircon grains were analysed from the sample S-922 collected at Giritale in the HC. Seventeen analyses were < 10% discordant. The Fig.2.5 (concordia plot) and Fig.2.7 (probability density plot drawn for <10% discordant grains) show that the maximum age of deposition of the S88 sample is found to be ~ 2000 Ma and major detrital peaks occur at 530 Ma, 590 Ma, 2000 Ma, 2300 Ma, and 2900 Ma. Also the maximum age of deposition of this HC metaquartzite can be constrained at ~2000 Ma based on >90% concordant point in Fig.2.5 –S-922. This suggests that the premetamorphic materials of the Giritale metaquartzite received detritus from several sources of Paleoproterozoic to Neoarchean sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for this metaquartzite had taken place in this terrane from about 2000 Ma to 530 Ma.

The rims of the sample show about 515 Ma and this is indicating Ediacaran-Cambrian metamorphism.

The Fig.2.6-S-922 shows deposition of sediments had taken place in the WC-HC terrane from about 2000 Ma (as the maximum age of deposition is about 2000 Ma based on a near concordant point in the Concordia plot) to 515 Ma.

2.5. Discussion

2.5.1. Age constraints of deposition

All the metaquartzite samples of WC and HC of Sri Lanka contain clear records for a considerable Paleoproterozopic to Neoarchaean to Mesoarchaean detrital grain input into their original sedimentary constitution (Fig.2.4, Fig.2.5, Fig.2.6 and Fig.2.7). Generally the maximum age of deposition with respect to the youngest <10% discordant core analyses in all the eight near boundary WC and HC samples ranges from ~1500 Ma to ~2000Ma except one sample in western WC (S814) indicates that the maximum age of deposition is ~ 820 Ma. This study reveals that both the near boundary WC and all the HC metaquartzites show similar provenance with common and major detrital peaks occurring at 1900 Ma, 2000 Ma, 2200 Ma, 2300 Ma, 2400 Ma, 2700 Ma and 2900 Ma. Therefore, the maximum age of deposition of all the eight samples of near boundary WC and all the HC metaquartzites except the S814 collected at Maradankadawela in the western WC can be approximately constrained at ~ 2000 Ma. The depositional age for the protoliths for these samples is constrained approximately between ~2000 Ma and ~550 Ma (between the youngest reliable detrital zircon grain and the age of regional metamorphism). However it is very interesting to note that one metaquartzite sample which was collected at Maradankadawela in the western WC relatively far away from the current tentative WC and HC boundary has yielded Neoproterozoic analyses of detritus with $^{206}Pb/^{238}U$ ages of 813.5 ± 11 Ma and 964 ± 14 Ma. It is interpreted as constraining the age of deposition of this WC (S814) sample to younger than 813 ± 11 Ma. But this particular WC metaquartzite sample showing Neoproterozoic detritus also contains Mesoproterozoic to Paleoproterozoic to Neoarchaean to Mesoarchaean detrital grains which indicating protolith ages 1050 Ma, 1900 Ma, 2300 Ma, 2450 Ma, 2600 Ma, and 2700 Ma. This shows that age mixtures of both Neoproterozoic and Paleoproterozoic to Neoarchaean sedimentary detritus were deposited in sediments which were deposited relatively far away in the western WC from the currently tentative WC-HC boundary. This also indicates that metasedimentary sequences of WC and HC existed adjacent to each other since early Neoproterozoic. But absence of Neoproterozoic detritus in all the other three near boundary metaquartzite samples (S813, S94 and S97) of WC which were collected closer to the tentative WC-HC boundary in the WC terrane clearly shows similar provenance characteristics to the all five HC metaquartzites (S821, S911, S917, S88 and S922). It is here suggested that the current tentative WC-HC boundary which was established based on Sm-Nd model ages is not accurate and the three (S813, S94 and S97) WC metaquartzites near WC-HC boundary should be belonging to the HC terrane. The discovery of Neoproterozoic detritus only in the western WC terrane strongly indicates that only western WC terrane exceptionally derived detritus from younger protolith sources.

The significant fact that this Neoproterozoic detritus is found in one western WC rock with age mixtures of Neoarchaean to Paleoproterozoic typical HC older detritus. It is important to note that metasedimentary rocks are very subordinately or rarely found in the WC terrane and also associated with and comprised of prominent continental arc type metaigneous rocks indicating WC terrane did not exist as a deep oceanic basin of an orogenic belt and WC is here interpreted as a continental block with shallow and scattered sedimentary basins whilst metasedimentary rocks are predominantly found in the HC indicating a thick pile or succession of typical limestone, shale and sandstone sediments were the pre-metamorphic materials and HC is here interpreted as a deep basin of an orogenic belt. This indicates that shallow sedimentary basins existing in continental blocks of WC and the deep basin of HC orogenic belt existed adjacent to each other since the early Neoproterozoic time and Neoproterozoic detritus of WC metaquartzites were derived from both the HC terrane as well as from probable east African sources (because it is interpreted in this study that deep basin of HC orogenic belt was existing in the ancient Mozambique ocean) but was deposited in the Neoproterozoic. This result is interpreted to describe that the WC is not the same crustal domain with the HC but western WC part received detrital sediments from both younger Neoproterozoic protolith sources as well as older Paleoproterozoic to Neoarchaean to Mesoarchaean protolith sources as age mixtures. I here also suggest that the true WC terrane exists further west of current tentative WC-HC boundary. Dharmapriya et al., 2016 summarised U-Pb detrital zircon ages of WC and HC of Sri Lanka as shown in the time-space plot (Fig.2.10) and showed that detrital U-Pb zircon ages of WC range from 3.0 Ga to 0.65 Ga and detrital U-Pb zircon ages of HC ranges from 3.25 Ga to 0.7 Ga. The present study on the WC and HC detrital zircon ages is found to be broadly consistent with the U-Pb detrital zircon data in above time –space plot and supporting the suggestion of age mixtures of detrital zircon cores from Mesoarchaean to Neoarchaean to Paleoproterozoic to Neoproterozoic ages by this present study.

The samples analysed in this study had been collected from a large area along two northern and southern transects across the island of Sri Lanka and there is no possibility that the protolith detrital garins to these metaquartzite rocks were deposited in the same sedimentary system of deposition. Within one sedimentary basin of orogenic belt or continental block there can be more than one sedimentary systems and more than one successions of sedimentary systems can be possible. I here suggest that all five HC and three WC near WC-HC boundary metaquartzites represent one succession of sediments while the sample S814 collected in the western WC and far away from the WC-HC boundary represents another succession of sediments most probably deposited in another different sedimentary shallow basin in an adjacent continental crustal block . The WC is clearly a different continental crustal domain which had collided with the HC deep sedimentary basin of orogenic mobile belt along the WC-HC boundary and double plunging synforms or arenas of KC are interpreted to have formed from WC continental parent rock materials when the basement oceanic crust of HC subducted underneath the WC and VC continental blocks in Ediacaran-Cambrian.

2.5.2 Provenance implications

The <10% discordant detrital peaks of all four WC metaquartzites are shown in the probability density plots, Fig.2.8(a), and Fig.2.6. It shows two Neoproterozoic detrital peaks corresponding to one sample and six Paleoproterozoic to Mesoarchean detrital peaks corresponding to three other samples. This shows that near boundary WC metaquartzites have derived detritus generally from Paleoproterozoic to Mesoarchean protolith sources. The < 10% discordant detrital peaks of the five HC metaquartzites are shown in the Fig.2.8 (b) and Fig.2.7. It shows one Mesoproterozoic detrital peak, seven Paleoproterozoic detrital peaks, one Neoarchean detrital peak, and one Mesoarchean detrital peak in all five metaquartzite samples. This shows that HC metaquartzites have derived sedimentary detritus generally from Mesoproterozoic to Paleoproterozoic to Neoarchaean to Mesoarchaean protolith sources. Thus, it indicates that the near boundary WC and HC metaquartzites have similar sedimentary provenance except one western WC metaquartzite sample showing Neoproterozoic detritus.

As far as possible protolith sources for the WC and HC metaquartzites are concerned with respect to paleotectonic positions prior to amalgamation of Gondwana, sources abundant in the Indian landmass, Madagascar, East Africa and Antarctica can be attempted. If, possible Indian sources are considered first, the Dharwar craton of Mesoarchaean to Neoacrchaean exists north of the Southern Granulite terrane of India and provided >3.0Ga detritus into Dharwar-derived sediments throughout the Proterozoic (Collins et al., 2003). But the protolith material from the Dharwar craton can be excluded as no > 3.0 Ga ages were found in these WC & HC metaquartzite samples. It was reported that rocks dated between 1880 and 1700 Ma are found in the Krishna province of the Eastern Ghats of India (Dobmeier and Raith, 2003). Zircon xenocrysts were dated as 2431 Ma and also a detrital grain was dated as 2747 Ma $^{206}Pb/^{207}Pb$ age (Shaw et al., 1997). But no prominent 1990 Ma to 2300 Ma peaks can be found in Eastern Ghats (Collins et al., 2007). So the Indian sources do not indicate Paleoproterozoic sources for the neighbouring WC and HC metaquartzies and it is suggested that protoliths to WC and HC terranes of Sri Lanka may be sourced from non-Indian sources.

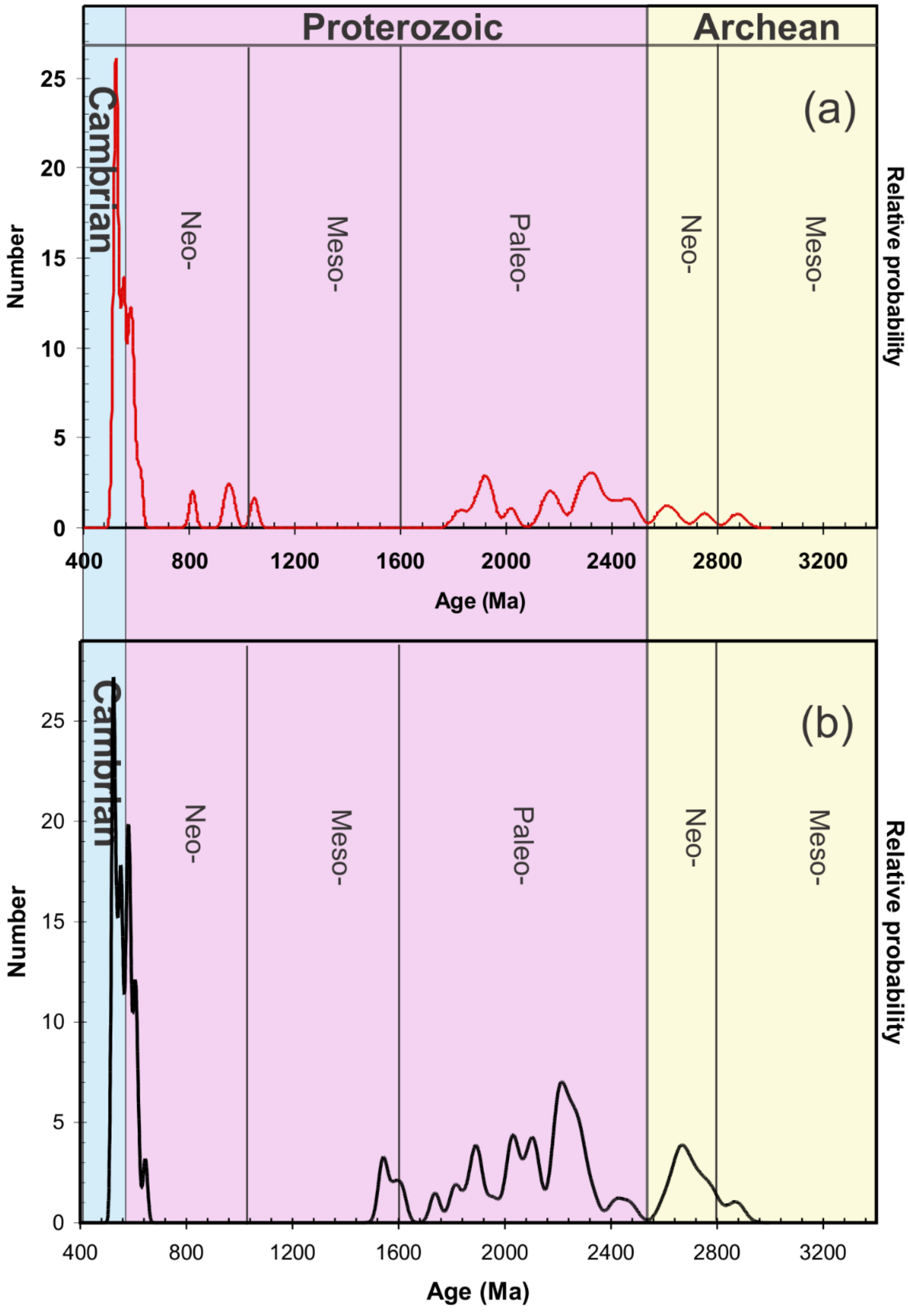


Fig. 2.8. Probability density distribution plot of all metaquartzite samples from the (a)Wanni Complex (WC) and (b) Highland Complex (HC) (b) of Sri Lanka. Bin size of 25 was used for the histogram calculation and 10 % discordance was used as a cut-off for the concordant zircon populations.

With respect to the current directions, the island of Madagascar exists west of the island of Sri Lanka and comprises of similar metasedimentary supracrustal rocks in the west and south of the Madagascar (Windley et al., 1994; Collins et al., 2003a; Fernandez et al., 2003; Cox et al., 1998; Cox et al., 2004; Fitsimons and Hulscher, 2005; Collins, 2006). These metamorphosed sedimentary rocks consists of two sedimentary successions: one succession of probable Paleoproterozoic age, named as the Itremo Group (Cox et al., 1998), which contains Neoarchaean and Paleoproterozoic detrital zircon grains; a second succession of Neoproterozoic age, known as the Molo Group with Neoarchean, Paleoproterozoic and Neoproterozoic zircon detritus (Cox et al., 2004; Fitzsimons and Hulscher, 2005). In recent Gondwana reconstructions these two successions are placed adjacent to each other and contain broadly similar detrital zircon records with predominant Paleoproterozoic protolith sources. It is found that the detrital zircon record of the HC of Sri Lanka correlates with the Paleoproterozoic Itremo Group of Madagascar metasedimentary succession whilst the detrital zircon record of the western WC of Sri Lanka correlates with the Neopoterozoic Molo Group of the Madagascar. Further, Collins et al. (2007b) showed that the protoliths to many of the metasedimentary gneisses of the Trivandrum Block of Southern India were sourced from Paleoproterozoic and Neoarchaean rocks and that the rocks were deposited sometime after c. 1900 Ma. It is very interesting to note that this formes a clear link between the Highland Complex of Sri Lanka and the Trivandrum Block of Southern India as this age and provenance study of metaquartzites of the HC of Sri Lanka shows similar provenance and maximum age of deposition ~ between 1900 Ma to 2000 Ma to that of Trivandrum Block of South India. So the Trivandrum Block and the HC were deposited sometime after c. 1900 Ma to 2000 Ma, most probably as a single system of sediments in one basin. Geological evidence also clearly supports that the HC of Sri Lanka is a part of a collisional and subduction associated orogeny whilst the Trivandrum Block of Southern India is also a part of a similar collisional orogeny. I here suggest a link between the HC of Sri Lanka, Trivandrum Block of Southern India and the Itremo Group of central Madagascar. This tends to pinpoint about the Paleotectonic position of Sri Lanka during the assembly of Gondwana supercontinent. I, here suggest a paleotectonic position of Sri Lanka (see Fig.6.1 and Fig.6.2 in chapter 6) which is somewhat similar to a paleotectonic position suggested by Plavsa et al 2014 (Fig.2.11). In this suggested paleotectonic position of this study the Itremo Group of central Madagascar, Trivandrum Block of South India and Highland Complex of Sri Lanka formed as one continuous orogenic mountainous terrane of the ancient micro-continent Azania which is associated with subduction, collision and arc related magmatic processes of the Molo Group of Madagascar, Southern Madurai Block of India and Wanni Complex of Sri Lanka. Sri Lanka's paleotectonic position could be south east of south India before Gondwana being amalgamated in Ediacaran-Cambrian (see Fig.6.1 and Fig.6.2 of chapter 6)) and the HC of Sri Lanka, Trivandrum Block of South India and Itremo Group of Madagascar formed as a part of the micro-continent Azania that lay above a south/west (present directions) dipping Cryogenian- Ediacaran subduction zone in a collisional orogeny when final consumption of the south Mozambique ocean occurred as double subduction during the assembly of Gondwana in the Ediacaran-Cambrian (This is also consistent with Collins and Pisarevsky, 2005). On the other hand U-Th-Pb SHRIMP secondary ion mass spectrometry of zircons of South India showed similar correlations with the Itremo Group and Molo Group metasedimentary successions of Madagascar (Collins et al., 2007). A coupled U-Pb and Hf isotopic analysis of detrital zircons from Southern Granulite Terrane of India showed that the Nothern Madurai Block and Trivandrum Blocks correlate with the Itremo Group of Madagascar whilst the Southern Madurai Block correlates with the Molo Group of Madagascar as shown in Probability Density Distribution Plots (Fig.2.9) of matasedimentary packages from across the adjacent Gondwanan terranes (Plavsa et al., 2014). It also reveals that the metasedimentary rocks of the HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metasedimentary rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Southern Indian sequences, and Malagasy sequences represent either shallow basins of continental blocks or deep basins of orogenic mobile belts. When the age, sedimentary provenance, maximum age of deposition, structural geological and lithological data are interpreted, it is suggested that the Trivandrum Block of South India shows a strong similarity to the HC of Sri Lanka. Therefore, it is interpreted that Trivandrum Block and HC had existed as a deep basin of an orogenic mobile belt since Paleoproterozoic (~ 2.0 Ga) to Neoproterozoic (~ 0.5 Ga). It is also to be noted that though there is similar sedimentary provenance the Northern Madurai Block of South India and HC may have not existed as a single terrane or basin connected to each other. Similarly, the WC of Sri Lanka is interpreted as the south eastern continuation of the Southern Madurai Block of South India based on data and results of age, provenance and maximum age of deposition of this study.

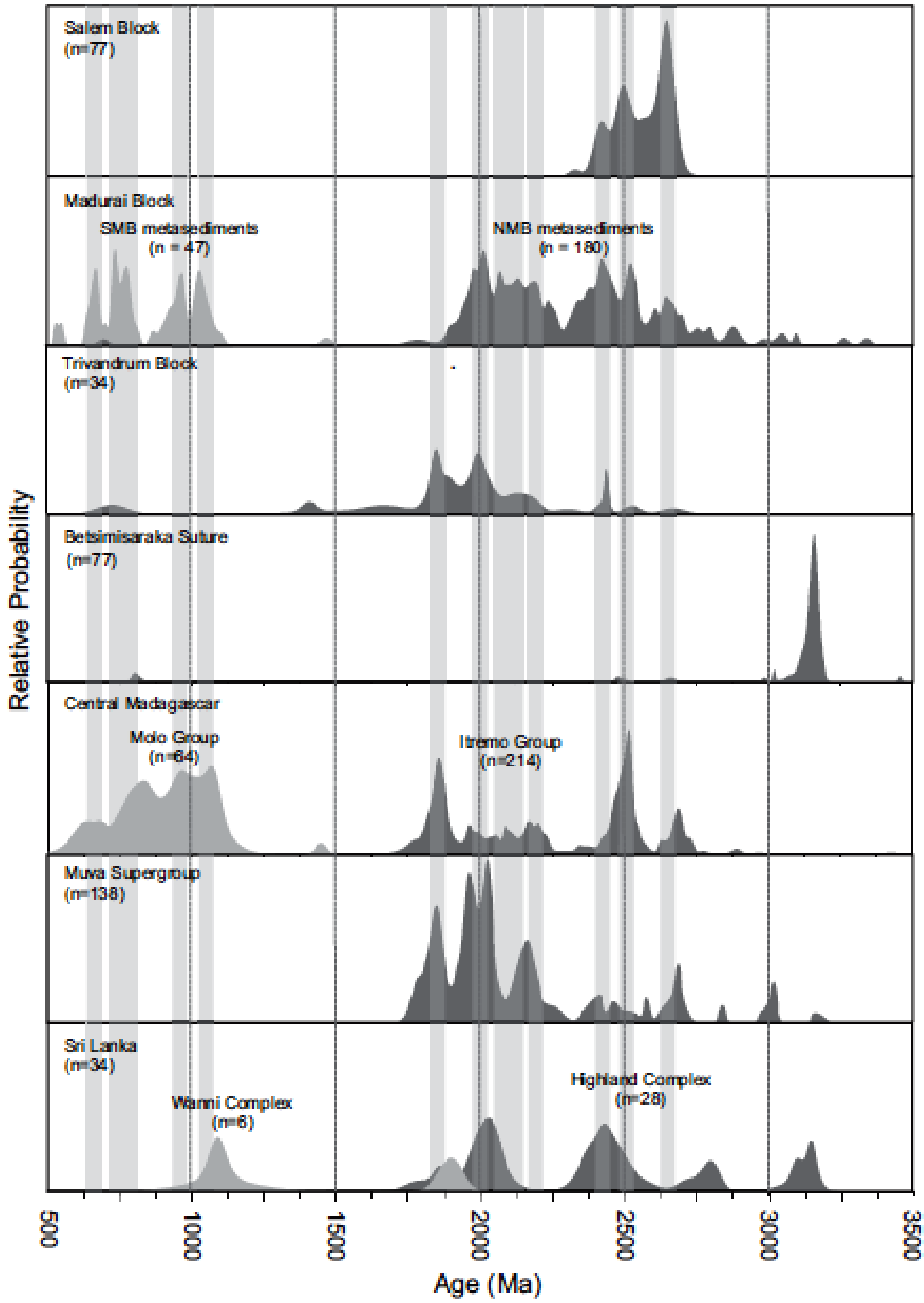


Fig. 2.9: Probability density distribution plots of the metasedimentary packages from across the adjacent Gondwanan terranes (SMB- southern Madurai block ; NMB- northern Madurai block). Only concordant (<10% discordant detrital zircon ages were used to calculate the probability density plots. Figure references; Salem block-this study, Collins et al. (2007 b), Kooijman et al. (2011), and Teale et al. (2011); Trivandrum block- Collins et al . (2007 b); Betsimisaraka suture- Collins et al. (2003); central Madagascar- Cox et al. (2004) and Fitzsimons and Hulscher (2005); Muva Supergroup- De Waele and Fitzsimons

(2007) and Rainaud et al (2003); Sri Lanka- Kröner et al (1987) (based on permission Plavsa et al 2014).

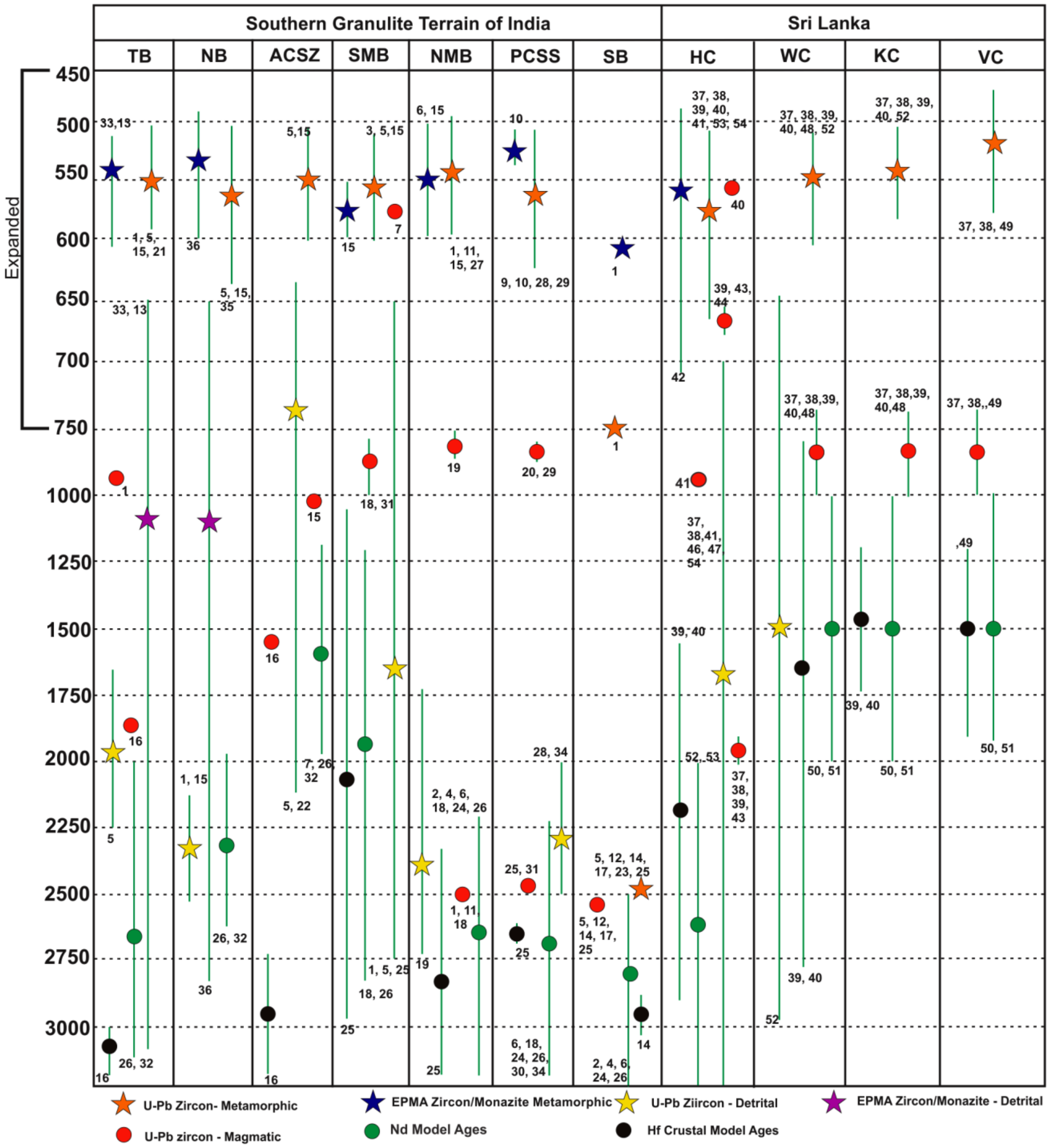
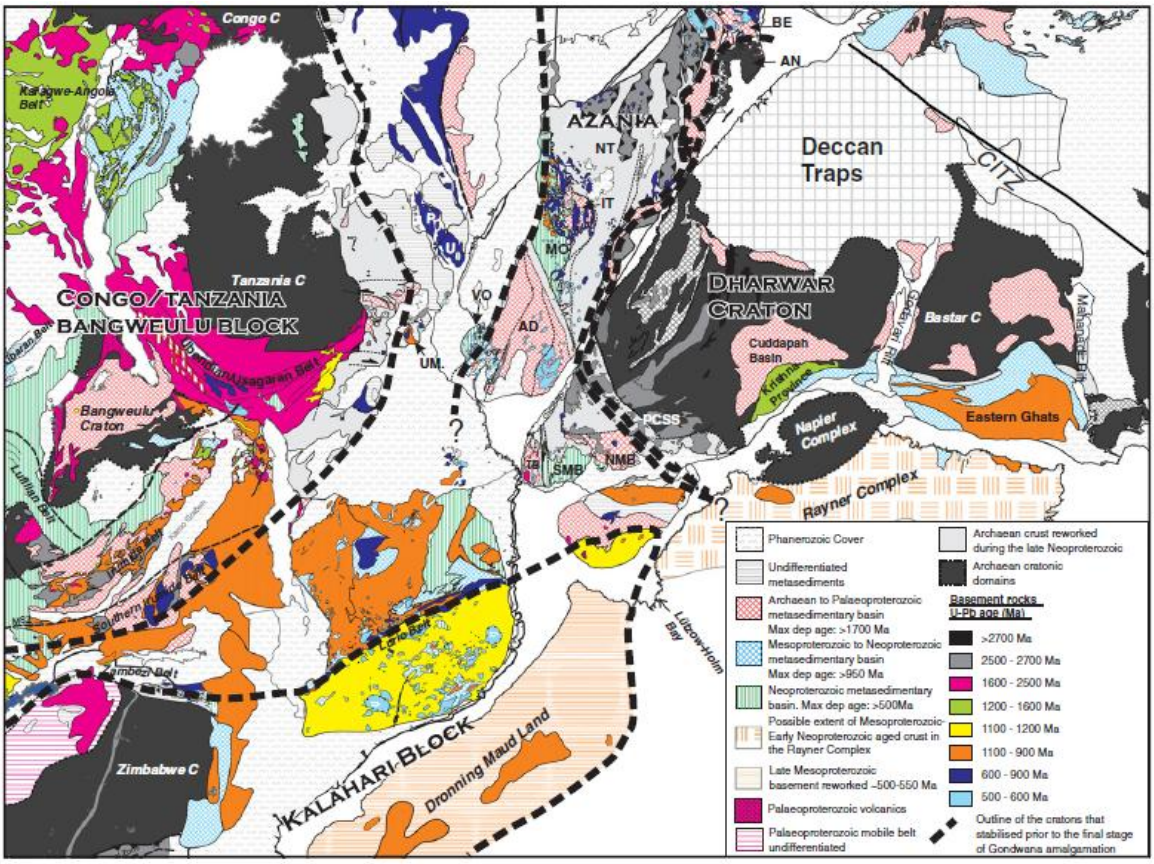


Fig. 2.10 Time–space plot of tectonothermal events in the Southern Granulite Terrane of India (after Dharmapriya et al., 2016).

It was suggested that the Itremo Group and the Molo Group were sourced from the eastern Africa (Cox et al., 2004; Fitssimons and Hulscher., 2005). Eastern Africa contains potential protolith source rocks for all the detrital age peaks obtained in this study from WC and HC metaquartzites of Sri Lanka. It was reported that the Irumide Orogens, Tanzanian craton and Usagaran/Ubende orogens contain ~2.7 Ga, 2.3 Ga- 1.8 Ga granitoid plutons (Lenoir et al., 1994; Borg and Krogh, 1999; Reddy et al., 2003b; Sommer et al., 2003; Collins et al., 2004; Johnson et al ., 2005; de Waele et al., 2007). In the Kibaran belt of eastern Africa Mesoproterozoic protoliths were dated at ~ 1.4 Ga (Kokonyangi., 2004) and Neoproterozoic magmatic rocks of central Madagascar were dated (Handke et al., 1999; Kröner et al., 2000) and Neoproterozoic rocks were dated from the Mozambique belt (Kröner et al., 2003). I here suggest that metaquartzites of WC and HC of Sri Lanka derived sedimentary detritus from east African sources. It is also suggested a plate tectonic model based on this study that the paleotectonic position of Sri Lanka (see Fig.6.1 and Fig.6.2 of chapter 6) would be south east of South India before Gondwana being amalgamated in Neoproterozoic and this position is somewhat similar to what was suggested by Teal et al.2011, (Plavsa et al., 2014 (b) and Collins et al., 2014) in Fig.2.11.



Fu. 2.11 Geological map showing the potential source areas and Precambrian sedimentary basins within the individual Gondwanan terranes after Plavsa et al. (2014). Gondwana reconstruction after Collins and Pisarevsky (2005). The compilation of ages and geological maps is based on the published work of a number of authors (for references see supplementary material). Block abbreviations; P-Pare Mountains; U-Usambara Mountains; UM- Uluguru Mountains; VO- Vohibory Block; AD- Androyen Block; MO- Molo Group; IT- Itremo Group; NT-Antananarive Block; AN- Antongil Block; BE- Bemarivo Block; CITZ- Central Indian Tectonic Zone; PCSS- Palghat Cauvery Shear System; NMB- Northern Madurai Block; SMB- Southern Madurai Block) (after permission from Collins et al. 2014)..

The field information and differences of grade of metamorphism show that HC rocks were subjected to relatively deeper burial into lower crust and greater uplifting from the lower crust level than the WC rocks during orogenesis. I suggest a plate tectonic model for the geological origin of Sri Lanka with 'HC orogeny' and this had taken place in late Neoproterozoic when WC and VC as two Mesoarchaean continental blocks with deposited shallow sediments had collided with the Paleoproterozoic deep basin of HC orogenic belt while south Mozambique ocean was being closed when HC basement oceanic crust had subducted underneath the two WC and VC Mesoarchaean continental blocks at two suture zones along boundaries of WC-HC and HC-VC. This had created continental arc setting in the W`C and VC continental blocks as shown in the Fig.6.2 of chapter 6. In order to cause uplifting of one crustal block more than 3000 m above mean sea level, a huge compression accompanied by collision of two adjacent crustal blocks must have essentially taken place with the crustal block which lies at the middle between two colliding crustal blocks. Therefore, here I suggest that 'HC orogeny' had essentially taken place when oceanic crust of deep HC sedimentary basin of orogenic belt which had been existing since ~ 1900 to 2000 Ma collided and subducted underneath the Mesoarchaean continental blocks of WC and VC during Ediacaran-Cambrian. This HC orogeny and subduction possibility of HC orogenic belt and oceanic crust underneath the WC and VC continental blocks is found to be supported by reported Mesoproterozoic to Cryogenian arc-related mafic and granitoid magmatism in the WC of Sri Lanka by Kröner and Jaeckel, 1994 and Kröner et al.,2003. The Wanni Complex is reported to have dominated by latest Mesoproterozoic to Cryogenian arc-related mafic and granitoid plutons (1.1-0.75 Ga) (Kröner and Jaeckel, 1994, Kröner et al., 2003). Further, this Cryogenian magmatism in WC of Sri Lanka has been correlated to Cryogenian mafic magmatism and metamorphism in Kadavur Gabbro-anorthosite complex of Madurai Block of South India by Teale et al., 2011. I also suggest that Cryogenian magmatism in the Madurai Block of South India and Wanni Complex of Sri Lanka is interpreted to form an extensive arc magmatic province within the southern East African Orogen and that can be traced from central Madagascar, through southern India to the Wanni Complex of Sri Lanka and this is consistent with that was suggested for Madurai Block by Teal et al. 2011. This province is interpreted to have formed above a south/west dipping subduction system as the south Mozambique ocean was subducted under the Neoproterozoic micro continent Azania (Teale et al., 2011). This shows that the

Southern Madurai Block (SMB) and Wanni Complex (WC) of Sri Lanka were welded together as a single continental block up to late Neoproterozoic and the deep basin of HC basement oceanic crust had collided and subducted under pre-exixting SMB-WC and VC continental blocks during the assembly of the ancient super continent Gondwana in Edaicaran-Cambrian to yield 'HC orogeny'. The WC-HC and HC-VC boundaries had become a suture zones along which the south Mozambique ocean had closed in the late Neoproterozoic (Fig.6.2 in chapter 6). The results show that the Kadugannawa Complex (KC) was formed from WC Mesoarchaean continental basement materials (which were identified as paleosome meterials of WC migmatites in this study as shown in the chapter 3) when the extreme eastern part of WC Mesoarchaean continental crust was subjected to intense ductile deformation and as a result of this the KC double plunging synforms (or 'arenas') were formed in the western HC terrane. In the plate tectonic model of the origin of Sri Lanka, it is suggested that the HC of Sri Lanka was formed together with the Trivandrum Block of Southern India and Itremo Group of central Madagascar as a single orogenic mountainous terrane of ancient micro continent Azania which was formed with the closure of the Mozambique ocean. The island of Sri Lanka had rotated anticlockwise after separating from the mainland India after late Cretaceous period.

2.5.3. Age of metamorphism

The analysis of rims of zircons indicates that an average of 547 Ma age is found as the Ediacaran-Cambrian metamorphism and which is similar to what is commonly observed also in other Gondwana terranes. As shown by the Fig.2.2 and Fig.2.3, the predominantly oscillatory zoned porphyritic zircon cores which were clearly formed from an igneous melts were coated by growth of metamorphic rims during regional metamorphism. This shows that both the WC and HC rocks were subjected to a common event of metamorphism around 547 Ma.

2.6 Conclusions

All the metaquartzite samples of WC and HC of Sri Lanka contain clear records for a considerable Paleoproterozopic to Neoarchaean to Mesoarchaean detrital grain input into their original sedimentary constitution with the youngest <10%discordant core analyses in all the eight near boundary WC and HC samples range from 1500 Ma to 2000 Ma. The maximum age of deposition of all the eight samples of near boundary WC and HC except the S814 collected at Maradankadawela can be approximately constrained at ~ 2000 Ma. The depositional age for the protoliths for these samples is constrained approximately between ~2000 Ma and ~550 Ma (between the youngest reliable detrital zircon grain and the age of regional metamorphism). However, one metaquartzite sample which was collected at Maradankadawela in the western WC yielded Neoproterozoic detritus and mixed with older Paleoproterozoic to Neoarchaean detritus. Existence of younger and older age mixtures in one rock indicates that WC and HC terranes existed adjacent to each other in early Neoproterozoic but WC and HC metaquartzites represent two different successions /systems of sediments deposited in two different basins. I here also conclude that the current tentative WC-HC boundary which was established based on Sm-Nd model ages is not accurate and the exact boundary could exist further westwards and further geochronological research is needed to accurately re-establish the WC-HC geological boundary. This study reveals that WC and HC are two different crustal domains and WC represents a continental block welded to Southern Madurai Block of South India and supracrustal HC represents an orogenic belt deep basin.

When attempting to locate protolith sources for the WC and HC of Sri Lanka, the Indian sources lack Paleoproterozoic sources for the neighbouring WC and HC metaquartzies and it is suggested that protoliths to WC and HC terranes of Sri Lanka may be sourced from non-Indian sources and it is suggested that source regions were in east Africa.

This study reveals that the metasedimentary rocks of the HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metasedimentary rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Southern Indian Madurai Block sequences, and Malagasy sequences represent different parts of basins of continental blocks or sedimentary orogenic belts. I also suggest that the Sri Lanka's paleotectonic position could be south east of south India before Gondwana being amalgamated in Ediacaran-Cambrian (Fig.6.1 in chapter 6).This suggestion is somewhat consistent with the Paleotectonic position of Sri Lanka which was suggested by Teale et al. (2011), Plavsa et al., 2014 (b), and Collins et al 2014 (Fig.2,11). Although the

HC of Sri Lanka is correlated to both Trivandrum Block and Northern Madurai Block of South India, only the Trivandrum Block shows geological similarity to the HC of Sri Lanka with respect to lithology and orogenesis. It is interpreted that HC is the south eastern continuation of the Trivandrum Block of South India in the Gondwana super continent.

The field information and difference in grade of metamorphism show that HC rocks were subjected to relatively deeper burial into lower crust and greater uplifting from the lower crust level than the WC rocks during orogenesis. I suggest a ‘HC orogeny” and this had taken place in late Neoproterozoic when WC and VC continental blocks had collided with the deep basin of HC orogenic belt when oceanic crust of the HC orogenic belt subducted underneath the WC and VC continental blocks to form two continental arcs (Fig.6.2 in chapter 6). This study reveals that boundaries of WC-HC and HC-VC are suture zones alone which subduction of HC oceanic crust had taken place. I also suggest that Cryogenian magmatism in the Madurai Block of South India and Wanni Complex of Sri Lanka is interpreted to form an extensive arc magmatic province within the southern East African Orogen that can be traced from central Madagascar, through southern India to the Wanni Complex of Sri Lanka and this interpretation is consistent with what was suggested for Madurai Block by Teal, et al, 2011. In addition to that a similar arc magmatic province is reported in the VC of Sri Lanka as evidenced by occurrence of acidic, mafic and ultramafic igneous rocks in the VC of Sri Lanka. This VC arc magmatic zone indicates subduction of HC ocanic crust underneath the VC continental block. I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Trivandrum Block and Southern Indian Madurai Block sequences, and Malagasy sequences represent different parts of either continental sedimentary basins or orogenic belt basins. Sri Lanka’s paleotectonic position could be south east of south India before Gondwana being amalgamated in Ediacaran-Cambrian and the HC of Sri Lanka and Trivandrum Block of South India formed in a collisional orogeny associated with granulite facies ultra high temperature regional metamorphism during the assembly of Gondwana in the Ediacaran-Cambrian. In addition to that the Kadugannawa Complex (KC) lies close to the WC-HC boundary in the HC terrane and it is interpreted that KC was formed during a collisional orogeny of HC from basement materials (As shown in the Fig.6.2 of chapter 6, the results of the chapter 3 show that basement materials of WC are found to be Mesoarchaean paleosomes of WC migmatites) and shallow continental sediments (as shown in chapter 3 these sediments became leucosome partial melts of WC migmatites) of the WC after being subject to intense ductile deformations to form KC ‘arena’ structures or doubly plunging synform structures. This South Indian and WC magmatic province is interpreted to have formed above a south/west dipping subduction system as the Mozambique ocean was subducted underneath the Neoproterozoic continent Azania (Teale et al., 2011). This shows that the Highland Complex and Wanni Complex (WC) of Sri Lanka had been formed in two different sedimentary systems during the assembly of Gondwana. In a platetectonic model of the origin of Sri Lanka, it is suggested that the HC of Sri Lanka was formed together with the Trivandrum Block of Southern India and Itremo Group of central Madagascar as a single orogenic mountainous terrane of the ancient micro continent Azania which was uplifted after the HC basement oceanic crust had subducted underneath the WC and VC continental blocks of Sri Lanka, Southern Madurai Block of India and Molo Group of Madagascar. The island of Sri Lanka had subsequently rotated anticlockwise after separating from the Mainland India after late Cretaceous period.

Acknowledgements

The authors wish to thank the University of Adelaide for the providing adequate laboratory facilities for sample preparation and U-Pb zircon dating. Dr. Benjamin Wade of Adelaide Microscopy is especially thanked for assistance during LA-ICPMS analysis. My PhD colleagues, Diana Plavsa, Jade Anderson, Ben McGee, Frank Robinson, Thomas Raimondo of the Department of Earth Sciences are also thanked. Mr.Prassana. Dharmapriya is thanked for improving figures in Corel draw and Mr. Moditha Kodikaraarachchi of the Department of Geology, University of Peradeniya is thanked for his assistance in petrographic photography. Dasith Bandara Wewegama, a third year undergraduate in Medicine, the University of Adelaide is thanked for all the encouragements and helps.

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Supplementary Table 2.1.

Grain No	Pb207/U235		Pb206/U238		rho	Concordance	Pb207/Pb206		Pb206/U238	
c10c	8.82788	0.1123	0.40906	0.00521	0.9987864	93	2365.3	16.88	2210.6	23.83
c11c	3.5977	0.04442	0.23125	0.00285	0.9981815	76	1768.6	17.77	1341	14.95
c12c	5.87297	0.07465	0.34109	0.00424	0.9779684	97	1947.2	18.36	1891.9	20.37
c13c	3.51561	0.04294	0.22647	0.00276	0.9977852	75	1748.8	17.63	1316	14.5
c14c	7.77261	0.0967	0.36564	0.00451	0.9914327	87	2296.8	16.99	2008.8	21.28
c15c	8.52203	0.10813	0.38932	0.00492	0.9959906	93	2273.4	16.23	2119.7	22.84
c16c	15.07341	0.18908	0.52839	0.00659	0.9942526	99	2774	16.12	2734.7	27.81
c17c	8.67103	0.10769	0.36899	0.00458	0.9994158	85	2386.2	15.73	2024.6	21.57
c18c	6.93085	0.08561	0.27745	0.00344	0.9962407	64	2462.9	15.12	1578.5	17.37
c19c	3.77122	0.05861	0.21071	0.00276	0.8428185	65	1906.6	25.07	1232.6	14.7
c1c	1.14828	0.0169	0.10536	0.00138	0.8899476	49	1311.1	25.75	645.7	8.04
c21c	10.68213	0.13979	0.47429	0.00597	0.9618606	111	2259.1	17.66	2502.4	26.12
c22c	5.90079	0.07744	0.34327	0.00442	0.9811406	107	1772.6	17.41	1902.4	21.21
c23c	6.04969	0.07758	0.29816	0.00379	0.9912271	81	2082.8	16.36	1682.2	18.83
c26c	7.87167	0.11436	0.37057	0.00482	0.8953019	93	2174.6	21.84	2032.1	22.67
c27c	2.13583	0.03338	0.15411	0.00199	0.8262331	72	1281.1	26.26	924	11.14
c2c	1.64229	0.02647	0.12749	0.00183	0.8905758	49	1579.6	25.96	773.6	10.45
c32c	4.39076	0.0538	0.27072	0.00334	0.9931537	96	1602.3	15.73	1544.5	16.92
c33c	4.14632	0.0533	0.22395	0.00286	0.9934604	71	1834.9	16.11	1302.7	15.09
c34c	1.91396	0.02899	0.13514	0.0018	0.8793732	66	1245	23.37	817.1	10.25
c35c	5.1693	0.06461	0.28423	0.00357	0.9951068	91	1766.7	15.19	1612.6	17.93
c36c	6.19647	0.0793	0.32434	0.00413	0.9949946	98	1852.5	15.74	1810.9	20.08
c37c	8.83527	0.11203	0.40546	0.00515	0.9982867	105	2087.7	15.04	2194.1	23.61
c38c	2.87963	0.03695	0.18382	0.00233	0.9878373	76	1429.1	16.46	1087.8	12.71
c39c	7.82134	0.10293	0.32111	0.00415	0.9820497	80	2232	15.88	1795.2	20.25
c3c	2.254	0.02931	0.14232	0.00185	0.9996406	44	1964.1	19	857.8	10.44
c40c	7.93457	0.10908	0.38197	0.00501	0.9540843	108	1935.8	17.93	2085.5	23.37

c41c	6.81685	0.08563	0.31631	0.00398	0.9983253	88	2007.5	14.55	1771.7	19.5
c42c	3.86542	0.06006	0.22867	0.00305	0.8584243	87	1520.5	23.95	1327.5	16
c43c	14.06659	0.17716	0.47101	0.00593	0.9996494		2493.4	13.66	2488	25.99
c44c	4.57706	0.06002	0.25778	0.00318	0.9407376		1692.2	18.56	1478.5	16.31
c4c	3.08991	0.04124	0.2027	0.00251	0.9277846	68	1753.9	20.98	1189.8	13.48
c5c	7.84519	0.10106	0.36092	0.00468	0.9934384	80	2494.7	17.58	1986.5	22.17
c6c	8.72733	0.11085	0.3607	0.00455	0.9931411	75	2661.7	17.71	1985.5	21.56
c7c	7.45972	0.09702	0.36067	0.00469	0.9998252	83	2386.5	17.86	1985.3	22.23
c8c	5.6026	0.07273	0.31802	0.00394	0.9543723	87	2045.4	19.65	1780.1	19.28
c9c	7.8134	0.10191	0.37468	0.00475	0.9719778	89	2316.5	18.34	2051.4	22.29
r12r	4.75018	0.06076	0.28706	0.00357	0.9722721	87	1869.2	18.71	1626.8	17.87
r16r	15.44459	0.19577	0.53837	0.00667	0.9774065	99	2812	17.32	2776.6	27.93
r17r	0.66425	0.00885	0.08317	0.00107	0.965618	170	303.8	22.89	515	6.34
r18r	10.39321	0.13288	0.40053	0.00516	0.9924194	85	2547.2	15.42	2171.5	23.74
r19r	8.99625	0.11879	0.41614	0.00524	0.9536158	102	2201.2	18.24	2242.9	23.86
r1r	8.87825	0.10986	0.40863	0.00499	0.9868657	88	2520.5	18.38	2208.7	22.86
r22r	5.24402	0.06583	0.30925	0.00379	0.9762701	99	1760.3	17.45	1737	18.67
r26r	9.42049	0.11757	0.4269	0.00525	0.9853945	106	2153	15.94	2291.7	23.73
r2r	2.83359	0.0371	0.17233	0.00214	0.9484534	50	2033.6	20.79	1024.9	11.78
r34r	2.93406	0.03958	0.19259	0.00249	0.9584265	77	1468.3	18.94	1135.4	13.44
r38r	4.93036	0.06277	0.26927	0.00344	0.996559	91	1694	14.94	1537.1	17.48
r3r	8.50076	0.11885	0.41859	0.00556	0.9500457	94	2389.3	20.55	2254.1	25.28
r40r	9.02148	0.12079	0.40846	0.00537	0.9819097	109	2019.8	16.2	2207.9	24.57
r43r	14.35658	0.17662	0.44812	0.00551	0.9994668		2631.2	13.63	2386.9	24.53
r5r	6.49642	0.08401	0.31045	0.00401	0.9988398	72	2423.1	17.92	1742.9	19.74
r7r	3.74068	0.05261	0.20539	0.00265	0.9173791	56	2160.3	21.94	1204.2	14.15
r9r	8.16064	0.10863	0.38708	0.00505	0.980088	90	2338.4	18.26	2109.3	23.45

Chapter 3 – Leucosomes of Migmatites of Wanni Complex of Sri Lanka Indicate Metasedimentary Origin and Correlation with Southern Madurai Block of India and Molo Group of Madagascar whilst Paleosomes show metaigneous origin: LA-ICPMS U-Pb Zircon Geochronology

Abstract

Migmatites or migmatitic gneisses of middle to upper amphibolite facies form predominant and type rocks of the Wanni Complex (WC) of Sri Lanka. These are the prominent rock types of the WC against the supracrustals of the Highland Complex (HC). In the past many believed that WC migmatitic gneisses to be mainly metaigneous/orthogneisses based on only the mineralogical composition but it was not well understood for a long period of time due to unavailability of precise geochronological data. Further, understanding age and origin of leucosome and paleosome parts of WC migmatites may also be useful to unravel the origin of WC terrane. In this study it is examined age distribution of detrital zircon cores and later metamorphic rims of leucosomes and paleosomes of migmatitic gneisses of WC using the Laser Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) to investigate the age and provenance of the migmatitic gneisses of the Wanni Complex (WC) of Sri Lanka.

Six migmatitic gneiss rock samples have been studied along two west to east transects in the Northwest of Sri Lanka covering Wanni Complex (WC) up to its tentative eastern boundary with the Highland Complex (HC). Two leucosome samples of migmatitic gneiss were analysed from Dombawela and Leeniwehara. Both leucosome and paleosome samples were also collected at Viharagala and Habarana and separately analysed to understand age and provenance relationships between partial melts and pre-existing materials. The concordia and probability density plots of this study clearly reveal for the first time that parent materials of leucosomes of WC migmatitic gneisses are of metasedimentary origin with late Mesoproterozoic to Neoproterozoic ages except two paleosome samples first time report metaigneous origin with older Mesoarchaean to Neoarchaean ages (3.0-2.85Ga). Detrital cores of leucosomes of WC migmatitic gneiss four rock samples yielded >90% concordant $^{206}Pb/^{238}U$ ages that generally range from

~700 Ma to 1150Ma with maximum age of deposition at ~700 Ma. This younger maximum age of deposition, age and sedimentary provenance proves that WC was a different crustal domain from the HC terrane. This study also reveals that paleosomes and leucosomes of WC migmatitic gneisses represent two different materials and were subjected to migmatization together during Ediacaran -Cambrian regional metamorphism. The results of this partial melting continued up to ~ 490 Ma. It is here suggested that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and became leucosomes and mixed with the older metaigneous paleosome materials to form WC migmatitic gneisses. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.

It is also here suggested that paleosome materials of WC migmatites represent the older reworked Mesoarchaean continental cratonic basement on which thin successions of WC sediments were deposited in late Neoproterozoic. The study of age, provenance and maximum age of deposition of metasedimentary leucosomes of WC migmatitic gneisses clearly show a correlation between the WC of Sri Lanka with Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources. I here interpret that WC of Sri Lanka was welded to the Southern Madurai Block since Paleoproterozoic and the Paleotectonic position of Sri Lanka is found to be linking Southern Madurai Block of India and WC of Sri Lanka as a single continental block. The Cryogenian felsic magmatism reported in the WC is interpreted as continental arc type and the Paleoproterozoic HC basement was an oceanic crust and which had subducted underneath the welded Southern Madurai Block-WC continental block along the suture of WC-HC boundary to close the ancient Mozambique ocean.

Keywords : Migmatitic gneiss**,** LA-ICPMS, Wanni Complex, Sri Lanka

3.1. Introduction

The island of Sri Lanka is located in a key position in the process of amalgamating Neoproterozoic supercontinent Gondwana. Sri Lanka forms a small but important crustal block of the supercontinent, Gondwana, and has been the focus of thorough research in the late 1980's and early 1990's (e.g. Cooray, 1994; Mathavan et al., 1999). According to present geographic coordinates, Sri Lanka is near to the Southern Granulite Terrane of South India but the island is understood to be a crustal block which was also understood to be linked to other neighbouring land blocks such as Madagascar and East Africa when the supercontinent Gondwana was assembled during Ediacaran to Cambrian along numerous orogenic belts. The Ediacaran (~635 – 541 Ma, Gradstein et al., 2012) to Cambrian assembly of Gondwana had taken place by the collision and amalgamation of numerous continental blocks along a number of disparate orogenic belts (see Collins and Pisarevsky, 2005). But Sri Lanka's most probable paleotectonic position and how the island crustal block was existing with adjacent land masses are not yet confidently answered and it is still a puzzle and a research gap. In order to find the paleotectonic position of Sri Lanka it necessiciates to deeper understand the sedimentary provenance and geological origin of the three main geologic units of Sri Lanka, the Wanni Complex (WC), the Highland Complex (HC) and the Vijayan Complex (VC). This study mainly focuses on study of age and sedimentary provenance of the WC of Sri Lanka in order to understand the geologic origin of the island of Sri Lanka.

The geological origin of the Wanni Complex (WC) of Sri Lanka is to be well understood to further understand the geologic and tectonic origin of the island of Sri Lanka. In this context, migmatites or migmatitic gneisses of the WC are to be further investigated because migmatites are the predominant and type rocks of the Wanni Complex (WC) of Sri Lanka. In the past many believed that WC migmatitic gneisses to be mainly metaigneous/orthogneisses based on only the mineralogical composition but it was not well understood for a long period of time due to unavailability of precise geochronological data. Migmatite is generally understood to be a mixed rock originated due to partial melting and migmatization of pre-existing materials of the earth's crust during regional metamorphism. The migmatites of the WC of Sri Lanka consist of light coloured leucosomes and dark coloured paleosomes and were formed due to regional metamorphism under upper amphibolites facies pressure and temperature conditions. Field studies show that only the leucosomes were subject to partial melting. There still exists a knowledge gap to understand the origin of leucosomes and paleosomes of WC migmatites to deeper understand the origin of WC migmatites. There could be differences in age and origin of paleosomes and leucosomes of WC migmatites and it is to be understood to unravel the geological origin of the WC terrane. If the origin of paleosomes or leucosomes of migmatitic gneisses of the WC is metasedimentary, it is significant to locate probable protolith sources with respect to ages of detrital zircon cores in migmatitic gneisses of the Wanni Complex of Sri Lanka for understanding paleotectonic position of the island of Sri

Lanka before Gondwana supercontinent being assembled in the Ediacaran-Cambrian. Therefore understanding age, sedimentary provenance and origin of leucosome and paleosome portions of WC migmatites must be useful to understand the geological origin of WC terrane and particularly to understand what was likely to be the basement rock materials of the WC terrane and also to understand the nature of WC sedimentary basin prior to the assembly of Gondwana super continent.

In addition to that on the basis of Sm-Nd model ages the Wanni Complex (WC) and Highland Complex (HC) of Sri Lanka have long been thought to form two distinct terranes or crustal domains, exotic to one another, with different tectonic histories. The HC is traditionally thought to be dominated by Paleoproterozoic matasedimentary rocks whilst the WC was thought to be largely composed of Mesoproterozoic to Neoproterozoic metaigneous rocks. While some geologists still say that WC and HC are two crustal domains some other geologists argue that WC and HC are not two crustal domains. So there remains still another knowledge gap and uncertainties on this matter without precise geochronological data on age, sedimentary provenance and maximum age of deposition of WC and HC terranes. However, this research question has not yet also been well answered and there exist debates because only a limited and a small number of true metasedimentary rock samples have been dated in the past. This necessitates a further verification based on applying modern and precise geochronological methods such as LA-ICPMS U-Pb zircon dating to examine the provenance WC matasedimentary rocks of Sri Lanka to compare with data of age, sedimentary provenance and maximum age of deposition of the HC of Sri Lanka. This will verify whether WC and HC are two different geologic terranes or not.

As far as provenance of high-grade metasedimentary rocks is concerned precise age information of sedimentary detritus would be a primary requirement. In this context, Holzl et al., (1994) had established a general geochronological framework for the crystalline basement of Sri Lanka based on U-Pb ages of zircons and monazites from ortho and paragneisses representing the major crystalline basement units of Sri Lanka. Previously, a geochronological framework for the island was put forward using Sm-Nd model ages (Milisenda et.al., 1988, 1994). Such Sm-Nd model ages considered as less reliable as average ages of all possible ages of protolith sources are also taken into account in calculating the model age of a given rock resulting in errors in ages. In previous geochronological studies in Sri Lanka rock samples were collected arbitrarily / in scattered manner from the four main geologic/tectonic provinces of Sri Lanka rather than collecting rock samples along west to east traverse lines or transects which runs approximately perpendicular to the general trend lines and strike of layerings/foliation of the terrane. In previous geochronological studies in Sri Lanka the detrital cores and their metamorphic rims were not also dated after imaging under cathodoluminescence (CL). Under these circumstances, a fresh and methodical geochronological research study has become a necessity to fill the research gap and overcome the remaining shortcomings in the current geochronological framework of Sri Lanka.

The present research study is mainly aimed at addressing above research gaps as well as tracing links of the Sri Lankan crustal block to her neighbouring crustal blocks such as South India, Madagascar and East Africa in the process of amalgamation of the Neoproterozoic super continent Gondwana based on a geochronological age and provenance study of leucosomes and paleosomes of migmatitic gneisses.

Recent advances in sector field inductively coupled plasma-mass spectrometry (ICPMS) have enabled precise measurements of this isotopic system in zircons by laser ablation (Plavsa et.al., 2014; Griffin et. al., 2000; Iizuka and Hirata, 2005). This method called LaICPMS is particularly useful as it allows for specific textural and age domains within zircon to be targeted during the analysis (Plavsa et al., 2014). Because migmatitic gneisses are the predominant rocks in the WC of Sri Lanka and assuming that these migmatitic gneisses were formed from partial melting or migmatization of pre-existing sedimentary successions, a sedimentary provenance study of migmatitic gneisses would be significant to trace protolith sources. Here I apply the LaICPMS method as the tool to the high-grade terrane of the Wanni Complex (WC) of Sri Lanka to unravel the source of the protoliths of high-grade migmatitic gneiss rocks of Sri Lanka which were collected systematically along two west to east transects in the WC of Sri Lanka that assist elucidate the Neoproterozoic paleogeography of the region.

3.2. Geological background

About 90% of the island of Sri Lanka is underlain by Precambrian high grade metamorphic rocks and the rest is mainly of Miocene limestone and isolated Jurassic, Quarternary rocks (Fig.3.1). The basement of Sri Lanka consists mainly of Mesoarchaean to Neoproterozoic metaigneous and metasedimentary rocks and subdivided into four major geological units named as the Highland Complex (HC), Wanni Complex (WC) Vijayan Complex (VC), and and Kadugannawa Complex (KC) (Fig.3.1) traditionally based on lithology, grade of metamorphism (Kröner et al., 1991), and Sm-Nd model ages (Milisenda et al., 1988; 1994; Sajeev et al., 2010). The basement of Sri Lanka was metamorphosed to upper amphibolite and or granulite grade in the Neoproterozoic, each complex having a distinct metamorphic history (Sajeev et al., 2010).

The past studies showed that the centrally located Highland Complex to be the oldest geologic terrane (Sajeev and Osanai, 2004, and Sajeev et al., 2010) consisting of granulite grade major supracrustal meta-sedimentary rocks, charnockites and metaigneous rocks. The most common metasedimentary rocks are garnet sillimanite graphite gneisses, marbles, calc silicates, garnetiferous granulites, and metaquartzites. Kröner et al (1991) described that more than 50% of the HC rocks are of igneous origin. The age of HC was estimated as 3.2 to 2.0 Ga based on Sm- Nd model ages (Milisenda et al., 1988; Kröner, and Williams, 1993). The high-grade metamorphism had taken place as a part of the Ediacaran-Cambrian regional metamorphism of Gondwana terranes and orogenisis at ca. 550 Ma (Kröner et al., 1991) and the rocks were metamorphosed under pressure and temperature conditions of 900°C and 9 K bars. Igneous intrusions to HC were emplaced around 1850-1990 Ma (Kröner and Williams, 1993; Schumacher et al., 1990).Subsequent to the regional metamorphism isobaric slow cooling and uplifting of the HC into higher crustal levels had occurred (Kröner et al., 1991; Jayawardane, and Carswell, 1976; Kröner, and Williams, 1993; Faulhaber, and Raith, 1991). The boundary between HC and VC is well identified as a tectonic boundary marked by a gravity and magnetic anomaly, thrust and shear zones, mafic to ultramafic intrusions, granitic intrusions, copper-magnetite deposits, acidic charnockites and a belt of hot water springs.

The Mesoproterozoic to Neoproterozoic (Milisenda et al., 1988, 1994; Sajeev et al., 2010) Vijayan Complex (VC) lies to the east of the central HC (Fig.3.1) and comprised mainly of granitic gneisses, migmatites, hornblend gneisses, and rare and isolated bands of metaquartzites and calc gneisses (Dahanayake and Jayasena, 1983). The VC was metamorphosed to upper amphibolite grade metamorphic rocks. Granitic intrusions, dolerite dykes and acidic charnockites occur close to the eastern coast in the VC (Milisenda et al., 1991). Milisenda, et al. (1988) and Corfu et al. (2003) had described the gneissose granitoids of the Vijayan Complex as having compositions ranging from tonalite to leucogranite.

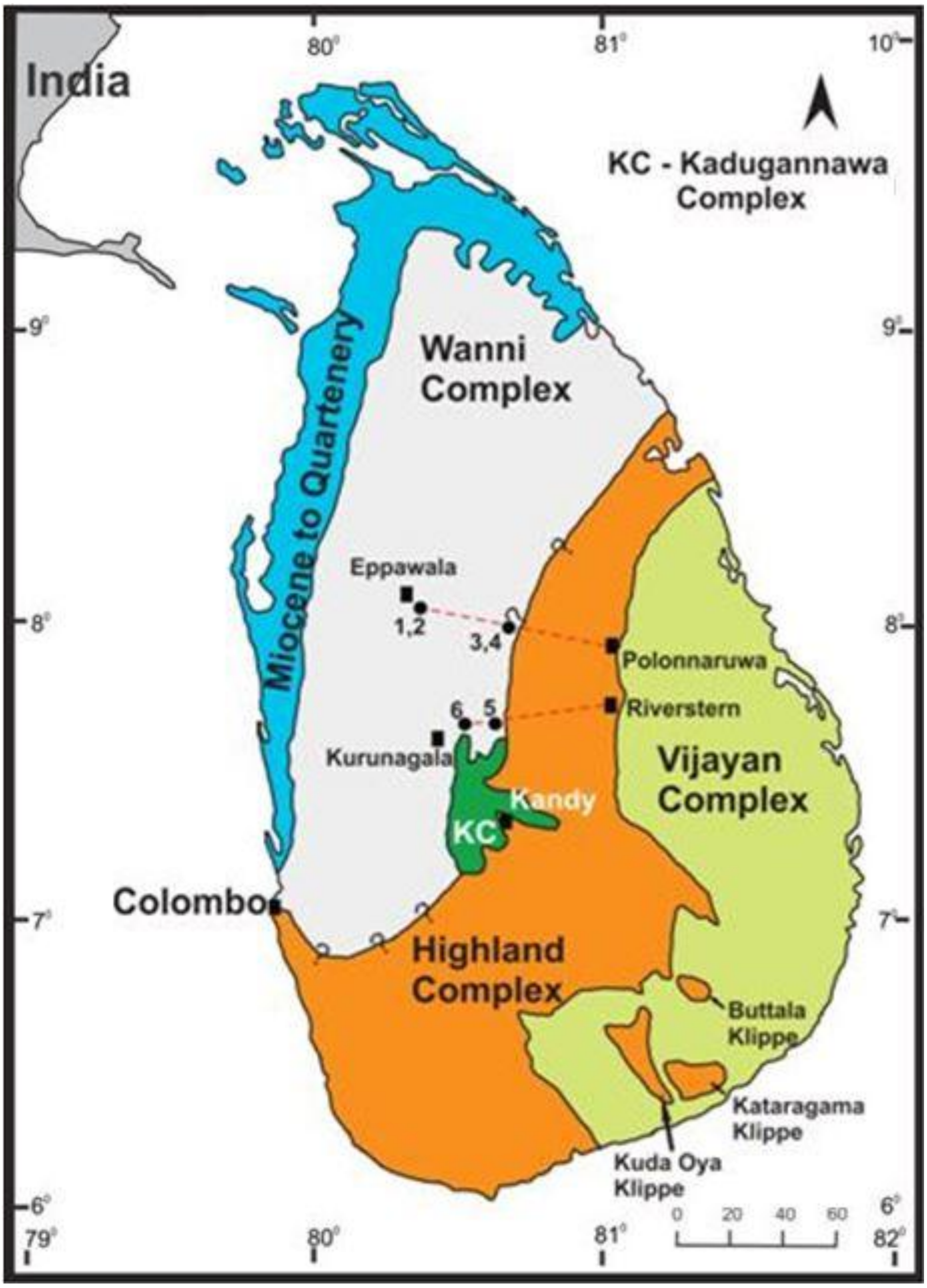

Fig.3.1. Generalized geological and tectonic framework of Sri Lanka showing major crustal blocks and their boundaries (after Cooray, 1994). The study area is shown along two west-east transects. Sample locations of migmatitic gneisses are shown by black circles. 1-Viharagala (leucosome), 2-Viharagala (paleosome), 3-Habarana (leucosome), 4-Habarana (paleosome), 5- Dombawela(leucosome) , 6- Leeniwehera (leucosome).

The Wanni Complex exists in the west of the HC and consists mainly of granitic gneisses, migmatitic gneisses, granitic intrusions, cordierite gneisses, and minor abundance of supracrustal metaquartzites, and metapelites. Migmatitic gneisses are considered as the type rocks and the predominant rock types in the WC. The origin of these migmatitic gneisses is not yet well understood and these may have been formed by partial melting and migmatization of either pre-existing metasediments or igneous rock materials. Although petrological and structural geological studies were carried out on WC migmatitic gneisses, geochronological research studies have not been reported. There is still insufficient geological evidence to mark an accurate boundary between the HC and the WC.

There are different and diverse views on the recognition of WC as a separate crustal domain different from the HC. There have been several workers attempted to describe the supracrusral rocks of WC and HC of Sri Lanka. Kehelpannala (1991) described that most of the metasedimentary rocks of the WC occur close to the assumed boundary with the HC. Voll and Kleinschrodt (1991) also rejected the establishment of WC as it is not clearly confined, no precise definitions for its delineation can be given and proposed that common history is represented by HC and WC rocks and HC represents a deeper crustal level than the WC. Willbold et al. (2004) also stated that though the Nd model ages and zircon age spectra suggest different origins for the WC and the HC, this division is difficult to substantiate with lithological and petrological data. Further geochronological studies may answer the question of whether WC and HC are two distinct crustal domains or a single crustal domain.

The Kadugannawa Complex (KC) exists as the smallest geological unit and it lies close to the WC-HC boarder as shown in the Fig.3.1. The KC consists of rocks similar to what is found in the WC of Sri Lanka. The geological structure of KC is unique with several doubly plunging synform structures which are known as 'arena' structures.

3.2.1 Geochronological studies in Sri Lanka

Kröner et al., 1987 analysed detrital zircon and monazite grains from the Highland Complex paragneisses and presented late Archaean to Paleoproterozoic near concordant ages (3.2-2.4 Ga). The data were highly discordant and indicated considerable scatter, which Kröner et al., (1987) originally speculated about a granulite grade metamorphism and to be consistent with lead loss ~1.1 Ga ago. Later, this explanation has since been substituted (Baur et al., 1991) in favour of a younger age of metamorphism. The maximum ages for zircons from a metaquartzite xenoliths in a Vijayan orthogneiss were interpreted to be ~ 1.1 Ga, suggesting that the Vijayan Complex is significantly younger than the Highland Complex.

Milisenda et al. (1988,1994) carried out a Sm-Nd geochronological study and reported Sm-Nd model ages and identified three distinct age units: the HC produced model ages of 3.4 to 2.2 Ga, indicating derivation from Mesorchaean to Neoarchaean sources. It is attached to the west and east by Wanni Complex and Vijayan Complex with model ages of 2.0 to 1.0 Ga. These results were supported by Pb isotope data (Lew et al., 1991 a, b, 1994) first showed that the primary ages of the three crustal blocks contrasted sharply with each other were studied showing primary crystallization ages of orthogneisses from the Highland Complex and Wanni Complex were analysed by Baur et al. (1991) and reported ages around 1940 Ma, 770 Ma and 660 Ma. They found severe Pb loss ~ 550 Ma ago in all the samples and they constrain the time of high-grade metamorphism to the range between 660 Ma (the age of youngest primary crystallization event) and 550 Ma (the age of lead loss). Holzl et al. (1991) presented preliminary data on Rb-Sr in whole rocks, Rb-Sr in biotites, Sm-Nd in garnets and U-Pb in zircons and monazites. These results showed primary ages of ~2.0 Ga for the Highland Complex and ~1.0 Ga for the Vijayan and Wanni Complexes.

Burton and O'Nions (1990b) studied late, small scale, in-situ charnockititation / arrested charnockitization process using rock samples collected near Kurunegala in the WC. They obtained Rb-Sr and Sm-Nd whole rock ages around 535 Ma for a sequence of small slices from an amphibolites-granulite transition zone, and Sm-Nd, Pb and Rb-Sr mineral data from 524 to 486 Ma, and suggested these as cooling ages. These results are consistent with those of Baur et al., (1991), They found a lower intercept for U-Pb ages of zircons 563 - 26 + 22 Ma for very similar, charnockitized rocks also near Kurunegala. However, the upper intercept of Baur's zircon Discordia lies at 771 – 14 + 17 Ma, which is significantly different from an U-Pb age of 1094 ± 8 Ma and a Pb-Pb age of 1058 ± 100 Ma reported by Burton and O'Nions (1990a) for illmenites from their Kurunegala samples.

Kagami et al. (1990) had reported Sm-Nd and Rb-Sr whole rock data. One of these, taken from the Highland Complex gneisses near Gampola, yielded a four point Sm-Nd isochron of 2330 +/- 30.

Kröner et al. (1994) applied zircon SHRIMP and single grain evaporation method for the charnockites of Vavuniya (Vavniya charnockite province) in the northern WC terrane, which indicated primary ages of 1000-1100 Ma and Pb loss as well as new zircon growth 55—560 Ma ago. They concluded that this extensive northern charnockite province should be regarded as part of the Wanni (rather than Highland) Complex.

Sajeev et al. (2010) studied detrital cores of zircons in the central Highland Complex terrane and found ages in the range 2.5 – 0.83 Ga. The LaICPMS U-Pb zircon dating was carried out by Amarasinghe and Collins, (2011) on metaquartzites of WC and

HC of Sri Lanka and reported that both WC and HC show derivation of detritus predominantly from Neoarchaean and Paleoproterozoic sources (1.9 – 2.9) Ga but metaquartzites of western WC yielded Neoproterozoic detritus as age mixtures with older Neoarchaean to Paleoproterozoic detritus. Teale et al 2011 correlated igneous intrusions of WC to Kadavur Anorthosite-Gabbro magmatism in Madurai Block of India using Amarasinghe et al. (unpublished data). He et al. (2015) carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of charnockites and metagabbro rocks (HC), hornblende biotite gneisses and charnockites of (KC) and charnockites (WC) and reported Early Neoproterozoic to Late Neoproterozoic ages (525 Ma to 950 Ma). He et al. (2015) also proposed about convergent margin magmatism in the WC and the KC during assembly of the Gondwana. He et al. (2016) also carried out a zircon U-Pb and Lu-Hf geochronological study of metamorphosed acidic, mafic and ultra mafic igneous plutonic rocks of the Vijayan Complex (VC) of Sri Lanka and reported Early to Late Neoproterozoic ages (542 Ma to 966 Ma). This literature has revealed that determination of age and provenance of leucosomes and paleosomes of migmatites of the WC has not been attempted in the past. Therefore, this paper focuses on studying age and sedimentary provenance of leucosomes and paleosomes of migmatites of the WC of Sri Lanka in an attempt to further understand the origin of the WC terrane and its tectonic relationship to the HC terrane.

3.3 Analytical Methods

3.3.1 sample selection and preparation

Sample collection was carried out during field geological mapping along two east-west transacts (Fig.3.1) as northern transact (between Eppawela and Hanbarana) and southern transect (between Kurunegala and Matale) running right across western WC terrane to eastern WC terrane in the island of Sri Lanka up to the current WC-HC tentative boundary.

Fig. 3.2. Representative field photographs of migmatitic gneiss rock samples from the Wanni Complex(WC). (a) Leucosome (S0803) and Paleosome (S0804) at Viharagala (b) Leucosome (S0805) and Paleosome (S0807) at Habarana , (c) Leucosome at Dombawela(S0824), and (d) Leucosome at Leeniwehera (S0906).

Particular emphasis was paid to select purely migmatised metasedimentary rocks for the study of age and provenance of WC migmatitic gneisses. As a result of that six migmatitic gneiss samples representing the WC were used for laboratory investigation.

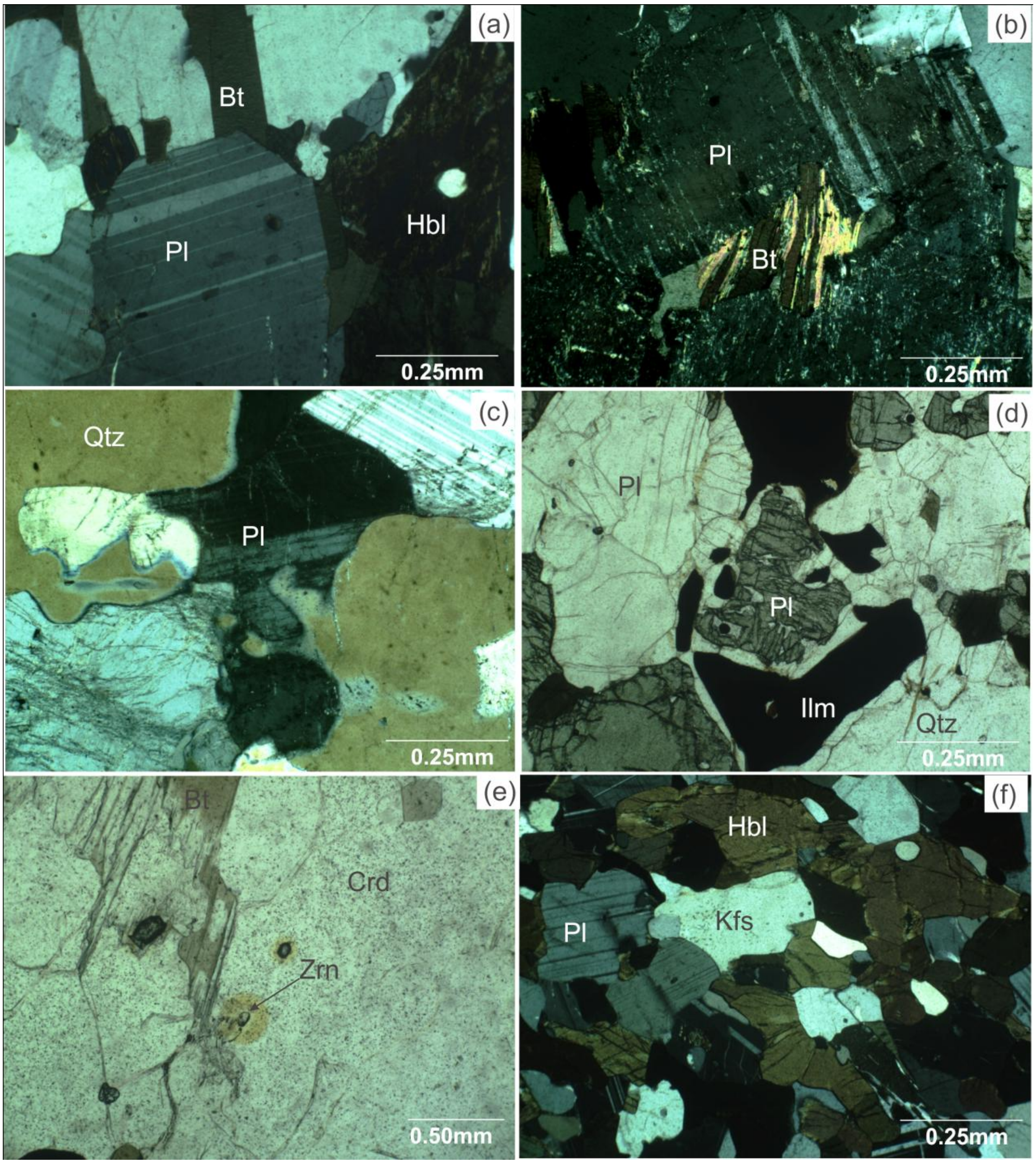

Fig.3. 3. Photomicrographs showing mineralogical composition and textures of representative migmatitic gneiss samples. (a) Leucosome (Viharagala), (b) Paleosome (Viharagala), (c) Leucosome (Habarana), (d) Paleosome (Habarana), (e) Leucosome (Dombawela) and (f) Leucosome (Leeniwehera). Abbreviations; Pl-plagioclase, Bt-biotite, Hbl-hornblend, Qtz- quartz, Ilm- ilmenite, Kfs- potash feldspar, Crd- cordierite, and Zrn-zircon.

Both leucosome (Whitish quartzofeldspathic veins and patches) and paleosome portions of migmatitic gneisses were sampled at Viharagala (S0803, S0804; Fig.3. 2(a)) and Habarana (S0805, S0807; Fig. 2(b)) location. Leucosome samples only were collected and analysed at Dombawela and Leeniwehera locations (S0824, S0906; Fig3.2(c),(d)). Firstly a petrographic thin section was made from each rock sample and petrography was studied under the polarising microscope (Fig.3. 3).

Each sample was crushed, milled, and sieved to produce a 79-400 micro meter fraction. This fraction was panned. Then all the magnetic minerals were removed using the magnetic separator as well as using a hand magnet. Then the grains were separated in the heavy liquid methylene iodide to separate zircon grains. The zircon grains were hand-picked selecting zircon grains of all sizes, shapes and colours (to avoid bias) and mounted using epoxy resin material discs. When the mounts were hardened the exposed surface was polished and carbon coated. The mounted zircon grains were subsequently imaged using the Cathodoluminescenece (CL) apparatus, Phillips XL 20 scanning electron microscope with attached Gatan CL at the Adelaide Microscopy of the Medical School of the University of Adelaide. The zircon grains have been imaged using ~16 mm working distance and accelerating voltage of 12 kV.

3.3.2 LAICPMS U-Pb zircon dating

The mounts of zircon minerals were placed in the Laser Ablation Inductively Coupled Plasma – Mass Spectrometer (La-ICPMS) of the University of Adelaide and each zircon grain was analysed on a new wave 213 mm Nd-YAG laser coupled plasma-mass spectrometer (ICP-MS) subjected to a laser beam with 30 micro meter spot size was used with a standard spot depth of 30-50 micro meter to obtain U-Pb age data. A particular emphasis was paid to target cores of the detrital zircon grains as well as the metamorphic rims. The isotopic ratios were observed and corrected for drift and within –run U-Pb fractionation by repeated analysis of GEMOC GJ-1 (a Sri Lankan pegmatitic zircon crystal) as the standard zircon (published thermal ionization mass spectrometry normalizing ages of $^{207}Pb/^{206}Pb$ =607± 4.3 Ma, $^{206}Pb/^{238}U$ = 600.7 ±1.1 Ma and $^{207}Pb/^{235}U$ =602.0± 1.0 Ma, Jackson et al., 2004). The data were analysed using computer software to produce U-Pb Concordia plots. During the process of analytical sessions , a total of 358 analyses of the GJ-1 external standard yielded a weighted average $^{207}Pb/^{206}Pb$ age of 610±3.9Ma (2 sigma, mean square of weighted deviates (MSWD) = 0.58) and $^{206}Pb/^{238}U$ = 600.02± 0.88 Ma (2 sigma MSWD = 0.54). Analysis of the Plesovice zircon standard (TIMS $^{206}Pb/^{238}U$ age = 337.13±0.37 Ma , 95% of confidence limits; Slama et al., 2008) was performed to check for validity of the applied method during the analysis of unknowns. A total of 110 analyses of the Plesovice internal standard yielded weighted average ages of $^{206}Pb/^{238}U$= 337.84± 0.94 Ma (2 sigma, MSWD = 1.07) and $^{207}Pb/^{206}Pb$ = 340.6 ± 7.1 Ma (2 sigma, MSWD = 0.8), demonstrating the accuracy of the operating conditions.

3.4. Results

3.4.1 Sample descriptions and U-Pb Geochronology

LAICPMS U-Pb age data presented in the Appendix A available from the on-line version of this paper, geochronological interpretations are presented in Figs.3.3 to Fig.3.8.

The concordia plots in Fig.5. show occurrence of dispersed /scattered detrital discordant points in three samples (S0803, S0804, S0807) and occurrence of closely spaced detrital concordant points in three other samples (S0805, S0824, and S0906). Both of these conditions considerably restrict any possibility of drawing accurate and average best fit curves to determine upper and lower intercepts to the concordia curve. Under these conditions the maximum and minimum ages of deposition are possible to determine with respect to concordant points occur on the concordia plot (Fig.3.5) as well as using the major and minor peaks found in the probability density plot which is drawn using < 10% discordant points (Fig.3.6).

3.4.1.1 S0803- Migmatitic gneiss- Viharagala- Leucosome

The sample is a migmatitic gneiss collected at Viharagala in the Wanni Complex. The rock is a leucosome part of hornblend biotite migmatitic gneiss collected from a rock outcrop exposed (Fig.3.2 (a)) in the Viharagala Buddhist temple close to Eppawala town. The migmatitic gneiss rock is comprised of dark paleosome (S0804) and light coloured leucosome portions (S0803) as shown in the Fig.3.2(a). The field photograph shows that the rock shows migmatitic structure with ptigmatitic folds with variable thickness and shape due to partial melting during migmatization of parent materials and linked to more uniformly thick whitish quartzofeldspathic veins. The sample S0803 represents the whitish leucosome portion of the migmatitic gneiss. The photomicrograph (Fig.3.3 (a)) of this leucosome sample shows that it consists of quartz, plagioclase, biotite and hornblend as the major minerals. The rock shows fine to medium to coarse grained granoblastic inequigranular texture.

As shown in the Fig.3.4, the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral, long tetragonal prism and pyramid combination forms. The zircon grains also show a diverse range of luminescence responses. In this leucosome sample most of the zircon grains are well rounded to sub-rounded due to long distance transportation and show sectors or patches of dark and bright luminescence as shown in Fig.3.4(a). The rims were formed during regional metamorphism and are generally moderate to bright luminescent. As shown in the Fig.3.4(a) the rock sample S803 is represented by two zircon grains, grain-I, and grain II. The grain-I shows that its core is long prismatic but sub-rounded to subhedral due to long distance transportation. The core consists of sectors or patches of dark luminescent and bright luminescent.. This grain is a Neoproterozoic detritus showing $^{206}Pb/^{238}U$ age of 562 ± 6Ma. The moderately luninescent metamorphic rim showing $^{206}Pb/^{238}U$ age of 517 ± 5 Ma. The grain II is long but rounded at edges and shows bright luminescence.. This grain shows a relatively thicker homogeneous and bright metamorphic rim. This is also a Neoproterozoic detritus showing $^{206}Pb/^{238}U$ age of 876±5 Ma.. This shows this leucosome portion of the migmatitic gneiss was sourced from Neoproterozoic protolith sources.

Thirty seven grains were analysed from S0803 sample. Four analyses were <10% discordant. The Fig.3.5 (concordia plot) and Fig.3.6 (probability density plot drawn for <10% discordant grains) show that the maximum age of deposition of the S0803 sample is found to be 640 Ma and the minimum age of deposition is found to be 520 Ma and major detrital peaks occur at 640 Ma, 870 Ma. The occurrence of detratal points and peaks in a broad age range in the concordia plot and the probability density plot indicate that leucosome part of the migmatite gneiss is metasedimentary. The peak at 490 Ma may have formed due to partial melting and the peaks at 520 Ma and 560 indicate zircons formed during metamorphism. The rims of the sample show a metamorphic $^{206}Pb/^{238}U$ age about 517±5Ma and this indicates Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the leucosome parts of the Viharagala migmatitic gneiss received detritus from two protolith sources of Neoproterozoic times of age 640 Ma and 870 Ma. It can be suggested that deposition of sediments for migmatitic gneiss had taken place in the WC terrane from about 640 Ma to 520 Ma.

3.4.1.2 S0804- Viharagala-Paleosome

The sample is a migmatitic gneiss collected at Viharagala in the Wanni Complex. The rock is a paleosome part of migmatitic biotite gneiss collected from a rock outcrop exposed (Fig.3.2(a)) in the Viharagala Buddhist temple close to the Eppawala town . The migmatitic gneiss rock is comprised of dark paleosome (S0804) and light coloured leucosome portions (S0803) as shown in the Fig.3.2(a). The field photograph shows that the rock shows migmatitic structure with ptigmatitic folds with variable thickness and shape due to partial melting during migmatization of parent materials and linked to more uniformly thick whitish quartzofeldspathic veins. The sample S0804 represents the whitish paleosome portion of the migmatitic gneiss. The photomicrograph (Fig.3.3 (b)) of this paleoosome sample shows that sample consists of plagioclase, biotite and hornblend as the major minerals and quartz as a minor mineral. The rock shows fine to medium to coarse grained granoblastic inequigranular texture. As shown in the Fig.3.4, the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral, long tetragonal prism and pyramid combination forms.. The zircon grains also show a diverse range of luminescence responses. In this paleosome sample most of the zircon grains are sub-rounded due to long distance transportation and show concentric dark and bright luminescence as shown in Fig.3.4(b). The rims were formed during regional metamorphism and are generally moderate to bright luminescent..

As shown in the Fig.3.4(b) the rock sample S804 is here represented by two zircon grains, grain-I and grain II. The grain I is long prismatic in form. Its inner core is dark luminescent and outer core is bright luminescent. The metamorphic rim is moderately luminescent. This grain is a Paleoproterozoic grain showing $^{207}Pb/^{206}Pb$ age of 1931±10. The grain II is short prismatic and subhedral to euhedral in form. The inner core is dark luminescent and the outer core is bright luminescent... This is also a Neoproterozoic grain showing $^{206}Pb/^{238}U$ age of 598 ± 4 Ma. The metamorphic rim of the grain II shows a $^{206}Pb/^{238}U$ age of 431± 2 Ma. This metamorphic rim was probably formed during isobaric cooling in the HC and WC of Sri Lanka. This shows that a mixture of zircon grains from Paleoproterozoic to Neoproterozoic age are found in this rock.

Forty-two zircon grains were analysed from the sample S-0804. Three analyses were <10% discordant. The Fig.3.5 (concordia plot) and Fig.3.6 (probability density plot drawn for <10% discordant grains) show that there is considerable disconcordancy due to lead loss and concordia plot Fig.3.5 (b) and the probability density plot Fig.3.6 indicate that this paleosome sample has metaigneous origin as the discordant points are directed towards 2863 ± 140 Ma old point on the concordia plot. Though there is a concordant point at 3000 Ma, the upper intercept is found to be 2863± 140 Ma and the lower intercept is found to be 535 ± 87 Ma (MSWD = 29). The oldest concordant core is 3010 ± 166 Ma old. This shows that the paleosome portion of Viharagala migmatitic gneiss was formed in the Archaean in age. The major peak (Fig.3.6) at 875 Ma may be due to slight contamination of rock material from the leucosome portion of the rock. The paleosome part of this migmatitic gneiss is found to be Neoarchaean age. The rims of the sample show a metamorphic age about 547 Ma and this indicates Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the paleosome portion of the Viharagala migmatitic gneiss could probably be Neoarchean meta igneous rocks.

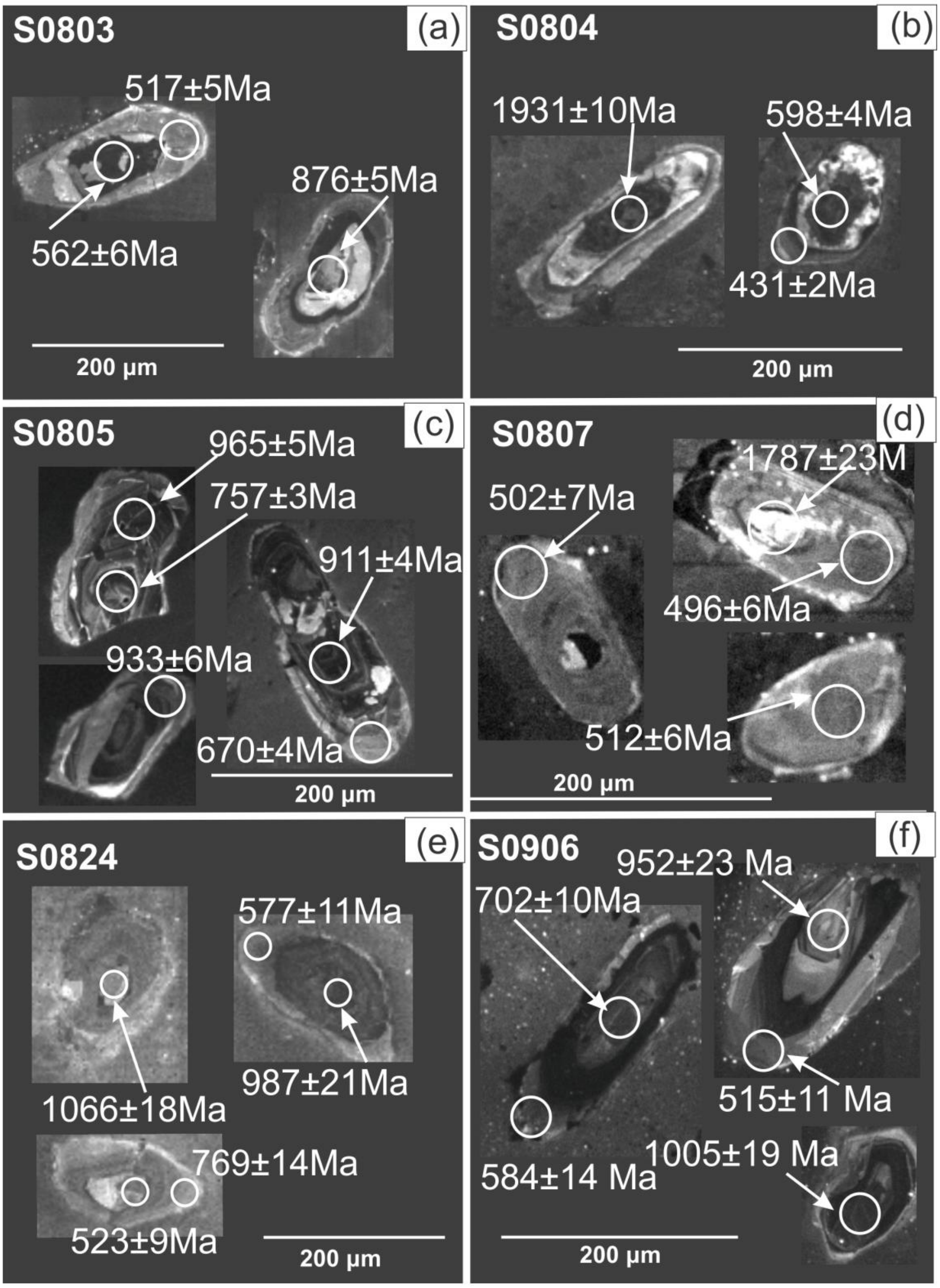

Fig. 3.4. CL images of Migmatitic gneisses of Wanni Complex, (a) S0803-Viharagala-Leucosome, (b) S0804- Viharagala-paleosome, (c) S0805-Habarana-Leucosome, (d) S0807-Habarana-Paleoosome,(e)S0824-Dombawela(leucosome),(f)S0906-Leeniwehera(leucosome).

3.4.1.3 S0805- Habarana- Leucosome

The sample is a migmatitic gneiss collected at Habarana in the Wanni Complex. The rock is a leucosome part of migmatitic gneiss collected from a rock outcrop exposed (

Fig.3.2(c)) close to Habarana junction. This location is close to the tentative WC-HC boundary. The migmatitic gneiss rock is comprised of dark paleosome (S0807) and light coloured leucosome portions (S0805) as shown in the Fig.3.2(c). This field photograph shows that the rock has migmatitic structure with complex ptigmatitic folds due to partial melting during migmatization of parent materials. The right side of the rock out crop shows less deformed gneissic foliation. The sample S0805 represents the whitish leucosome portion of the migmatitic gneiss. The photomicrograph (Fig.3.3(c)) of this leucosome sample shows that sample consists of quartz and plagioclase as the major minerals and biotite as a minor mineral. The rock shows fine to medium grained granoblastic inequigranular texture. As shown in the Fig.3.4, the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral to anhedral, long tetragonal prism and pyramid combination forms.The zircon grains also show a diverse range of luminescence responses. In this leucosome sample most of the zircon grains are sub-rounded due to long distance transportation and show concentric dark and bright luminescence as shown in Fig.3.4(c). The rims were formed during regional metamorphism and are generally moderate to bright luminescent. Most of the zircon grains show oscillatory zoning indicating crystallization from an igneous melt. The zircon cores frequently show oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003).

As shown in the Fig.3.4 (c) the rock sample S0805 is represented by three zircon grains, grain I, grain II and grain III. The grain I is prismatic and subhedral to euhedral. The core is oscillatory and concentric zoned with dark to bright luminescent. This grain is a Neoproterozoic detritus showing $^{206}Pb/^{238}U$ age of 965± 5 Ma The grain II is long prismatic and subhedral to euhedral. The core is oscillatory and concentric zoned with dark to bright luminescent. The variation of luminescence is shown with low to moderate brightness. This grain shows a relatively thicker homogeneous and bright metamorphic rim. This is also a Neoproterozoic detritus showing $^{206}Pb/^{238}U$ age of 911 ± 4 Ma. The grain III is subhedral and short prismatic. The core of this grain is bright luminescent. This grain shows a Neoproterozoic $^{206}Pb/^{238}U$ age of 933 ± 6 Ma. The thicker metamorphic rim of the grain II shows a $^{206}Pb/^{238}U$ age of 670±4 Ma. This shows that a mixture of detritus from Neoproterozoic protolith sources are found in this rock.

Thirty zircon grains were analysed from the sample S-0805. Sixteen analyses were < 10% discordant. The Fig.3.5 (c) (concordia plot) and Fig.3.6 (c) (probability density plot drawn for < 10% discordant grains) show that the maximum age of deposition of the S0805 sample is found to be 630 Ma and the minimum age of deposition is found to be 550 Ma and major detrital peaks occur at 550 Ma, 660 Ma, 830 Ma, 840 Ma, 920 Ma, 980 Ma, , these Neoproterozoic detrital grains are found in one rock of leucosome portion of migmatitic gneiss as age mixtures of detrital grains from several Neoproterozoic sources. Occurrence of several detrital peaks clearly reveals that this leucosome portion has a sedimentary parentage. The occurrence of detratal points and peaks in a broad age range in the concordia plot and the probability density plot indicate that leucosome part of the migmatite gneiss is matasedimentary This result is consistent with the reported Neoproterozoic detrirus from the South Indian metasediments (Collins et.al., 2007).The rims of the sample show a metamorphic age about 547 Ma and this indicates Ediacaran-Cambrian metamorphism.. It can be suggested that deposition of sediments for leucosome portion of the migmatitic gneiss from Habarana had taken place in the WC terrane from about 550 Ma to 630 Ma.

3.4.1.4 S0807- Habarana- Paleosome

The sample is a migmatitic gneiss collected at Habarana in the Wanni Complex. The rock is a paleosome part of migmatitic gneiss collected from a rock outcrop exposed (Fig.3.2(b)) close to Habarana junction. This location is close to the tentative WC-HC boundary. The migmatitic gneiss rock is comprised of dark paleosome (S0807) and light coloured leucosome portions (S0805) as shown in the Fig.3.2(b). This field photograph shows that the rock has migmatitic structure with complex ptigmatitic folds due to partial melting during migmatization of parent materials. The right side of the rock out crop shows less deformed gneissic foliation. The sample S0807 represents the dark paleosome portion of the migmatitic gneiss. The photomicrograph (Fig.3,3 (d)) of this paleoosome sample shows that sample consists of quartz and plagioclase and potassium feldspar as the major minerals and biotite and hornblend as minor minerals. The rock shows fine to medium grained granoblastic inequigranular texture. As shown in the Fig.3.4(d), the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral, long and short tetragonal prism and pyramid combination forms. The zircon grains also show a diverse range of luminescence responses and

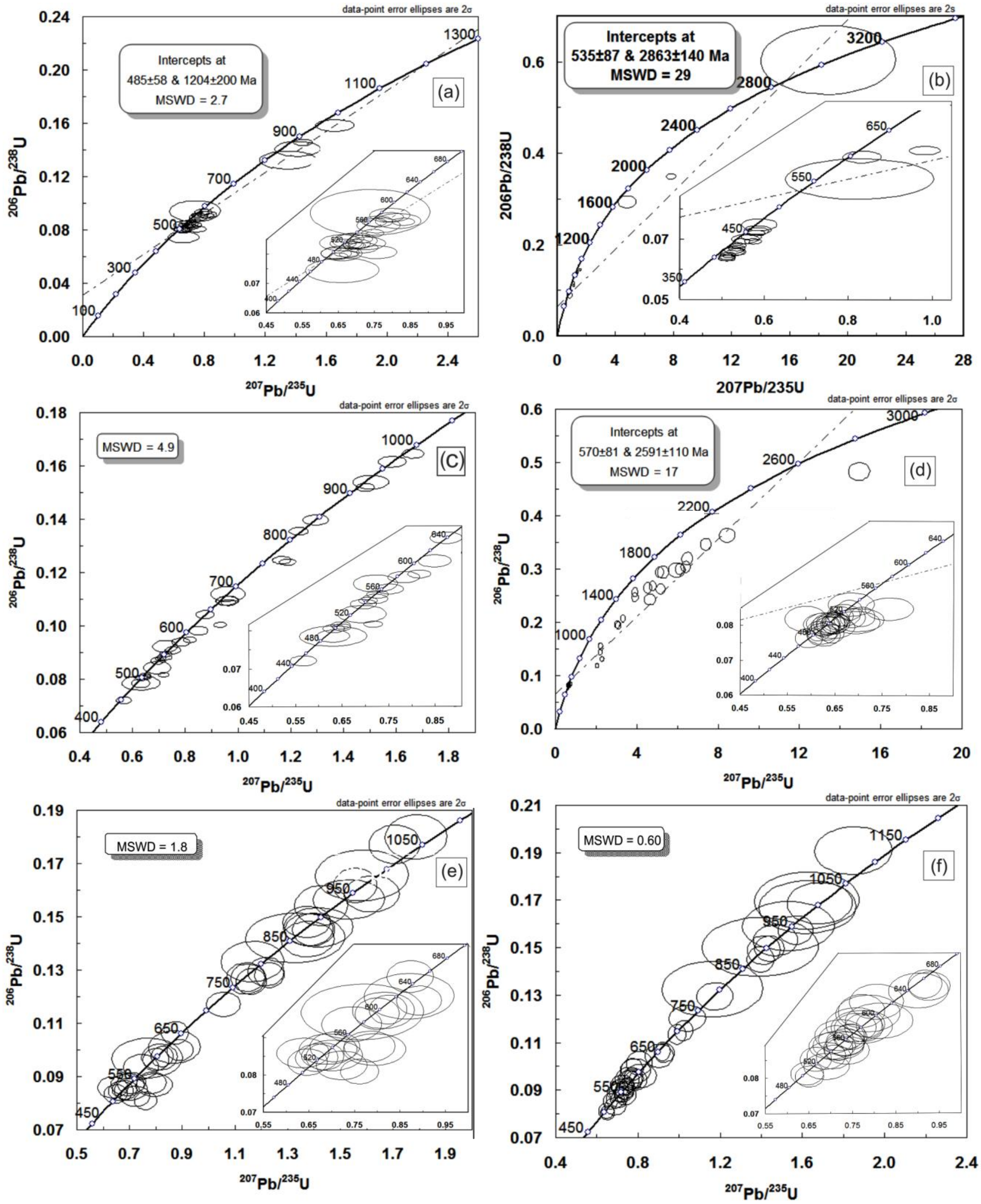

Fig. 3.5. U-Pb Concordia plots of analysed migmatitic gneisses of Wanni Complex (WC) of Sri Lanka (MSWD- mean square of weighted deviates). Upper and lower intercepts were not calculated as there is no linear lead loss. Inset figures show weighted mean of regional metamorphism. (a) S0803-Viharagala-Leucosome, (b) S0804-Viharagala-paleosome, (c) S0805-Habarana-Leucosome, (d) S0807-Habarana-Paleosome, (e) S0824-Dombawela (leucosome), (f) S0906-Leeniwehera (leucosome).

show concentric dark and bright luminescence as shown in Fig.3.4(b). The rims were formed during regional metamorphism and are generally moderate luminescent.

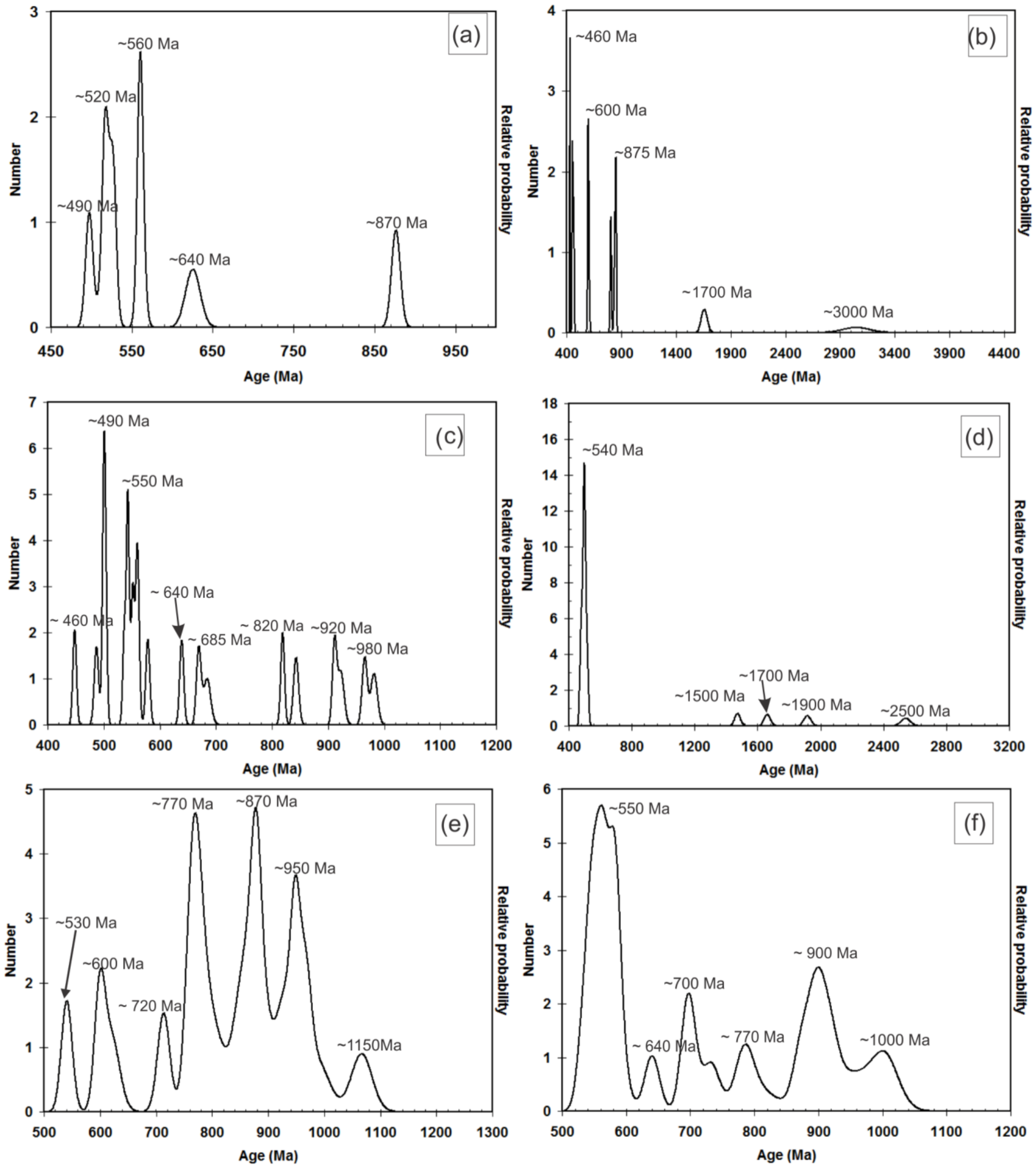

Fig.3.6. Probability Density Plots of Wanni Complex Migmatitic Gneisses (>90% concordant), Probability density distribution plots of individual migmatitic gneiss samples from the Wanni Complex (WC) of Sri Lanka. Bin size of 25 was used for the histogram calculation and 10 % discordance was used as a cut-off for the concordant zircon populations (a) S0803-Viharagala-Leucosome, (b) S0804- Viharagala-paleosome, (c) S0805-Habarana-Leucoosome, (d) S0807-Habarana-Paleoosome, (e) S0824-Dombawela (leucosome), (f) S0906-Leeniwehera (leucosome).

As shown in the Fig.3.4 (d) the rock sample S0807 is here represented by three zircon grains, grain I, grain II and grain III. The grain I is prismatic and showing concentric zoning. The inner core shows two zones of bright and dark luminescence. The metamorphic rim shows moderately bright luminescence. This grain is showing age 502 ± 7 Ma. The grain II is prismatic and subhedral. The core is bright luminescent. The metamorphic rim is moderately bright luminescent. This is a Paleoproterozoic grain showing $^{207}Pb/^{206}Pb$ age of 1787± 23 Ma. This zircon grain is moderately bright luminescent. This grain shows a $^{206}Pb/^{238}U$ age of 520 ± 6 Ma. The thicker metamorphic rim of the grain II shows an age of 496± 6 Ma. This shows that a mixture of grains from Paleoproterozoic to Neoproterozoic protolith sources are found in this rock.

Forty one grains were analysed from the sample S-0807. Sixteenteen analyses were <10% discordant. The Fig.3.5 (d) (concordia plot) and Fig.6 (probability density plot drawn for < 10% discordant grains) show that there is considerable disconcordancy due to lead loss and this paleosome sample has metaigneous origin as the discordant points are directed towards 2591 ± 110 Ma old point on the concordia plot. The upper intercept is found to be 2591± 110 Ma and the lower intercept is found to be 570 ± 81 Ma (MSWD = 17). The rims of the sample show a metamorphic age about 540 Ma and this indicates Edicaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the Paleosome portion of the Habarana migmatitic gneiss were igneous rocks of Neoarchaean age. The Fig.3.5(d) and Fig.3.6 indicate that paleosome portion of the Habarana migmatitic gneiss has metaigneous origin.

3.4.1.5 Sample S0824 – Dombawela Migmatitic gneiss (Leucosome sample)

The sample is a migmatitic gneiss collected at Dombawela in the Wanni Complex. This location is about 20 Km far and west of the tentative WC-HC boundary. The migmatitic gneiss rock is comprised of dark paleosome and whitish to pink coloured leucosome portions as shown in the Fig.3.2 (c). This field photograph shows that the rock has migmatitic structure with complex ptygmatitic folds due to partial melting during migmatization of parent materials. The sample S0824 represents light coloured leucosome portions of the migmatitic gneiss. The photomicrograph (Fig.3.3(e)) of this sample shows that sample consists of cordierite as the major mineral and biotite and hornblend as minor minerals. The rock shows fine to medium grained granoblastic inequigranular texture. As shown in the Fig.3.4(e), the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral, short tetragonal prism and pyramid combination forms. The zircon grains also show a diverse range of luminescence responses. In this sample most of the zircon grains are sub-rounded due to long distance transportation and show concentric dark and bright luminescence as shown in Fig.3.4(e). The rims were formed during regional metamorphism and are generally moderate luminescent. Most of the zircon cores show bright luminescence and oscillatory zoning indicating crystallization from an igneous melt. The zircon cores frequently show oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003).

As shown in the Fig.3.4 the rock sample S0824 is here represented by three zircon grains , grain I, grain II and grain II. The grain I is short prismatic and subhedral. It shows concentric moderately bright luminescence. The metamorphic rim is moderately bright luminescent. This grain is a Mesoproterozoic detritus showing $^{207}Pb/^{206}Pb$ age of 1066±18 Ma. The grain II is short prismatic and shows dark luminescence. The metamorphic rim is moderately bright luminescent.. This is a Neoproterozoic grain showing $^{206}Pb/^{238}U$ age of 987 ± 21 Ma. The metamorphic rim shows a $^{206}Pb/^{238}U$ age of 577 ± 11 Ma. The grain III is short prismatic and subhedral and shows bright to moderately bright luminescence. The metamorphic rim is bright luminescent. This grain shows a Neoproterozoic $^{206}Pb/^{238}U$ age of 769 ± 14 Ma. The thicker metamorphic rim of the grain III shows a $^{206}Pb/^{238}U$ age of 523 ± 9 Ma. This shows that a mixture of detritus from Mesoproterozoic to Neoproterozoic protolith sources are found in this rock.

Thirty three zircon grains were analysed from the sample S0824. Twenty analyses were <10% discordant. The Fig.3.5 (concordia plot) and Fig.3.6 (e) (probability density plot drawn for <10% discordant grains) show that the maximum age of deposition of the S0824 sample is found to be ~720 Ma and the minimum age of deposition is found to be ~600 Ma and major detrital peaks occur at 720 Ma,770 Ma, 870 Ma, 950 Ma, and 1000Ma . Also the maximum age of deposition of this leucosomes of WC migmatitic gneiss at Dombawela can be constrained at 720 Ma based on >90% concordant point in Fig.3.5 –S0824 and a major peak in the probability density plot (Fig.3.6 (e)). The rims of the sample show a metamorphic age about 523 ± 9 Ma and this indicates Ediacaran-Cambrian metamorphism. Occurrence of several detrital peaks clearly reveals that this leucosome portion has a sedimentary parentage. The occurrence of detratal points and peaks in a broad age range in the concordia plot and the probability density plot indicate that leucosome part of the migmatite gneiss is matasedimentary This suggests that the premetamorphic materials of the leucosomes of migmatitic gneiss at Dombawela received detritus from several sources of Neoproterozoic times as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for metaquartzites had taken place in the WC terrane from about 720 Ma to 523 Ma. The probability density plot Fig.6e indicates several peaks and leucosomes of Dombawela migmatitic gneiss is found to have metasedimentary origin.

3.4.1.6. Sample S0906 – Leeniwehera Migmatitic Gneiss (Leucosome)

The sample is a migmatitic hornblend biotite gneiss collected at Leeniwehera in the Wanni Complex. This location is about 42 Km far and west of the tentative WC-HC boundary. The migmatitic gneiss rock is comprised of whitish coloured leucosome portions as thick to thin bands and lenses or pods as shown in the field photograph, Fig.2(d). This field photograph shows that the rock has migmatitic structure with complex ptigmatitic folds due to partial melting during migmatization of parent materials. The sample S0906 represents light coloured leucosome portions of the migmatitic gneiss. The photomicrograph (Fig.3.3 (f)) of this sample shows that sample consists of quartz, plagioclase, potassium feldspar, biotite and hornblend as the major minerals .The rock shows fine to medium grained granoblastic inequigranular texture. As shown in the Fig.3.4(f), the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with subhedral to anhedral long tetragonal prism and pyramid combination forms. The zircon grains also show a diverse range of luminescence responses. In this sample most of bulk migmatitic gneiss the zircon grains are sub-rounded due to long distance transportation and show concentric dark and bright luminescence as shown in Fig.3.4(f). The rims were formed during regional metamorphism and are generally moderate luminescent. Most of the zircon cores show bright luminescence and oscillatory zoning indicating crystallization from an igneous melt. The zircon cores frequently show oscillatory zoning that commonly indicates zircon crystallization from a melt (Corfu et al., 2003).

The rims were formed during regional metamorphism. As shown in the Fig.3.4 the rock sample S0906 is represented by three zircon grains, grain I, grain II and grain III. The grain is long prismatic and subhedral to subrounded. The rounded edges of the grain shows abrasion due to sedimentary transportation. This core shows bright to moderately bright luminescence. The core is rimmed by dark to moderately bright luminescent rims. This grain is a Neoproterozoic and showing $^{206}Pb/^{238}U$ age of 702± 10 Ma. The metamorphic rim shows a $^{206}Pb/^{238}U$ age of 584 ± 14 Ma. The grain II is short and broad prismatic. The core of the grain shows anhedral to rounded shape/form. The core shows concentric and faintly oscillatory zoned luminescent patches. The metamorphic rim is dark to moderately bright luminescent. This is also a Neoproterozoic and showing $^{206}Pb/^{238}U$ age of 952 ± 23 Ma. The metamorphic rim shows a $^{206}Pb/^{238}U$ age of 515 ± 11. The grain III is short prismatic and anhedral to subhedral. The core shows bright and dark luminescent concentric zones. The core of this grain has a truncated surface and is also interpreted here as resulting from sedimentary abrasion during transportation. The metamorphic rim is dark to bright luminescent. This grain shows a late Mesoproterozoic age of 1005± 19 Ma. This shows that a mixture of detritus from Mesoproterozoic to Neoproterozoic protolith sources are found in this rock.

Forty one zircon grains were analysed from the sample S0906. Twenty five analyses were <10% discordant. The Fig.3.5 (concordia plot) and Fig.3.6 (probability density plot drawn for <10% discordant grains) show that the maximum age of deposition of the S0906 sample is found to be 640 Ma and the minimum age of deposition is found to be 550 Ma and major detrital peaks occur at 640 Ma, 700 Ma, 770 Ma, 900 Ma, and 1000 Ma. These Neoproterozoic detrital grains are found in one rock of migmatitic gneiss as age mixtures of Neoproterozoic detrital grains. Occurrence of several detrital peaks clearly reveals that this leucosome portion has a sedimentary parentage. The occurrence of detratal points and peaks in a broad age range in the concordia plot and the probability density plot indicate that the Leeniwehera migmatite gneiss is matasedimentary. The rims of the sample show a metamorphic age of about 547 Ma and this indicates Ediacaran-Cambrian metamorphism. This suggests that the premetamorphic materials of the leucosomes of Leeniwehera migmatitic gneiss received detritus from several Neoproterozoic sources as well as detritus were well mixed during transportation and deposition as shown by above ages. It can be suggested that deposition of sediments for leucosomes of migmatitic gneiss had taken place in the WC terrane from about 640 Ma to 550 Ma.

3.5. Discussion

3.5.1 Age constraints of deposition

All leucosomes of migmatitic gneiss samples from Viharagala (S0803) and Habarana(S0805) except two paleosome samples show evidence for a considerable Mesoproterozoic to Neoproterozoic detrital input into the original sedimentary basin of the Wanni Complex terrane (Fig.3.5 and 3.6). The leucosomes of migmatitic gneiss samples from Dombawela and Leeniwehera (S0824 and S0906) had also derived detritus from Neoproterozoic to late Mesoproterozoic protolith sources (~700 Ma to ~1150Ma). However, two paleosome samples of migmatitic gneiss (S0804 and S0807) collected at Viharagala and Habarana contain concordant cores from Neoarchaean to Mesoarchaean protolith sources (2.85 Ga to 3.0 Ga). Further, it would be probable that leucosome portions had originated from partial melts produced from melting of younger succession of WC sediments and these partial melts may have most probably mixed with Mesoarchaean igneous basement material which subsequently became paleosome portions due to migmatization during Ediacaran-Cambrian metamorphism.

This study also reveals that zircon cores younger than 541 ± 10 Ma may have been formed in partial melts which cooled and solidified up to Cambrian. The maximum age of deposition of Wanni Complex detrital cores of leucosomes can be constrained at ~700 Ma. The depositional age for the protoliths to these samples is constrained between about 700 Ma and 540 Ma. The metasedimentary parentage of leucosomes of migmatitic gneisses of WC is also clearly indicated by the occurrence of several detrital peaks from about 700 Ma to about 1150 Ma (Fig.3.6). Newly formed zircon grains are also found in leucosome samples which constrain the event of partial melting and migmatization in the WC to have occurred between ~460 Ma to 540 Ma.

This study also reveals that parent detrital sediments of the WC migmatitic gneisses deposited after ca 700 Ma compared to parent sediments for HC deposited after ca. 1900 to 2000 Ma (Amarasinghe et al. 2011) as reported in the chapter 2 of this thesis. This clearly reveals and confirms that WC and HC of Sri Lanka are two different crustal domains with different geological origins and histories. The leucosomes of WC migmatitic gneisses form concordia spectra of series of zircon ages together with occurrence of several detrital peaks in the probability density plot (Fig.3.6) which are characteristic of metasedimentary as proved by occurring zircon ages in a series or a broad range from ~700

Ma to ~1150 Ma rather than a concentrated cluster which is characteristic of metaigneous /orthogneisses. So this study reveals for the first time that parent/precursor materials of leucosomes of WC migmatitic gneisses are found to be sedimentary. It is possible to interpret that parent sedimentary materials of the leucosomes of migmatitic gneisses of WC were belonging to a different sedimentary succession compared to parent sedimentary materials of the HC supracrustal rocks.

3.5.2 Provenance implications

As far as possible protolith sources for the WC migmatitic gneisses of Sri Lanka are considered with respect to paleotectonic positions prior to amalgamation of Gondwana are concerned sources abundant in the Indian land mass, Madagascar, East Africa and Antarctica can be attempted. If possible Indian sources are considered first, the Dharwar craton of Mesoarchaean to Neoacrchaean exists north of the Souithern Granulite Terrane of India and provided >3.0Ma detritus into Dharwar-derived sediments throughout the Proterozoic (Collins et al., 2003). But the protolith material from the Dharwar croton can be excluded as no > 3.0 Ga ages were found in these WC migmatitic gneisses. But this study reveals that only paleosome parts of WC migmatitic gneisses are metaigneous and Mesoarchean (2.85 Ma to 3.0 Ma) and may have served as the continental crustal basement for the WC sedimentary deposits. It was reported that rocks dated between 1880 and 1700 Ma are found in the Krishna province of the Eastern Ghats of India (Dobmeier and Raith, 2003). Zircon xenocrysts were dated as 2431 Ma and also a detrital grain was dated as 2747 Ma $^{206}Pb/^{207}Pb$ age (Shaw et al., 1997). But no prominent 1990 Ma to 2300 Ma peaks can be found in Eastern Ghats (Collins et al., 2007). So the Indian sources lack Mesoproterozoic to Neoproterozoic sources for the neighbouring WC migmatitic gneisses and it is suggested that protoliths to WC terrane of Sri Lanka may be sourced from non-Indian sources.

With respect to the current directions the island of Madagascar exists west of the island of Sri Lanka and comprises of similar metasedimentary supracrustal rocks in the west and south of the Madagascar (Windley et al., 1994; Collins et al., 2003a; Fernandez et al., 2003; Cox et al., 2004; Fitsimons and Hulscher., 2005; Collins, 2006). These metamorphosed sedimentary rocks consists of two sedimentary successions: one succession of probable Paleoproterozoic age, named as the Itremo Group (Cox et al., 1998), which contains Neoarchaean and Paleoproterozoic detrital zircon grains; a second succession of Neoproterozoic age, known as the Molo Group with Neoarchaean, Paleoproterozoic and Neoproterozoic zircon detritus (Cox et al., 2004; Fitzsimons and Hulscher, 2005). In recent Gondwana reconstructions these two successions are placed adjacent to each other and contain broadly similar detrital zircon records with predominant Paleoproterozoic protolith sources. The detrital zircon record of the leucosome portions of migmatitic gneisses of WC of Sri Lanka correlates broadly with the Neopoterozoic to Mesoproterozoic Molo Group of the Madagascar. On the other hand U-Th-Pb SHRIMP secondary ion mass spectrometry of zircons of southern Madurai block of South India showed similar correlations with the Molo Group metasedimentary successions of Madagascar (Collins et al., 2007; Plavsa et al., 2014).

A coupled U-Pb and Hf isotopic analysis of detrital zircons from Southern Granulite Terrane of India showed that the Southern Madurai Block correlates with the Molo Group of Madagascar as shown in Probability Density Distribution Plots of matasedimentary packages from across the adjacent Gondwanan terranes (Plavsa et al., 2014). The metasedimentary leucosome portions of migmatitic gneiss rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. It is here interpreted that the WC of Sri Lanka was welded to the Southern Madurai Block of South India as a merged continental block from Paleoproterozoic to late Neoproterozoic and the paleotectonic position of Sri Lanka can be decided connecting the WC of Sri Lanka to the Southern Madurai Block of South India as shown in the Fig.2.12 in the chapter 2. I here suggest that metasedimentary sequences of WC of Sri Lanka, Southern Madurai Block of South Indian sequences, and Malagasy sequences represent different parts of shallow sedimentary basins of continental blocks which existed from late Mesoproterozoic to late Neoproterozoic.

It was suggested that the Molo Group was sourced from the eastern Africa (Cox et al., 2004; Fitzsimons and Hulscher, 2005). Eastern Africa contains potential protolith source rocks for all the detrital age peaks obtained in this study from leucosomes of WC migmatitic gneisses. In the Kibaran belt of eastern Africa Mesoproterozoic protoliths were dated at ~ 1.4 Ga (Kokonyangi., 2004) and Neoproterozoic magmatic rocks of central Madagascar were dated (Handke et al., 1999; Kröner et al., 2000) and Neoproterozoic rocks were dated from the Mozambique belt (Kröner et al., 2003).

3.5.3 Age of metamorphism

The concordia plot of metamorphic rims (Fig.3.5) shows that the Wanni Complex was subjected to Ediacaran-Cambrian regional metamorphism between about 515 Ma to 600 Ma. Fig3.4 also shows that the event of partial melting proceed and continued into Cambrian (~448 Ma) and new detrital zircon grains had formed from the partial melts. Partial melting and migmatization are well marked in the Wanni Complex and migmatitic gneisses have become the type rocks of the Wanni Complex of Sri Lanka.

3.6 Conclusions

The concordia and probability density plots of this study clearly reveal for the first time that parent materials of leucosome portions of WC migmatitic gneisses are metasedimentary. Detrital cores of leucosomes of migmatitic gneiss rock samples from WC yielded >90% concordant $^{206}Pb/^{238}U$ ages that generally range from ~700 Ma to 1150 Ma. The WC migmatitic gneisses generally show maximum age of deposition at ~700 Ma compared to parent sediments for HC deposited after ca. 1900 to 2000 Ma (Amarasinghe et al. 2011) and also chapter 2 of this thesis. This reveals and confirms that WC and HC of Sri Lanka are two different crustal domains with different geological origins and histories. It is first time reported that the two paleosome samples (S0804 and S0807) show metaigneous characteristics based on concentrated detrital point on the concordia plot and Mesoarchean (2.85-3.0 Ga) concordant ages. I suggest that the paleosome portions of WC migmatitic gneisses probably represent the Mesarchaean igneous continental crustal block type basement on which Neoproterozoic to Mesoproterozoic WC metasediments were deposited in shallow basins. The two leucosome samples of migmatitic gneisses from Dombawela and Leeniwehera also show metasedimentary origin (occurring a series of detrital points on the concordia curve in a broad age range) and late Mesoproterozoic to Neoproterozoic provenance (1.15 to 0.65 Ga). This also reveals that paleosome portions and leucosome parts of WC migmatitic gneisses represent two different materials of a continental block. The leucosomes of migmatitic gneisses of the WC of Sri Lanka record a mixture of predominent late Mesoproterozoic to Neoproterozoic protolith sources. The detrital signatures of leucosomes of WC migmatitic gneisses best fit the combined basement ages of Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources. It reveals that the metasedimentary leucosome portions of migmatitic gneiss rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. The WC of Sri Lanka is interpreted as the welded and continuous terrane of the Southern Madurai Block of South India before the assembly of Gondwana. I here suggest that metasedimentary sequences of WC of Sri Lanka, metasedimentary sequences of HC of Sri Lanka, Southern Indian sequences, and Malagasy sequences represent different parts of either continental sedimentary basins or orogenic belts which existed since Paleoproterozoic to late Mesoproterozoic to Neoproterozoic. I here suggest based on the results that the paleotectonic position of Sri Lanka would be south east of South India (see Fig.2.12 of the chapter 2) and the WC is interpreted to be the welded terrane to the Southern Madurai Block of South India and it is also somewhat consistent with what was suggested by Teale et al. (2011), Plavsa et al. (2014b) and Collins et al, (2014). I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older metaigneous Mesoarchean re-worked cratonic continental crustal basement material to form WC migmatitic gneisses.

It is also here suggested that paleosome materials of WC migmatites represent the older reworked Mesoproterozoic continental cratonic basement on which a thin succession of WC sedimentary succession was deposited. The study of age and provenance of metasedimentary leucosomes of WC migmatitic gneisses clearly show a correlation between the WC of Sri Lanka with Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources. The Cryogenian felsic magmatism reported in the WC is suggested as continental arc type and the Paleoproterozoic HC basement was an oceanic crust and which had subducted underneath the welded Southern Madurai Block-WC continental block along the suture of WC-HC boundary marking the closure of the ancient south Mozambique ocean.

Partial melting continued up to ~ 490 Ma. I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older igneous cratonic basement materials to form WC migmatitic gneisses. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.

Acknowledgements

The authors wish to thank the University of Adelaide for the providing adequate laboratory facilities for sample preparation and U-Pb zircon dating. Dr. Benjamin Wade of Adelaide Microscopy is especially thanked for assistance during LA-ICPMS analysis. My PhD colleagues, Diana Plavsa, Jade Anderson, Frank Robinson of the Department of Earth Sciences are also thanked. Prassana Dharmapriya is thanked for improving figures in Corel draw and Moditha Kodikaraarachchi of the Department of Geology, University of Peradeniya is thanked for his assistance in petrographic photography. Dasith Bandara Wewegama, a third year undergraduate in Medicine, the University of Adelaide is thanked for all the encouragements and helps.

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Supplementary Table 3. 1

Analysis_#	Pb207/U235	1σ	Pb206/U238	1σ	rho	Concordancy	Pb207/Pb206	1σ	Pb206/U238	1σ
803										
c1	0.85392	0.03645	0.10187	0.00155	0.356455	57	872.5	64.31	499.6	5.28
c2	0.76284	0.01245	0.09069	0.00053	0.35808	61	752.9	134.41	462.9	10.13
3c	0.79424	0.01498	0.09255	0.00062	0.355185	71	720.7	53.31	508.8	4.25
4c	0.73805	0.06816	0.0941	0.00319	0.367077	73	771.6	68.84	562.6	6.06
6c	0.79288	0.02284	0.09317	0.00096	0.35769	75	663.1	35.55	495.5	2.72
7c	1.41163	0.06119	0.1407	0.00228	0.373836	77	1038.7	116.5	801.6	15.44
8c	0.81618	0.0259	0.0912	0.00103	0.3559	79	678.7	37.89	538.2	3.14
10c	0.71492	0.01239	0.08507	0.00052	0.352706	80	647.6	45.46	516.8	3.62
11c	0.74594	0.01269	0.08708	0.00053	0.357767	81	633	39.75	513.3	3.12
13c	0.69501	0.01234	0.08288	0.00052	0.35337	82	605.7	69.77	494.5	5.31
14c	0.7569	0.02268	0.08058	0.00089	0.368602	83	637.7	38.8	526.3	3.12
15c	1.4466	0.02588	0.14564	0.00096	0.368447	83	620.5	38.65	513.7	3.02
16c	1.65537	0.05185	0.15842	0.00178	0.358721	84	682.6	41.88	570.6	3.67
18c	0.68438	0.01505	0.08521	0.00066	0.35222	84	660.4	71.61	553.8	6.18
19c	1.34903	0.07672	0.13241	0.00271	0.359883	84	585.3	37.2	491.4	2.76
20c	0.69161	0.0119	0.08296	0.00051	0.357286	84	1007.5	90.24	848.6	12.86
21c	0.69601	0.02529	0.08447	0.00111	0.361649	84	589.5	78.79	497.4	6.06
22c	0.64391	0.01744	0.08024	0.00077	0.354306	86	664.5	63.71	574.3	5.64
23c	0.64978	0.0107	0.07922	0.00046	0.352619	87	1089.6	64.75	948	9.89
c25	0.65931	0.02326	0.08022	0.00102	0.360411	87	639.6	36.55	559.6	3.11
c26	0.67942	0.01081	0.07989	0.00046	0.361891	88	594.7	81.42	522.7	6.6
c28	0.71751	0.01738	0.08212	0.00071	0.356934	89	987.4	37.76	876.5	5.39
c29	0.66044	0.04163	0.07445	0.00169	0.360121	93	537	61.85	497.5	4.59
c30	0.66301	0.01485	0.08355	0.00065	0.347345	98	538.8	50.53	527.1	3.94

31c	0.70468	0.01435	0.08346	0.00061	0.358915	99	632.1	94.05	625.4	9.06
33c	0.76189	0.0247	0.08971	0.00104	0.357592	101	512.8	51.29	517.3	3.88
34c	0.66016	0.02067	0.07973	0.00089	0.356514	119	486.6	202.76	579.7	18.78
r1	0.75246	0.01288	0.09079	0.00055		92	607.6	38.52	560.2	3.27
r2	0.75874	0.01745	0.09101	0.00075		90	620.4	51.43	561.5	4.42
r	0.83071	0.01295	0.09094	0.00051		68	814.6	34.03	561.1	3.04
4r	0.72955	0.02104	0.08359	0.00087		72	718.4	63.32	517.5	5.18
5r	0.67223	0.01482	0.08053	0.00063		80	623.1	49.32	499.3	3.77
6r	0.65697	0.02414	0.08384	0.00111		107	484.4	84.11	519	6.6
804										
1c	0.58104	0.00852	0.07202	0.00038	0.35983	66	1026.8	54.67	677.2	6.51
3c	7.81696	0.13992	0.34934	0.00229	0.366223	67	828.2	180.05	555.1	16.14
6c	18.66793	1.90088	0.60402	0.0307	0.499147	71	608	32.07	431.7	2.14
9c	0.83253	0.01873	0.09722	0.00079	0.361188	73	563.2	39.78	410.8	2.51
12c	4.80376	0.24785	0.29353	0.0055	0.363164	74	541.1	36.95	397.8	2.22
13c	0.53427	0.00937	0.0658	0.00042	0.363952	74	535.3	35.38	398.5	2.13
14c	0.98173	0.01509	0.09939	0.00056	0.366563	76	1146.8	37.95	873.9	5.47
c17	0.53548	0.00813	0.06702	0.00037	0.363622	76	525.6	36.73	400.9	2.24
c18	0.58884	0.01711	0.0748	0.00079	0.363474	78	2479.8	31.52	1931.5	10.94
c21	0.5394	0.00754	0.06782	0.00034	0.358642	78	909	63.98	708.8	7.55
c23	1.38889	0.02421	0.14132	0.0009	0.365352	78	524.5	51.45	410.8	3.24
c24	0.57027	0.00983	0.07068	0.00044	0.361146	78	516.1	33.66	404.6	2.06
c25	0.55561	0.01327	0.07006	0.0006	0.358575	79	527.5	35.06	418.2	2.22
c27	1.56116	0.0286	0.14518	0.00097	0.364709	79	521.4	41.65	414.2	2.63
28c	0.58395	0.0111	0.07263	0.0005	0.362165	80	549.3	39.22	440.3	2.64
30c	0.51133	0.0078	0.06377	0.00035	0.359798	82	549.1	33.44	448.3	2.29

31c	0.82685	0.07202	0.08993	0.00273	0.348523	82	517.6	32.35	423	2.07
32c	0.52869	0.00959	0.06636	0.00044	0.365535	84	541.1	43.95	452	3
33c	0.51218	0.00816	0.06416	0.00037	0.361968	85	511.2	54.77	436.5	3.63
35c	0.54656	0.00782	0.06926	0.00036	0.363288	85	531.9	51.51	454.3	3.55
36c	0.51175	0.00814	0.06365	0.00037	0.365457	86	1936.8	94.23	1659.2	27.41
38c	0.52497	0.01181	0.0658	0.00054	0.364798	86	936.7	42.34	805.5	5.48
40c	1.3629	0.03453	0.1398	0.00132	0.372678	86	500.1	32.93	431.7	2.16
40r	1.11124	0.0333	0.11623	0.00131	0.376112	88	677.9	49.94	598.1	4.67
41c	1.28969	0.02557	0.13309	0.00096	0.363815	88	965.7	37.12	852.1	5.08
42c	0.5741	0.00815	0.06926	0.00036	0.366142	89	949.1	53.86	843.5	7.45
43c	0.51486	0.00749	0.06478	0.00034	0.360782	90	670	73.14	602.6	6.97
44c	0.58453	0.01312	0.07301	0.00059	0.360033	94	494.8	66.89	465	4.77
45c	1.12187	0.02902	0.11076	0.00112	0.390913	101	3010.9	166.07	3046	123.4
805										
1c	1.26647	0.0364	0.10746	0.00126	0.40796	50	1326.5	58.39	658	7.32
2c	1.22939	0.01465	0.13549	0.00059	0.365424	102	800.5	26.13	819.1	3.32
3r	0.87448	0.0141	0.10424	0.00061	0.362933	101	633.9	36.22	639.2	3.57
4c	1.5851	0.02176	0.16157	0.00082	0.369701	100	961.9	29.33	965.5	4.57
4r	1.16544	0.01382	0.12468	0.00055	0.372004	88	862.5	25.78	757.4	3.14
7c	0.85	0.01445	0.09819	0.00066	0.395392	90	540.9	52.81	487.2	3.92
7r	0.63118	0.02959	0.07851	0.00108	0.293432	96	1023	37.55	982.3	5.96
8c	1.66416	0.01678	0.16461	0.0007	0.42174	92	726.8	38.69	669.4	4.09
8r	0.9588	0.01797	0.10943	0.00068	0.331553	96	951.5	25.96	911.8	3.81
9c	1.48294	0.01411	0.15193	0.0006	0.415054	93	602.9	42.31	559.6	3.56
11c	0.70655	0.00805	0.08781	0.00036	0.359837	100	543.3	26.05	542.6	2.13
11r	0.72128	0.01133	0.08827	0.0005	0.360604	95	576.9	35.6	545.3	2.96

13c	0.72272	0.01949	0.09231	0.00091	0.365553	118	482.6	62.41	569.2	5.36
15c	1.50339	0.02784	0.15391	0.00104	0.364896	97	953	39.49	922.9	5.82
16c	0.9622	0.02668	0.11198	0.00115	0.370371	100	685.3	61.44	684.2	6.65
17c	0.69391	0.02103	0.08429	0.00093	0.364058	88	593.5	67.67	521.7	5.52
18c	0.72714	0.00956	0.08944	0.00042	0.357172	98	566	29.27	552.2	2.5
18r	0.63269	0.00947	0.08049	0.00043	0.356917	102	491.4	34.69	499.1	2.54
19c	0.75269	0.01228	0.09085	0.00053	0.357576	92	607	36.79	560.5	3.15
19r	0.64975	0.00809	0.08082	0.00036	0.357751	93	540.9	29.12	501	2.15
20c	0.93168	0.00993	0.10039	0.00039	0.364495	73	847.5	23.21	616.7	2.28
20r	0.71766	0.00822	0.08163	0.00034	0.363644	69	733.9	25.42	505.9	2.04
21c	0.69666	0.01151	0.08692	0.00051	0.355137	101	534.4	38.2	537.3	3.04
23c	1.29489	0.01988	0.13975	0.0008	0.372868	100	844.2	33.39	843.3	4.53
24c	0.96311	0.01109	0.10873	0.00046	0.367412	89	749.9	25.47	665.4	2.67
26c	0.78362	0.01395	0.09396	0.00061	0.364685	93	621.3	40.02	578.9	3.59
30c	1.18842	0.01318	0.12389	0.00051	0.371183	82	915.9	23.94	752.9	2.94
29c	0.56732	0.01168	0.07204	0.00054	0.364087	90	495.7	47.72	448.4	3.22
27c	0.81704	0.01014	0.09477	0.00043	0.365597	97	520.7	27.71	504	2.53
27r	0.64764	0.00876	0.08132	0.00039	0.354566	52	1873.9	31.21	980	2.34
31c	2.59441	0.04473	0.16418	0.00104	0.367412	46	925.4	32.47	424.4	5.74
3r	0.87448	0.0141	0.10424	0.00061			638	7.64	639.2	3.57
4r	1.16544	0.01382	0.12468	0.00055			784.5	8.55	757.4	4.57
7r	0.63118	0.01445	0.07851	0.00066			496.8	6.48	487.2	3.14
8r	0.9588	0.01678	0.10943	0.0007			682.7	8.99	669.4	3.92
807										
1c	5.11229	0.0852	0.29413	0.00398	0.811932	56	1679.6	36.55	933.5	12.72
3c	8.44225	0.15877	0.36326	0.00534	0.781652	61	1888.7	26.16	1145.9	16.52

4c	2.21089	0.04544	0.15582	0.00228	0.711935	63	1836.7	25.25	1154.6	15.38
5c	5.2956	0.11671	0.2941	0.00462	0.712778	63	2212.6	43.52	1401.1	21.53
6c	0.63565	0.01891	0.08064	0.00128	0.533563	64	1895.8	19.46	1215.3	14.87
7c	0.76453	0.02076	0.08475	0.00132	0.57359	66	2266.5	30.64	1502	19.55
9c	4.64092	0.11562	0.24278	0.00415	0.68613	66	790.7	56.27	524.4	7.86
10c	0.65015	0.01111	0.08108	0.00112	0.808358	72	2377.4	18.98	1711.5	21.46
11c	0.66804	0.01426	0.08298	0.00127	0.71699	73	2320.9	18.42	1692.2	20.61
12c	0.66185	0.01082	0.08268	0.00114	0.843406	73	2089.8	20.03	1531.7	19.01
13c	0.61497	0.01023	0.07838	0.00114	0.874335	73	2290.9	49.51	1681.5	27.75
14c	4.54182	0.08191	0.26475	0.00412	0.862888	75	2023.1	26.71	1514.1	21
15c	0.62913	0.0122	0.07983	0.00118	0.762248	75	679.5	27.89	511.2	6.82
16c	6.48226	0.11222	0.31951	0.00485	0.876826	76	1877.6	28.25	1423.8	17.59
17c	3.90822	0.06683	0.24715	0.0034	0.8045	77	2314	25.09	1787.3	23.67
18c	0.68011	0.01103	0.08444	0.00117	0.854361	78	2545.5	29.89	1997.6	25.25
19c	0.62167	0.01569	0.08034	0.00129	0.636202	79	2108.2	37.91	1662	23.03
20c	0.59509	0.01204	0.07643	0.00115	0.743687	80	2403	20.86	1916.4	22.38
21c	4.78334	0.06932	0.2682	0.00374	0.962245	81	2046	26.62	1662.1	19.83
22c	0.64587	0.01466	0.08067	0.00123	0.671745	82	1804.3	21.45	1472.7	18.42
24c	3.90173	0.05772	0.25665	0.00359	0.945549	84	3012.5	18.21	2540.8	29.8
25c	0.70708	0.01109	0.08254	0.00114	0.880597	84	567	45.69	478.7	7.23
26c	6.11517	0.08602	0.30018	0.00416	0.985192	90	555	29.68	497.9	6.72
27c	6.40383	0.09375	0.30408	0.00434	0.974923	90	534	41.18	482.1	7.3
28c	0.64514	0.01036	0.08055	0.00112	0.865858	94	533.3	30.03	499.4	6.69
29c	0.63793	0.01376	0.08065	0.00115	0.661071	94	535.6	33.55	502.5	6.67
30c	0.62183	0.013	0.07766	0.00122	0.751434	94	532.7	46.84	500.1	7.34
31c	0.62648	0.01424	0.07709	0.00121	0.690533	94	545.7	42.6	513.9	7.55
32c	7.3995	0.10752	0.3462	0.00467	0.928331	96	546	30.2	522.6	6.94

34c	14.94033	0.21634	0.48312	0.00686	0.980601	96	531.7	31.19	512.1	6.8
35c	3.09166	0.05341	0.19454	0.00306	0.910504	99	506.6	45.61	500	6.88
36c	3.31806	0.04581	0.20746	0.00279	0.974078	100	497.2	37.91	495.1	7.05
37c	5.17278	0.09672	0.26238	0.00383	0.780685	100	488.3	30.62	486.5	6.79
38c	5.95941	0.16831	0.29802	0.00559	0.66414	100	500.5	65.31	499.9	7.65
39c	0.58807	0.01795	0.0819	0.00148	0.592028	100	472.5	40.34	474.8	6.92
40c	0.64936	0.01053	0.0803	0.00113	0.867801	109	458.3	52.77	498.2	7.7
824										
1c	0.89151	0.02018	0.09992	0.00159	0.702991	57	875.5	39.79	501.7	14.14
2c	0.70056	0.02726	0.08521	0.00166	0.500653	80	763.7	43.77	614	9.34
3c	1.38125	0.03721	0.1452	0.00246	0.628899	81	800.2	39.92	652.1	12.4
4c	1.3724	0.03688	0.14806	0.00239	0.600689	82	987.4	76.14	807.8	16.88
5c	0.63679	0.02346	0.08589	0.00162	0.511965	84	919.3	32.59	776.8	10.96
5c2	1.23078	0.02277	0.12806	0.00192	0.810411	89	592.8	82.85	527.1	9.87
7c	1.1618	0.02346	0.12572	0.00197	0.776006	90	876.4	47.26	784.4	15.37
8c	1.70629	0.03969	0.17723	0.00296	0.718003	90	692.7	88.63	620.7	14.55
9c	1.05622	0.02595	0.11709	0.00188	0.653514	91	943.4	53.19	853.8	15.33
10c	0.87232	0.02086	0.10636	0.00174	0.68412	91	785.7	47.36	713.8	10.86
11c	1.53196	0.05542	0.15652	0.00304	0.536889	91	1043.9	38.13	948.9	8.14
12c	1.14864	0.02623	0.12713	0.00211	0.726809	91	838.2	36.43	763.4	11.3
14c	0.82348	0.01683	0.09752	0.00159	0.79776	93	647.1	37.09	599.9	9.36
15c	0.70649	0.02228	0.08755	0.00163	0.590367	94	938.5	56.83	878.6	8.56
17c	1.41612	0.0539	0.14602	0.003	0.539784	97	898.1	52.21	874	13.84
18c	0.64705	0.01781	0.08345	0.00144	0.626917	98	791	41.88	771.5	12.09
19c	1.55617	0.0338	0.1618	0.00263	0.748372	98	876.2	99.38	856.7	21.59
20c	0.96573	0.01854	0.10645	0.00173	0.846538	98	955.9	72.42	937.4	16.96

3.45

21c	1.21743	0.02798	0.12939	0.00217	0.729718	98	784.1	43.52	769.8	13.67
22c	1.61961	0.04267	0.15858	0.00276	0.660615	98	549.3	64.92	541	9.66
23c	0.76128	0.01712	0.08093	0.00136	0.747257	105	921.3	30.92	966.8	10.11
24c	1.3984	0.03284	0.14522	0.00251	0.735996	106	843.4	54.06	890.1	13.45
25c	1.37661	0.04106	0.14161	0.00272	0.643972	108	986.7	43.42	1066.9	18.51
26c	1.16667	0.04855	0.13319	0.00308	0.555697	109	906.1	79.09	987.5	21.54
27c	1.78717	0.04791	0.17999	0.00339	0.702572	110	842.6	48.47	924.6	17.17
28c	1.14237	0.0306	0.12683	0.00239	0.703495	110	732.9	82.55	806	17.55
29c	1.42727	0.04117	0.15422	0.00307	0.690117	111	584.6	47.33	651.5	10.15
30c	1.58174	0.0722	0.16555	0.0039	0.516099	112	461.1	38.05	516.7	14.58
31c	0.87006	0.04029	0.10108	0.00249	0.531969	114	922.7	43.1	1051.8	16.19
32c	1.32846	0.07655	0.14212	0.00382	0.466457	121	494.7	143.8	596.2	17.95
33c	0.76716	0.05491	0.0969	0.00305	0.439755	146	362.6	81.12	531.2	9.59
17r	0.69169	0.02589	0.08693	0.00166	0.510173	104	519.2	79.59	537.4	9.86
19r	0.68472	0.01696	0.08491	0.00147	0.698949	96	548.5	48.04	525.3	8.74
21r	0.66691	0.01916	0.08464	0.0015	0.616861	105	497	58.57	523.8	8.9
22r	0.79404	0.02795	0.08681	0.00173	0.566157	66	817.7	70.33	536.7	10.29
23r	0.72176	0.02269	0.08256	0.00156	0.601054	71	721.8	61.88	511.4	9.27
24r	0.79978	0.01982	0.0964	0.00173	0.724162	97	611.1	45.8	593.3	10.16
25r	0.78331	0.02276	0.08763	0.00168	0.659808	70	771	53.48	541.5	9.98
26r	0.74366	0.02686	0.0936	0.00191	0.564971	111	520.8	71.14	576.8	11.28
29r	0.81366	0.02779	0.09729	0.00198	0.59587	96	626.3	63.74	598.5	11.65
906										
2c	1.43937	0.02923	0.14964	0.00219	0.720676	84	642.2	55.68	541.9	9.39
3c	1.02207	0.01787	0.11504	0.00174	0.86508	88	732.2	45.95	647.6	8.07
4c	0.78928	0.01218	0.09477	0.00135	0.923096	89	594.8	49.81	531.1	8.23

5c	0.92788	0.01973	0.10568	0.00162	0.72092	89	558.4	40.83	498.8	9.44
6c	0.70728	0.01628	0.08587	0.00136	0.688073	91	705.1	56.71	640.4	11.67
7c	0.7337	0.01798	0.08951	0.00139	0.633683	92	645.5	71.85	590.8	11.94
8c	1.4695	0.04405	0.15313	0.00266	0.579489	93	756.4	30.27	702	10.03
9c	1.04083	0.03651	0.12023	0.00221	0.524019	94	618.4	26.31	583.7	7.96
10c	1.56677	0.03479	0.15745	0.00245	0.700768	95	584.4	59.44	552.7	14.87
11c	0.71906	0.02405	0.08916	0.00165	0.553304	95	922.7	33.15	873.5	12.51
12c	0.98976	0.01761	0.11347	0.00171	0.847004	96	569.4	33.45	545.1	8.13
13c	0.74405	0.01378	0.09171	0.00141	0.830148	96	601	41.1	579.9	9.55
14c	1.39625	0.02678	0.14511	0.00222	0.797642	97	717.7	30.67	692.8	9.89
15c	1.17457	0.03613	0.12945	0.00236	0.592681	97	573.6	47.42	555.8	9.09
17c	0.71831	0.01366	0.08824	0.00137	0.816425	97	923.7	38.45	898.9	12.3
18c	0.73827	0.02097	0.0877	0.00158	0.63427	98	801.2	60.72	784.7	13.49
19c	0.74625	0.01549	0.09145	0.00146	0.769134	98	574.7	37.77	564.1	8.63
20c	1.41212	0.03295	0.14899	0.00246	0.70761	100	533	49.3	533.2	9.2
22c	0.73439	0.01822	0.09005	0.00154	0.689311	100	918	72.49	918.5	12.74
23c	0.75745	0.01962	0.09411	0.00164	0.672764	100	549.3	69.9	550.5	9.78
25c	0.77709	0.01793	0.09412	0.00162	0.745975	100	892.6	41.48	895.3	13.81
26c	0.69036	0.01815	0.08622	0.00155	0.68379	100	1001.5	69.01	1005	19.69
28c	0.90318	0.0281	0.10444	0.002	0.615504	101	562.2	32.56	565.6	8.3
29c	1.16184	0.10055	0.13262	0.00481	0.419083	104	916.8	106.17	951.9	23.33
30c	1.84721	0.07725	0.19087	0.00409	0.512393	104	702.7	41.16	731.9	13.62
31c	0.71258	0.01623	0.09086	0.00158	0.763483	105	950	103.34	996.4	25.15
32c	1.68409	0.0648	0.1687	0.00357	0.549976	106	544.8	49.17	579.8	9.64
33c	1.39548	0.11562	0.15031	0.00506	0.406306	108	836.5	151.16	902.7	28.37
34c	0.72213	0.02363	0.09199	0.00177	0.588009	108	741	175.3	802.8	27.39
35c	1.53094	0.09112	0.15912	0.0042	0.443475	111	911.5	108	1011.5	27.08

3.47

36c	1.62514	0.09662	0.16716	0.00455	0.457828	112	537.4	70.89	602.9	12.41
37c	0.81234	0.03182	0.09597	0.00203	0.540006	115	489.6	40.04	560.6	9.33
38c	0.80659	0.02536	0.10135	0.00202	0.633915	115	493	62.59	567.3	10.46
39c	0.78674	0.03018	0.09804	0.00211	0.561037	119	523.8	56.84	622.3	11.84
40c	1.6206	0.10377	0.16989	0.00491	0.451354	121	933.5	74.79	1126.1	22.12
41c	0.77177	0.02188	0.09872	0.0019	0.678874	125	486	49.72	606.9	11.17
2r	0.70439	0.02192	0.08901	0.00154	0.555974	108	506.9	67.01	549.7	9.13
4r	0.65163	0.01337	0.08044	0.00121	0.733133	89	558.4	40.47	498.8	7.2
5r	0.64628	0.01541	0.08125	0.00131	0.676186	97	518.2	48.64	503.6	7.8
8r	0.69085	0.0214	0.08322	0.0015	0.58188	84	611.3	63.99	515.3	8.92
12r	0.9181	0.01588	0.10628	0.00162	0.881258	93	696.8	29.05	651.1	9.45
15r	0.66641	0.01473	0.08527	0.00138	0.732186	110	479.1	43.33	527.5	8.17
29r	0.75761	0.02757	0.09489	0.00194	0.561811	110	530.7	70.45	584.4	11.4
32r	0.77226	0.02879	0.09426	0.00191	0.543535	101	574.9	70.67	580.7	11.25

Chapter 4 – Charnockites of the Highland Complex and the Vijayan Complex of Sri Lanka show two different Geological Origins: LA-ICPMS U-Pb Zircon Geochronology

ABSTRACT

Charnockites of granulite facies form one of the predominant rocks of the Highland Complex (HC) of Sri Lanka. Minor charnockite occurrences are also found in the adjacent Vijayan Complex (VC) terrane. These rocks are found conformable with other supracrustal rocks of the HC and VC. In order to further understand the age and geological origin of the HC and VC terranes, it is significant to determine age of charnockites of these two terranes. In the past many believed that Sri Lankan charnockites to be mainly metaigneous/orthogneisses but it was not yet well understood for a long period of time due to unavailability of precise geochronological data of charnockites with U-Pb concordia and probability density plots which may enable determining whether metaigneous or metasedimentary origin. On the other hand in order to understand the paleotectonic position of Sri Lanka before Gondwana super continent assembled in Ediacaran-Cambrian, it is significant to understand the protolith sources of metasedimentary charnockites and intrusion ages of metaigneous charnockites. In this study it is examined age distribution of detrital zircon cores and later metamorphic rims of charnockites of HC and VC using the Laser Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) to investigate age, provenance and age of the charnockites of the HC and VC of Sri Lanka.

Three charnockite rock samples have been collected and analysed along two west to east transects in the HC and VC. One sample was collected in the Vijayan Complex (close to the HC-VC boundary) and other two samples were collected in the central HC. The concordia and probability density plots of this study clearly reveal for the first time that parent materials of Sri Lankan charnockites have two different geological origins. The two central HC charnockite samples clearly show metaigneous origin whilst the sample from the VC shows metasedimentary origin. The upper intercepts of two metaigneous charnockites show primary intrusion ages ~1.82 to 1.85 Ga. The metasedimantary charnockite sample shows deposition in the late Neoproterozoic after ~640 Ma with major detrital peaks occurring at 640 Ma, 830 Ma, and 920 Ma. The detrital signatures of the VC metasedimentary charnockite sample best fit the current basement ages (1.0 to 1.1 Ga) of the Vijayan Complex (VC) of Sri Lanka and give sedimentary provenance of VC rocks. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources. It is here suggested that VC metasedimentary charnockites have sourced probably from east African protolith sources. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.

Keywords: LaICPMS; Migmatitic gneiss; Highland Complex, Vijayan Complex, Sri Lanka

4.1 Introduction

Charnockites form one of the predominant rocks of the Highland Complex (HC) of Sri Lanka. Minor charnockite occurrences are also observed in the adjacent Vijayan Complex (VC) terrane. These rocks are frequently found conformable with other supracrustal rocks of the HC and VC. Determining geological origin of Sri Lanka is significant in the process of amalgamating Neoproterozoic supercontinent Gondwana and in further studies of continental evolution. Understanding the geological origin of Sri Lanka is not possible without understanding the geological origin of the Highland Complex (HC) and the Vijayan Complex (VC) terranes. In order to further understand the age and geological origin of the HC and VC terranes, it is significant to determine age of charnockites of these two terranes. In the past many believed that Sri Lankan charnockites to be mainly metaigneous/orthogneisses but it was not yet well understood for a long period of time due to unavailability of precise geochronological data of charnockites with U-Pb concordia and probability density plots which may enable determining whether metaigneous or metasedimentary origin

The Island of Sri Lanka is located in a key position in the process of amalgamating Neoproterozoic supercontinent Gondwana. Sri Lanka forms a tiny but important crustal block of the supercontinent, Gondwana, and has been the focus of through research in the late 1980's and early 1990's (Mathavan et al., 1999). According to present geographic coordinates Sri Lanka is near to the Southern Granulite Terrane of South India but the island is understood to be a crustal block which was also understood to be linked to other neighbouring/adjacent land blocks such as Madagascar, East Africa and Antarctica when the supercontinent Gondwana was assembled during Ediacaran to Cambrian along numerous orogenic belts. The Ediacaran (~635-541 Ma; Gradstein et al., 2012) to Cambrian assembly of Gondwana had taken place by the collision and amalgamation of numerous continental blocks along a number of disparate orogenic belts (see Collins and Pisarevsky, 2005). But Sri Lanka's most probable paleotectonic position and how the island crustal block was existing with neighbouring land masses are not yet confidently answered and it is still a puzzle and a research gap. The best way of addressing this research problem is by finding the origins of protolith sources/provenance of high grade metasedimentary rocks of the major geological complexes and also age of igneous intrusions into the basement of Sri Lanka and attempting whether other neighbouring crustal blocks have similar age and provenance or not as well as ages of emplacement of igneous intrusions into their sedimentary successions.

The present study has focused on the age and provenance of charnockitic rocks of the Highland Complex (HC) and Vijayan Complex (VC) of Sri Lanka with an aim to understand their age relationship to metaquartzite like other supracrustal rocks which are generally found interlayered with charnockitic gneisses of the HC terrane. Charnockitic gneisses and massive charnockites occur in the HC and VC of Sri Lanka. Both of these charnockitic rocks were metamorphosed under granulite facies conditions. Hypersthene bearing charnockitic gneisses generally show gneissic fabric due to preferred orientation of biotite and hornblend like flackey and platy minerals. Massive charnockites do not show any gneissosity. Both types show greyish green quartz and feldspar and orthopyroxene as the predominant minerals. Mineralogical and petrological studies in the past indicated that charnockitic gneisses may have sedimentary parentage while massive charnockites may have igneous parentage. Though there have been many different views on the origin of the HC charnockitic gneisses and charnockites, no clear determination has been possible for a long period of time due to unavailability of precise geochronologica data.

Charnockitic gneisses of Sri Lanka were studied by several workers in the past. Vitanage (1959), and Cooray (1961, 1984) described charnockitic gneisses are of widespread distribution in the Highland Complex of Sri Lanka and occur regularly interlayered with quartzites, marbles and sillimanite garnet gneisses. These rocks are often of great thickness and well exposed (Adams, 1929). Katz (1971) described charnockitic gneisses of HC as quartz-microperthite-hypersthene bearing rock and named acid charnockites as charnockitic gneisses. Similar charnockitic gneisses are found in the Southwest Group of the HC (Cooray, 1965) and also in the Kataragama area in the Vijayan Complex (Oliver and Erb, 1957). Based on study of zircons, Vitanage (1957) suggested that charnockitic gneisses of HC are of sedimentary origin but Searle (1964) considered them of intrusive as well as volcanic igneous origin. This shows that there has been no clear understanding and certainty about the origin and formation of charnockitic gneisses of HC without studying zircon grains under CL and dating using modern U-Pb geochronological methods and studying their concordia and probability density plots.

There are also isolated occurrences of charnickites in the VC of Sri Lanka. Among the other prominent geological formations of the VC are the occurrence of granitic intrusions and acidic charnockites (Milisenda et al., 1991) If the origin of charnockites of the HC and VC is metasedimentary, it is significant to locate probable protolith sources with respect to ages of detrital zircon cores in charnockites of the HC and VC of Sri Lanka for understanding paleotectonic position of the island of Sri Lanka before Gondwana supercontinent being amalgamated in the Ediacaran-Cambrian . There is lack of age and provenance data on the metasedimentary rocks of the VC of Sri Lanka and dating of VC metasidimentary rocks will be a strong necessity to search its probable correlations with the Antarctic continental mass. If the origin of charnockites of the HC and VC are metaigneous, it will be significant to understand igneous intrusive activities to the original HC and VC sedimentary make up. The Highland Complex is traditionally thought to be dominated by Paleoproterozoic matasedimentary rocks whilst the Vijayan Complex was thought to be largely composed of Mesoproterozoic to Neoproterozoic metaigneous rocks. However, this research question has not yet been well answered and there exist debates because only a limited and a small number of true metasedimentary rock samples have been dated in the past from the HC and VC. This necessitates a further verification based on applying modern and precise geochronological methods such as LaICPMS U-Pb zircon dating to examine the provenance of the two terranes and also to address their geological and tectonic relationship.

Recent advances in sector field inductively coupled plasma-mass spectrometry (ICPMS) have enabled precise measurements of this isotopic system in zircons by laser ablation (Plavsa et.al., 2014; Griffin et. al., 2000; Iizuka and Hirata, 2005). This method called LaICPMS is particularly useful as it allows for specific textural and age domains within zircon to be targeted during the analysis (Plavsa et al., 2014). Because charnockites are the predominant rocks in the HC of Sri Lanka and charnockites are one of the significant isolated rocks of the VC of Sri Lanka and assuming that these charnockites were formed from charnockitization of pre-existing sedimentary successions, age and sedimentary provenance study of charnockites would be significant to trace protolith sources. Here I apply the LaICPMS method as the tool to the high-grade terranes of the Highland Complex (HC) and Vijayan Complex (VC) of Sri Lanka to unravel the source of the protoliths of high-grade charnockitic rocks of HC and VC of Sri Lanka.

4.2. Geological background

More than two thirds of the island of Sri Lanka is underlain by Mesoarchaean to Neoproterozoic highgrade regional metamorphic rocks and the rest is mainly of Miocene limestone and scattered Jurassic, Quarternary rocks (Fig.4.1). The high-grade metamorphic basement of Sri Lanka consists mainly of Mesoarchaean to Neoproterozoic orthogneiss and paragneiss rocks and four major crustal units subdivided as the Highland Complex (HC), Vijayan Complex (VC), and Wanni Complex (WC) and Kadugannawa Complex (KC) (Fig.4.1) defined based on rock type, metamorphic grade (Kröner et al., 1991), and Nd model ages (Milisenda et al., 1988, 1994; Sajeev et al., 2010). The Precambrian land mass of the island was metamorphosed to upper amphibolite and or granulite grade in the Neoproterozoic during Ediacaran- Cambrian, each complex having a discrete metamorphic history (Sajeev et al., 2010).

It is generally accepted that the oldest rocks are in the Highland complex (Sajeev and Osanai, 2004, and Sajeev et al., 2010) which lies in the centre of the island consisting of granulite grade major supracrustal meta-sedimentary rocks, charnockites and concordant to discordant metaigneous rocks. The major meta-sedimentary rocks are garnet sillimanite gneisses, marbles, calc silicates, garnetiferous granulites, and metaquartzites. Kröner et al., (1991) suggested that majority of the HC rocks are of granitoid origin. The age of HC was interpreted as 3.2 to 2.0 Ga based on Nd model ages (Milisenda et al., 1988; Kröner, and Williams, 1993). Igneous intrusions to HC were reported to have taken place around 1850-1990 Ma (Kröner and Williams, 1993; Schumacher et al., 1990). The high-grade metamorphism had taken place as a part of the Ediacaran-Cambrian metamorphism and orogeny at ca. 550 Ma (Kröner et al., 1991) and the rocks were subjected to peak metamorphic PT conditions of 900^0C and 9 K bars. The regional metamorphism was followed by slow cooling and uplifting of the HC into higher crustal levels (Kröner et al., 1991; Jayawardane and Carswell, 1976; Kröner and Williams, 1993; Faulhaber and Raith, 1991). The boundary between HC and VC is well defined as a tectonic boundary marked by thrust and shear zones, mafic to ultramafic intrusions, and a belt of hot water springs.

The Mesoproterozoic to Neoproterozoic (Milisenda et al., 1988, 1994; Sajeev et al., 2010) Vijayan Complex (VC) lies to the east of the central HC (Fig.4.1) and consists mainly of granitic gneisses, hornblend gneisses, and isolated and rare bands of metaquartzites and calc gneisses (Dahanayake and Jayasena, 1983). The VC represents upper amphibolites grade metamorphic rocks. Among the other prominent geological

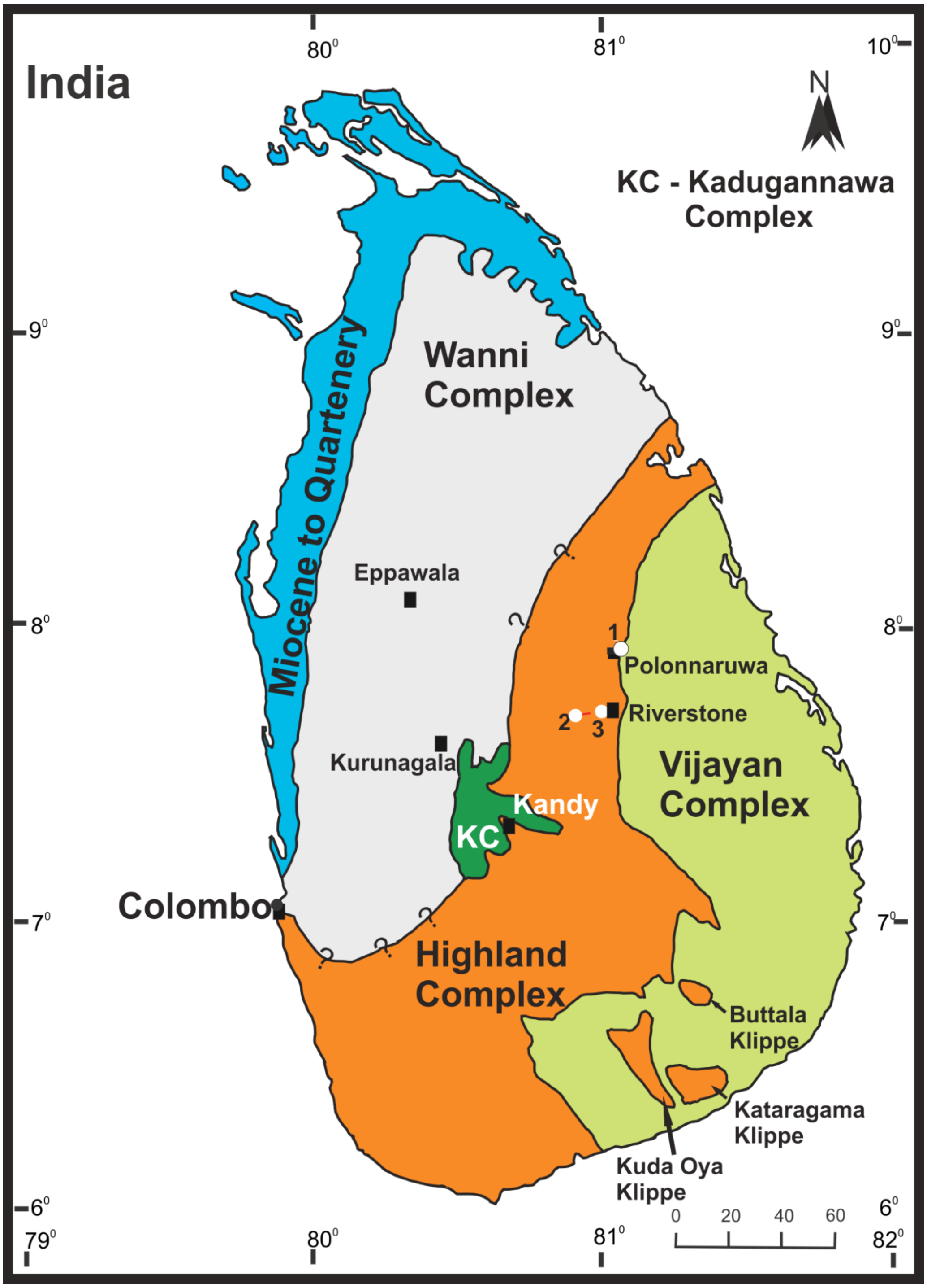

Fig.4 1. Generalized geological and tectonic framework of Sri Lanka showing major crustal blocks and their boundaries (after Cooray,1994). The study area is shown along two west-east transects. Sample locations of charnockites are shown by black circles. White circles show sample locations; 1- Jayanthipura, 2- Rattota, and 3- Dankanda.

formations of the VC are the occurrence of granitic intrusions and acidic charnockites close to the eastern coast (Milisenda et al., 1991) and the NW trending suite of dolerite dykes in the VC. References (Milisenda, et al., 1988; Corfu et al., 2003) had described the gneissose granitoids of the Vijayan Complex as having compositions ranging from tonalite to leucogranite.

The Mesoproterozoic to Neoproterozoic (Milisenda et al., 1988, 1994; Sajeev et al., 2010) Wanni Complex lies in the west of the HC. The WC consists mainly of granitic gneisses, migmatitic gneisses, granitic intrusions, cordierite gneisses, and minor abundance of supracrustal metaquartzites, and metapelites.

4.2.1 Recent geochronological studies in Sri Lanka

Detrital grains from the Highland Complex metasediments were analysed by Kröner et al. (1987) and documented Mesorchaean to Paleoproterozoic near concordant ages (3.2-2.4 Ga). Their discordant data indicated considerable scatter, which Kröner et al. (1987) originally thought to be consistent with lead loss ~1.1 Ga ago, caused by granulite grade metamorphism. Later, this explanation has since been retracted (Baur et al., 1991) in favour of a younger age of metamorphism. A pink granite close to Kandy produced U-Pb ages extending from an inferred upper concordia intercept near 1100 Ma for zircon cores to an inferred lower intercept near 550 Ma for new zircon growth. Kröner et al. (1987) interpreted these results as indicating an intrusion age of 1100 Ma.

Milisenda et al. (1988, 1994) carried out a Sm-Nd model age study and reported Sm-Nd model ages and identified three distinct age provinces: the HC produced model ages of 3.4 to 2.2 Ga, indicating derivation from late Mesoarchaean to Paleoproterozoic sources. It is bounded to the west and east by Wanni Complex and Vijayan Complex with modal ages of 2.0 to 1.0 Ga. These results were supported by Pb isotope data (Lew et al., 1991 a, b, 1994) first showed that the primary ages of the three crustal blocks contrasted sharply with each other, and that the Vijayan and Wanni Complexes are not simply “overprinted” or retrograded Highland Complex material but represent much younger additions to the continental crust.

Sajeev et al. (2010) studied ultrahigh-temperature metamorphism in the central Highland Complex terrane and dated detrital cores and found ages in the range 2.5 – 0.83 Ga. The LaICPMS U-Pb zircon dating was carried out on metaquartzites of WC and HC of

Sri Lanka and suggested that both WC and HC show derivation of detritus predominantly from Neoarchean and Paleoproterozoic sources (1.9-2.9 Ga) but one WC sample reported Neoproterozoic detritus (Amarasinghe and Collins, 2011). He et al. (2015) carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of charnockites and metagabbro rocks (HC), hornblende biotite gneisses and charnockites of (KC) and charnockites (WC) and reported Early Neoproterozoic to Late Neoproterozoic ages (525 Ma to 950 Ma). He et al. (2015) also suggested about convergent margin magmatism in the WC and the KC during assembly of the Gondwana. He et al. (2016) also carried out a geological, petrological, geochemical and zircon U-Pb and Lu-Hf geochronological study of metamorphosed acidic, mafic and ultra mafic igneous plutonic rocks of the Vijayan Complex (VC) of Sri Lanka and reported early to late Neoproterozoic ages (542 Ma to 966 Ma) and suggested an eastern suture along the boundary between the HC and the VC of Sri Lanka with arc accretion and subduction in the Neoproterozoic.

4.3. Analytical Methods

4.3.1 Sample selection and preparation

Sample collection was carried out during field geological mapping along two east-west transacts (Fig.4.1and 4.2) as northern transact right across HC terrane into about 20 Km distance into the VC terrane (between Habarana and Jayanthipura-Polonnaruwa) and southern transect (between Matale and Riverstone) running right across HC terrane in the island of Sri Lanka.

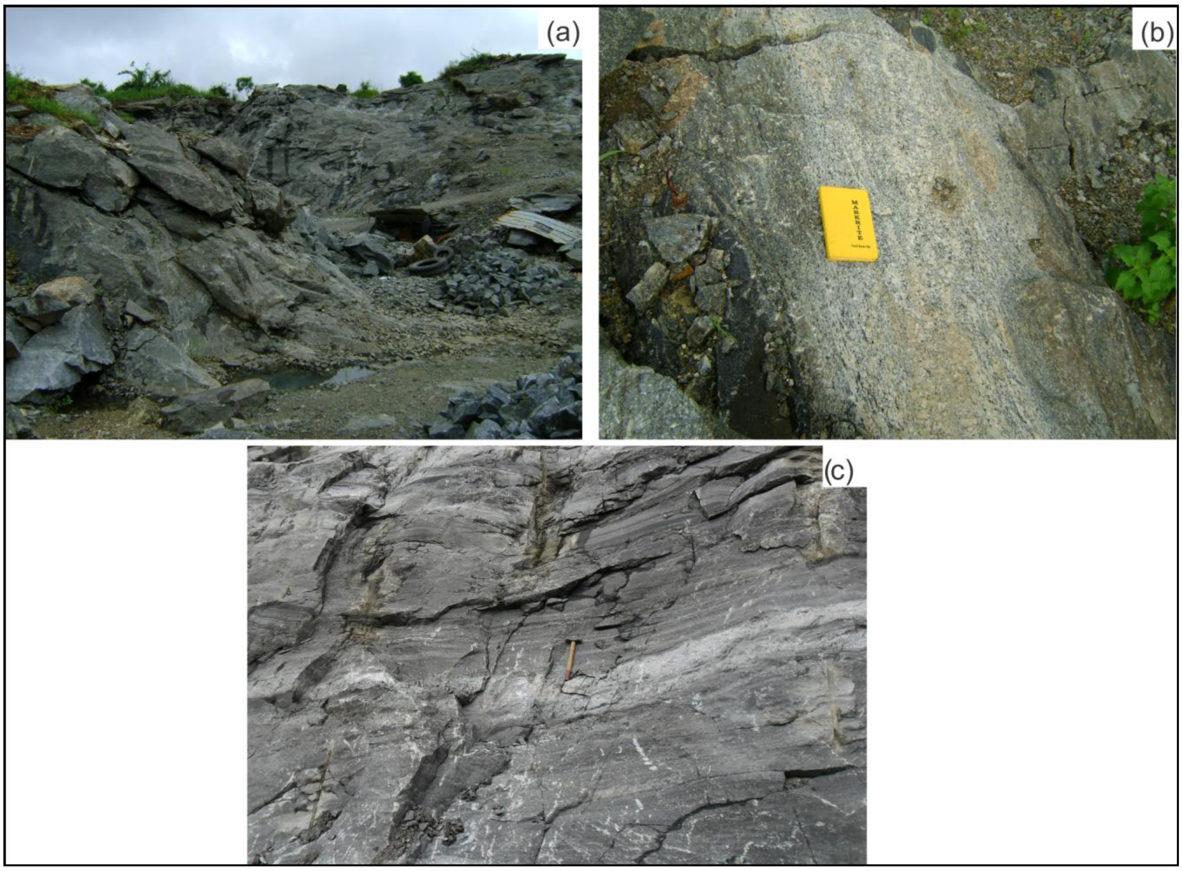

Fig.4. 2. Representative field photographs of charnockite rock samples from the Highland Complex(HC) and Vijayan Complex (VC). (a) Jayanthipura-S0923 (VC) (b)Rattota-S0817 (HC), (c) Dankanda-S0818 (HC).

Particular emphasis was paid to select purely hypersthenes bearing charnockitic rocks (Fig. 3(a),(b),(c) for the study of age and provenance of HC and VC charnockites. As a result of that two charnockite samples representing the HC and one charnockite sample representing VC were used for laboratory investigation. Firstly a petrographic thin section was made from each rock sample and petrography was studied under the polarising microscope.

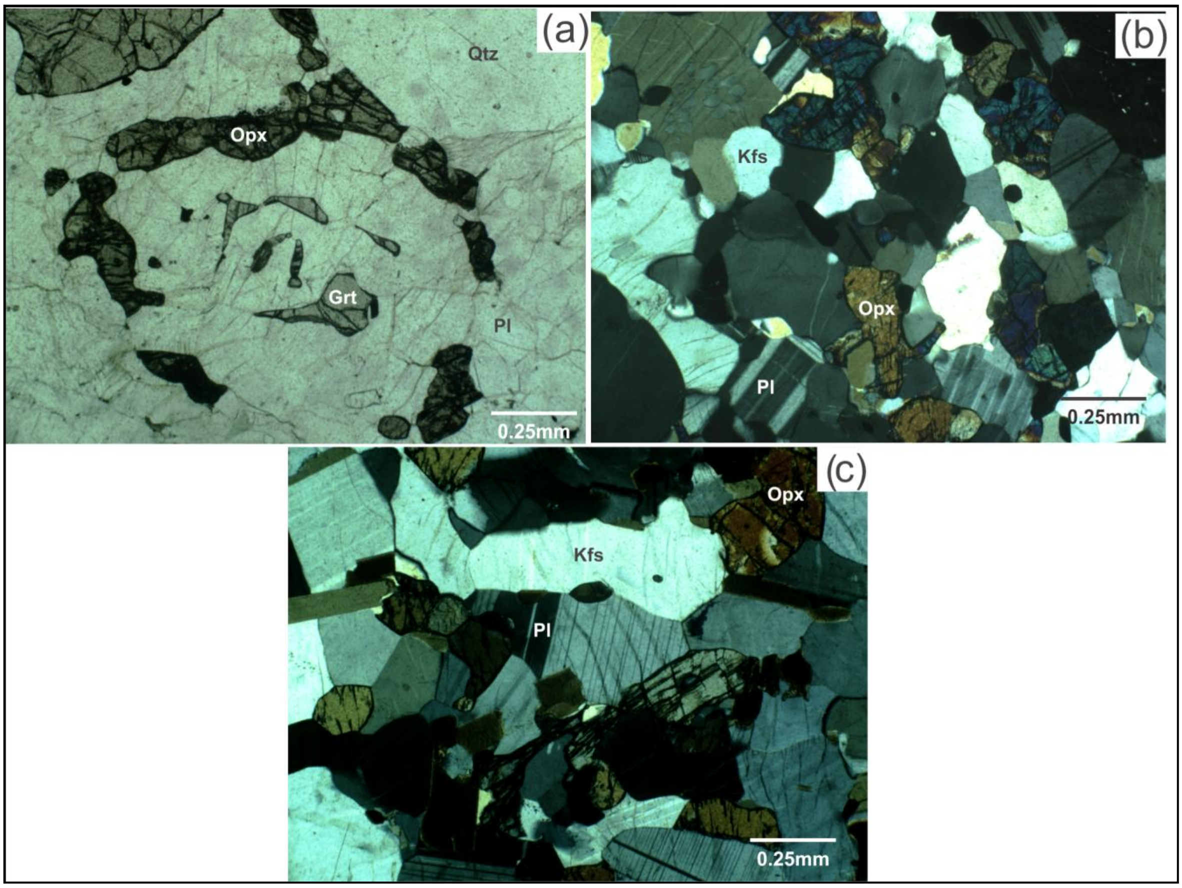

Fig.4. 3. Photomicrographs showing mineralogical composition and textures of representative charnockite samples from the Highland Complex (HC) and Vijayan Complex (VC). (a) Jayanthipura-S0923 (VC) (b)Rattota-S0817 (HC), (c) Dankanda-S0818 (HC).(a) Abbreviations; Pl-plagioclase, Bt-biotite, Hbl-hornblend, Qtz- quartz, Ilm-ilmenite, Kfs- potash feldspar, Crd- cordierite, Opx= orthopyroxene, Grt-garnet, and Zrn-zircon.

Each sample was crushed, milled, and sieved to produce a 79-400 micro meter fraction. This fraction was panned. Then all the magnetic minerals were removed using the magnetic separator as well as using a hand magnet. Then the grains were separated in the heavy liquid methylene iodide to separate zircon grains. The zircon grains were hand-picked selecting zircon grains of all sizes, shapes and colours (to avoid bias) and mounted using epoxy resin material discs. When the mounts were hardened the exposed surface was polished and carbon coated. The mounted zircon grains were subsequently imaged using the Cathodoluminescenece (CL) apparatus, Phillips XL 20 scanning electron microscope with attached Gatan CL at the Adelaide Microscopy of the University of Adelaide. The zircon grains have been imaged using ~16 mm working distance and accelerating voltage of 12 kV.

4.3.2 LaICPMS U-Pb zircon dating

The mounts of zircon minerals were placed in the Laser Ablation Inductively Coupled Plasma – Mass Spectrometer (La-ICPMS) of the University of Adelaide and each zircon grain was analysed on a new wave 213 mm Nd-YAG laser coupled plasma-mass spectrometer (ICP-MS) subjected to a laser beam with 30 micro meter spot size was used with a standard spot depth of 30-50 micro meter to obtain U-Pb age data. A particular emphasis was paid to target cores of the detrital zircon grains as well as the metamorphic rims. The isotopic ratios were observed and corrected for drift and within –run U-Pb fractionation by repeated analysis of GEMOC GJ-1 (a Sri Lankan pegmatitic zircon crystal) as the standard zircon (published thermal ionization mass spectrometry normalizing ages of $^{207}Pb/^{206}Pb$ =607± 4.3 Ma, $^{206}Pb/^{238}U$ = 600.7 ±1.1 Ma and $^{207}Pb/^{235}U$ =602.0± 1.0 Ma, Jackson et al., 2004). The data were analysed using computer software to produce U-Pb Concordia plots. During the process of analytical sessions, a total of 358 analyses of the GJ-1 external standard yielded a weighted average $^{207}Pb/^{206}Pb$ age of 610±3.9Ma (2 sigma, mean square of weighted deviates (MSWD) = 0.58) and $^{206}Pb/^{238}U$ = 600.02± 0.88 Ma (2 sigma MSWD = 0.54). Analysis of the Plesovice zircon standard (TIMS $^{206}Pb/^{238}U$ age = 337.13±0.37 Ma, 95% of confidence limits; Slama et al., 2008) was performed to check for validity of the applied method during the analysis of unknowns. A total of 110 analyses of the Plesovice internal standard yielded weighted average ages of $^{206}Pb/^{238}U$= 337.84± 0.94 Ma (2 sigma, MSWD = 1.07) and $^{207}Pb/^{206}Pb$ = 340.6 ± 7.1 Ma (2 sigma, MSWD = 0.8), demonstrating the accuracy of the operating conditions.

4.4. Results

4.4.1 Sample descriptions and LaICPMS U-Pb Geochronology

LaICPMS U-Pb age data presented in the Appendix B available from the on-line version of this paper, geochronological interpretations are presented in Figs.4.3-4.6. The Concordia plots in Fig.4.5, it was possible to draw best fit line to samples S0817 and S0818 to find the upper intercept and the lower intercept (to determine the maximum age of deposition and minimum age of deposition). However, due to occurrence of closely spaced detrital concordant points in the concordia curve of the other sample (S0923), considerable restriction occurred for any possibility of drawing accurate and average best fit curves to determine upper and lower intercepts to the concordia curve. Under these conditions the maximum and minimum ages of deposition are possible to determine with respect to concordant points occur on the concordia plot (Fig.4.5) as well as using the major and minor peaks found in the probability density plot which is drawn using <10% discordant points (Fig. 4.6).

4.4.1.1 Sample S0923- Jayanthipura- Charnockite

The sample is a charnockite collected at Jayanthipura in the Vijayan Complex of Sri Lanka (Fig.4.1). The rock is a charnockitic sample collected from a rock outcrop exposed in the Jayanthipura rock quarry (Fig. 4.2(a)). The charnockite rock is dark greyish to dark greenish in appearance (Fig. 4.2(a). The field photograph shows that the rock shows slightly developed gneissic structure. The photomicrograph (Fig. 4.3(a)) of this sample shows that it consists of quartz, plagioclase, orthopyroxene and garnet as the major minerals. The rock shows fine to medium to coarse grained granoblastic inequigranular texture.

As shown in the Fig.4a, the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies. In this charnockite sample most of the zircon grains are subhedral to anhedral and show diverse luminescence responses. Some zircon cores show sector zoning with bright and dark luminescent responses. The rims were formed during regional metamorphism and are generally moderate to bright luminescent.. As shown in the Fig. 4.4 (a) the rock sample S0923 is here represented by two zircon grains, grain-I, and grain II. The grain-I shows sector zoning with dark and bright luminescent responses. The metamorphic rim is moderately dark luminescent. This grain is a Neoproterozoic and showing $^{206}Pb/^{238}U$ age of 750 ± 15Ma. The grain II shows a bright core and dark outer concentric zoning. The metamorphic rim is moderately dark luminescent. This is also a Neoproterozoic and showing $^{206}Pb/^{238}U$ age of 575 ±13 Ma. This shows this leucosome portion of the migmatitic gneiss was sourced from Neoproterozoic protolith sources.

Thirty seven grains were analysed from S0923 sample. Four analyses were <10% discordant. The Fig.4. 5 (concordia plot) and Fig.4. 6 (probability density plot drawn for

<10% discordant grains) show that the maximum age of deposition of the S0923 sample is found to be 640 Ma and the minimum age of deposition is found to be 565 Ma and major detrital peaks occur at 640 Ma, 830 Ma and 920 Ma. Occurrence of several detrital concordant points in the concordia plot (Fig. 4.5) and several detrital peaks in the probability density plot indicate characteristic metasedimentary origin for this sample. This suggests that the premetamorphic materials of the Jayanthipura charnockite sample received detritus from two protolith sources of Neoproterozoic times of age 640 Ma and 830 Ma. It can be suggested that deposition of sediments for this charnockite rock had taken place in the VC terrane from about 640 Ma to 565 Ma.

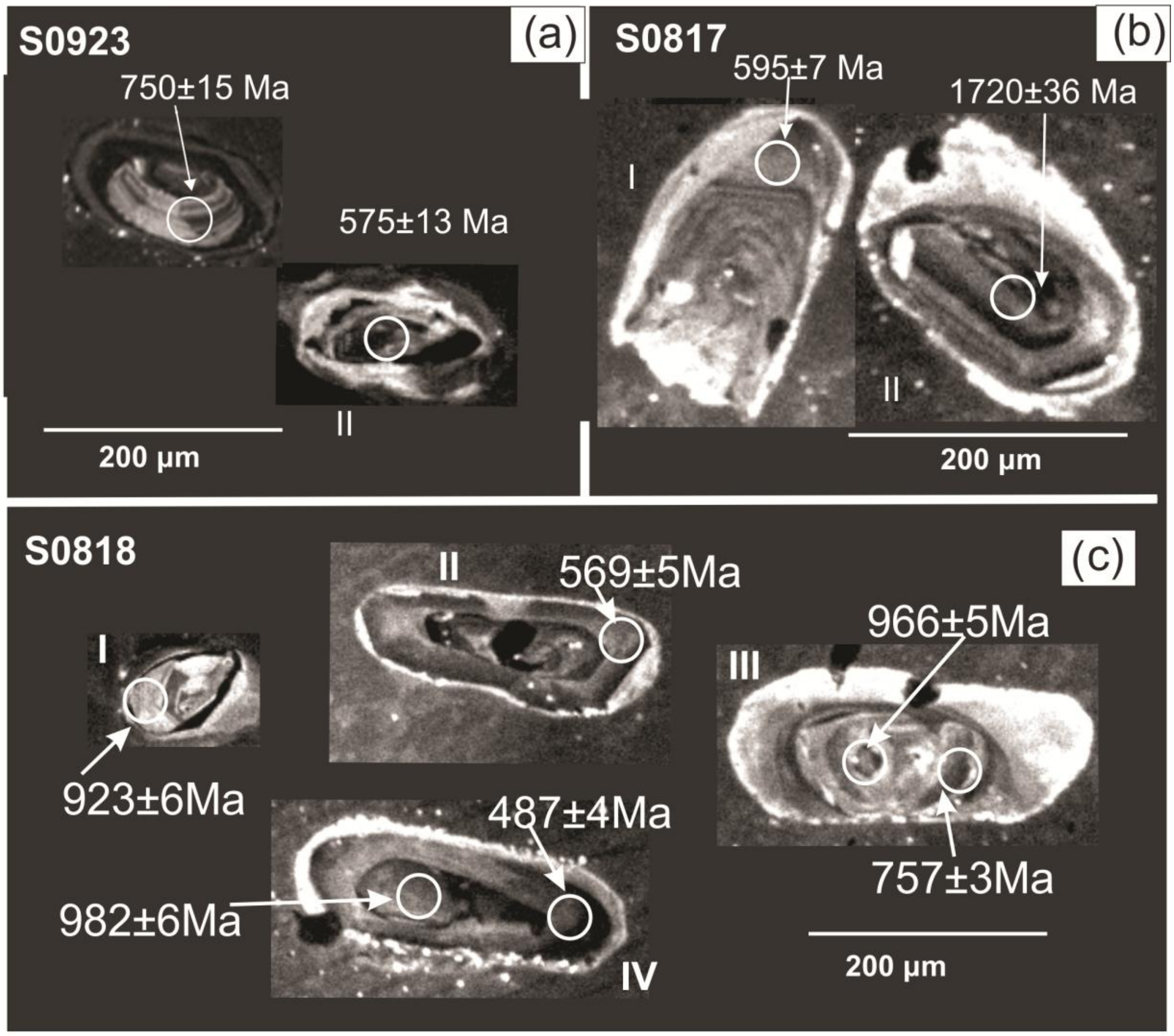

Fig.4.4 Cathodoluminescence (CL) images and the U-Pb zircon ages of analysed detrital zircons of charnockites of Highland Complex (HC) and Vijayan Complex (VC) of Sri Lanka (discordance < 10%). (a) Jayanthipura-S0923 (VC) (b) Rattota-S0817 (HC), (c) Dankanda-S0818 (HC).

4.4.1.2 Sample S0817- Rattota- Charnockite

The sample is a charnockite rock collected at Rattota in the Highland Complex (HC). The rock is a charnockite rock collected from a rock outcrop exposed (Fig. 2(b)) in a road cutting close to the Rattota town. The charnockite rock is comprised of dark greenish grey to light compositional layers as shown in the Fig.4.2 (b). The field photograph shows gneissic structure in this rock. The photomicrograph (Fig.4.3 (b)) of this sample shows that sample consists of quartz, plagioclase, potassium feldspar and orthopyroxene as the major minerals. The rock shows fine to medium grained granoblastic inequigranular texture. As shown in the Fig.4.4 (b), the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with euhedral to anhedral zircon grains with diverse luminescence responses. Most of the zircon cores show dark luminescence.

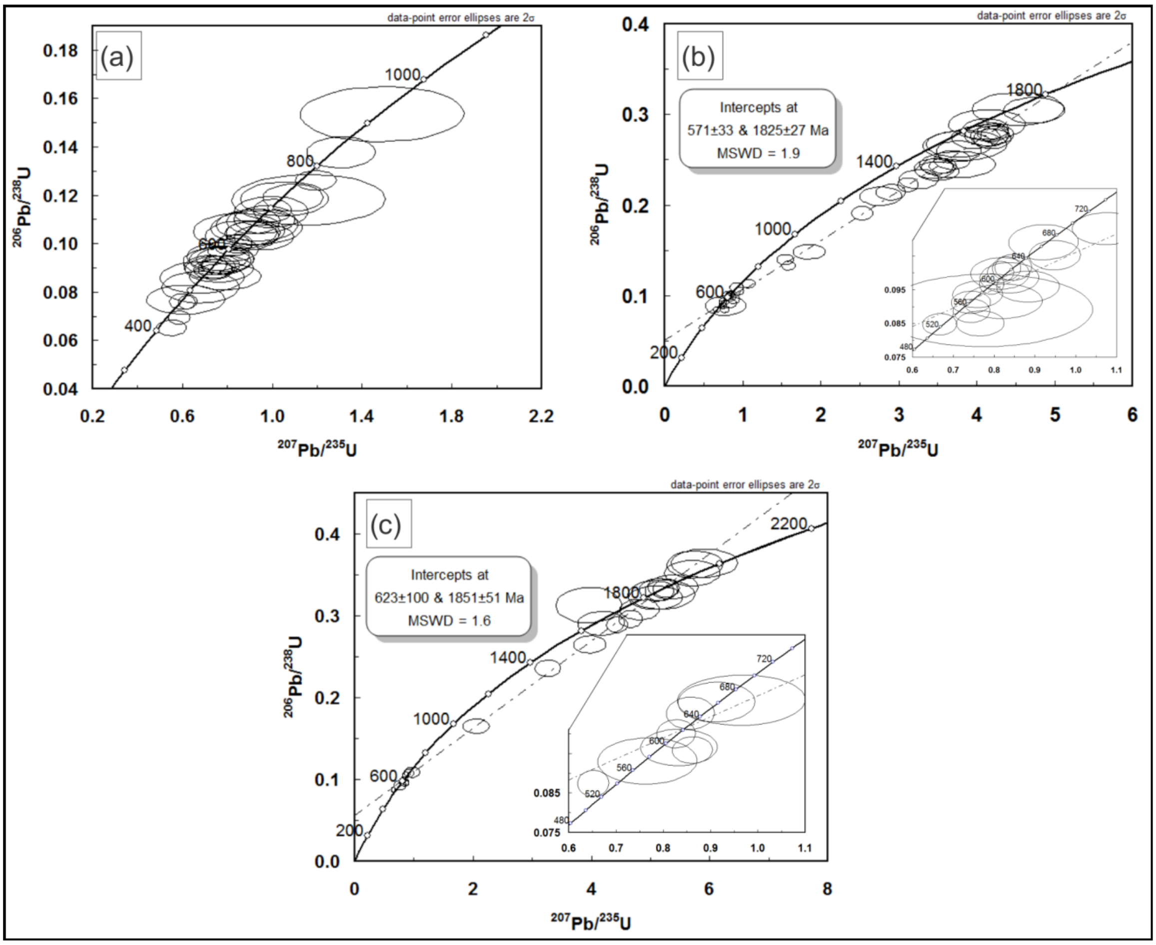

Fig. 4.5. U-Pb Concordia plots of analysed charnockites of Highland Complex (HC) and Vijayan Complex (VC) of Sri Lanka (MSWD- mean square of weighted deviates). Upper and lower intercepts were calculated whenever there is a linear lead loss. (a) Jayanthipura-S0923 (VC) (b) Rattota-S0817 (HC), (c) Dankanda-S0818 (HC).

The rims were formed during regional metamorphism and are generally moderate to bright luminescent. As shown in the Fig.4.4 (b) the rock sample S0817 is here represented by two zircon grains, grain-I and grain II. The grain I is short prismatic and suhedral. It shows a zircon core with dark luminescence. The metamorphic rim shows moderately bright luminescence. This grain is a Neoproterozoic and showing $^{206}Pb/^{238}U$ age of 750±15 Ma. The grain II is short prismatic and its core shows dark luminescence and it has a bright luminescent outer overgrowth. Metamorphic rim is moderately bright luminescent. This is also a Paleoproterozoic grain showing $^{207}Pb/^{206}Pb$ age of 1720 ± 36 Ma. This metamorphic rim was probably formed during isobaric cooling in the HC of Sri Lanka. This shows that this charnockite rock had originated from igneous intrusive material intruded in the Paleoproterozoic times.

Forty two zircon grains were analysed from the sample S-0804. Three analyses were <10% discordant. It has been possible to draw a best fit line for this charnockite sample. The Fig.4.5 (concordia plot) show that the primary age of formation of the S0817 charnockite sample is found to be 1825 ± 27 Ma (MSWD=1.9, upper intercept) and the minimum age of formation is found to be 571 ± 33 Ma (MSWD= 1.9, lower intercept). As shown in the Fig.4.6, the probability density plot (<10% discordant zircon grains) shows that major peaks are clustered around ~1800 Ma. The Fig.4.5 and Fig.4.6 both indicate characteristic concordia plot and probability density plot of an igneous intrusive body. This clearly indicates that the S0817 charnockite rock shows metaigneous origin. This charnockite rock had formed from an igneous intrusive body which was intruded into the HC sedimentary make up from ~1825 to 1850 Ma period.

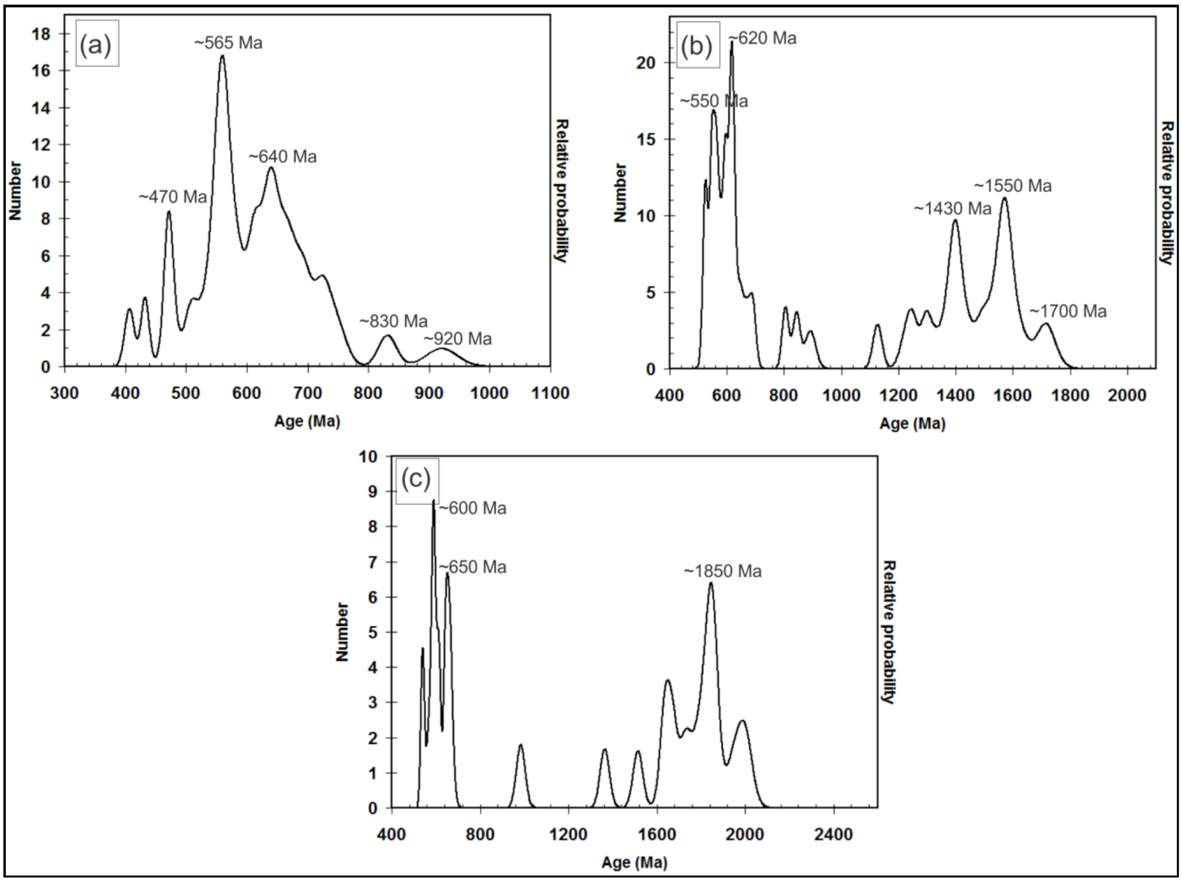

Fig.4. 6 Probability density distribution plots of individual charnockite samples from the Highland Complex(HC) and Vijayan Complex (VC) of Sri Lanka. Bin size of 25 was used for the histogram calculation and 10 % discordance was used a cut-off for the concordant zircon populations. (a) Jayanthipura-S0923 (VC) (b)Rattota-S0817 (HC), (c) Dankanda-S0818 (HC).

4.4.1.3 Sample S0818- Dankanda- Charnockite

The sample is a charnockite rock collected at Dankanda in the Highland Complex (HC). The rock is a charnockite rock collected from a rock outcrop exposed (Fig.4.2(b)) in a rock quarry. The charnockite rock is comprised of dark greenish grey to light compositional layers as shown in the Fig.4.2(c). The field photograph shows gneissic structure in this rock. The photomicrograph (Fig.4.3 (b)) of this sample shows that sample consists of quartz, plagioclase, potassium feldspar and orthopyroxene as the major minerals. The rock shows fine to medium to coarse grained granoblastic inequigranular texture. As shown in the Fig.4.4(c), the cathodoluminescent images (CL) of the zircon grains generally show a diverse range of morphologies with euhedral to anhedral zircon grains with diverse luminescence responses. Most of the zircon cores show dark luminescence. The rims were formed during regional metamorphism and are generally moderate to bright luminescent..

As shown in the Fig.4.4(c) the rock sample S0818 is here represented by four zircon grains, grain-I, grain II, grain III and grain IV. The grain I is short prismatic and subhedral. It shows a zircon core with dark luminescence. The metamorphic rim shows moderately bright luminescence. This grain is a Neoproterozoic detritus showing age 923±6 Ma. The grain II is long prismatic and its core shows dark luminescence and it has a bright and sector zoned luminescence. Metamorphic rim is moderately bright luminescent. This is also a Neoproterozoic detritus showing $^{206}Pb/^{238}U$ age of 569 ± 5 Ma. The grain II is long prismatic and showing concentric bright to moderately bright luminescence. This grain shows $^{206}Pb/^{238}U$ ages of 966 ± 5 Ma and 757 ± 3 Ma at west and eastern ends. The grain IV is long prismatic with a dark luminescent core and it shows Neoproterozoic $^{206}Pb/^{238}U$ age of 982 ± 6 Ma. The metamorphic rim shows $^{206}Pb/^{238}U$ age of 487 ± 4 Ma and which had probably formed during isobaric cooling. This shows that this charnockite rock had originated from igneous intrusive material intruded in the Paleoproterozoic times.

Forty two zircon grains were analysed from the sample S-0804. Three analyses were <10% discordant. The Fig.4.5 (concordia plot) show that the primary age of formation of the S0818 charnockite sample is found to be 1851 ± 51 Ma (MSWD = 1.9, upper intercept) and the minimum age of formation is found to be 623 ± 100 Ma (MSWD = 1.9, lower intercept). As shown in the Fig.6, the probability density plot (<10% discordant zircon grains) shows that major peaks are clustered around ~1850 Ma. The Fig.4.5 and Fig.4.6 both indicate characteristic concordia plot and probability density plot of an igneous intrusive body. This clearly indicates that the S0818 charnockite rock from Dankanda shows metaigneous origin. This charnockite rock had formed from an igneous intrusive body which was intruded into the HC sedimentary make up from ~1825 to 1850 Ma period.

4.5. Discussion

4.5.1 Age constraints of formation and deposition

The concordia and probability density plots of this study clearly reveal for the first time that parent materials of Sri Lankan charnockites have two different geological origins. The two central HC charnockite samples clearly show metaigneous origin whilst the sample from the VC shows metasedimentary origin with respect to the typical characteristics of concordia plots and probability density plots. The upper intercepts of two metaigneous charnockites show primary intrusive ages ~1.82 to 1.85 Ga. The metasedimantary charnockite sample of VC shows deposition in the late Neoproterozoic after ~640 Ma with major detrital peaks occurring at 640 Ma, 830 Ma, and 920 Ma.. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources.

4.5.2 Provenance implications

The detrital signatures of the VC metasedimentary charnockite sample best fits the current basement ages (1.0 to 1.1 Ga) of the Vijayan Complex (VC) of Sri Lanka and give sedimentary provenance of VC rocks. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources. Figure 4.7 indicates probability-density plots of all data for studied charnockite samples

As far as possible protolith sources for the VC charnockites of Sri Lanka are considered with respect to paleotectonic positions prior to amalgamation of Gondwana are concerned sources abundant in the Indian land mass, Madagascar, East Africa and Antarctica can be attempted. If possible Indian sources are considered first, the Dharwar craton of Mesoarchaean to Neoacrchaean exists north of the Souithern Granulite terrane of India and provided >3.0Ma detritus into Dharwar-derived sediments throughout the Proterozoic (Collins et al., 2003). But the protolith material from the Dharwar croton can be excluded as no > 3.0 Ga ages were not found in these VC charnockites. It was reported that rocks dated between 1880 and 1700 Ma are found in the Krishna province of the Eastern Ghats of India (Dobmeier and Raith, 2003). Zircon xenocrysts were dated as 2431 Ma and also a detrital grain was dated as 2747 Ma $^{206}Pb/^{207}Pb$ age (Shaw et al., 1997). But no prominent 1990 Ma to 2300 Ma peaks can be found in Eastern Ghats (Collins et al., 2007).

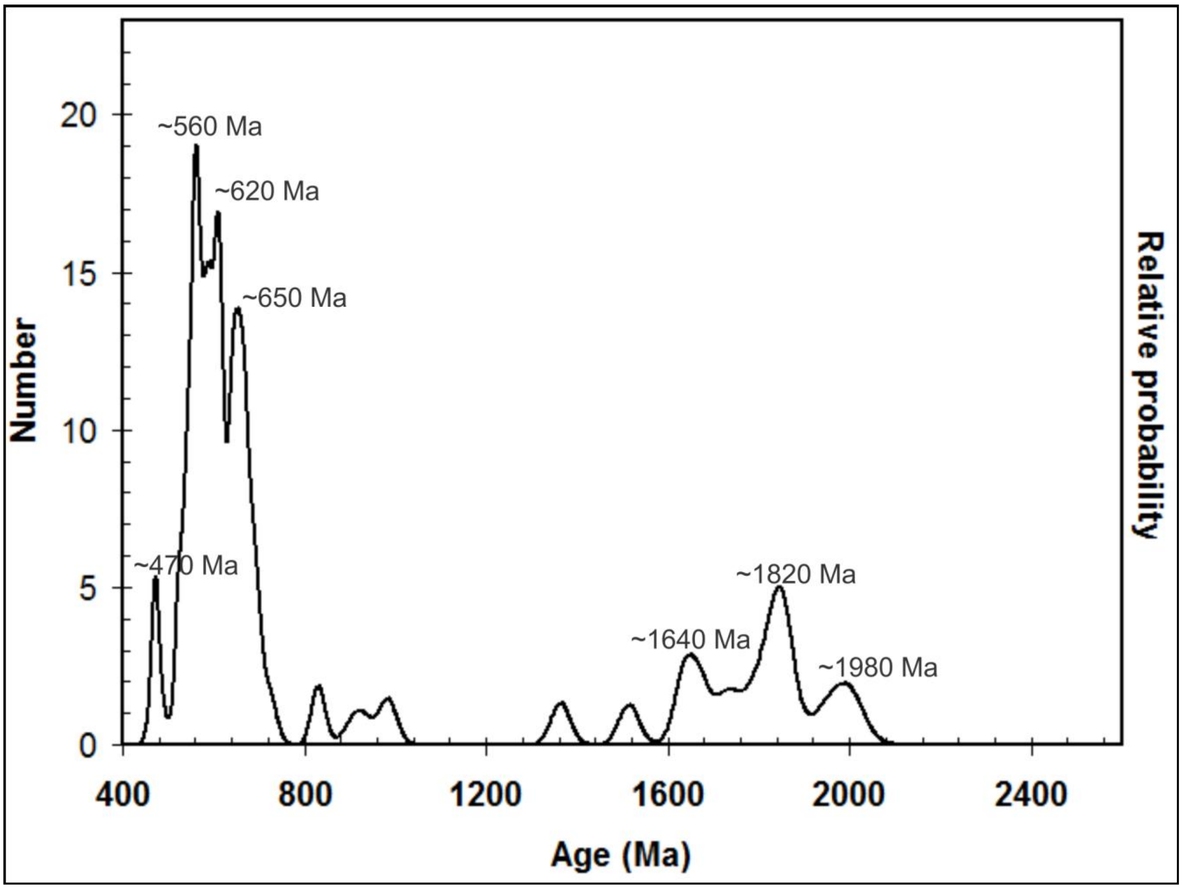

Fig. 4.7 Probability-density plots of all data for studied charnockite samples. Bin size of 25 was used for the histogram calculation and 10 % discordance was used a cut-off for the concordant zircon populations.

So the Indian sources had not provided sedimentary detritus to VC metasedimentary charnockites as the VC charnockites lack Paleoproterozoic detritus. With respect to the current directions the island of Madagascar exists west of the island of Sri Lanka and comprises of similar metasedimentary supracrustal rocks in the west and south of the Madagascar (Windley et al., 1994; Collins et al., 2003a; Fernandez et al., 2003; Cox et al., 2004; Fitsimons and Hulscher, 2005; Collins, 2006). These metamorphosed sedimentary rocks consists of two sedimentary successions: one succession of probable Paleoproterozoic age, named as the Itremo Group (Cox et al., 1998), which contains Neoarchaean and Paleoproterozoic detrital zircon grains; a second succession of Neoproterozoic age, known as the Molo Group with Neoarchean, Paleoproterozoic and Neoproterozoic zircon detritus (Cox et al., 2004 ; Fitzsimons and Hulscher, 2005). In recent Gondwana reconstructions these two successions are placed adjacent to each other and contain broadly similar detrital zircon records with predominant Paleoproterozoic protolith sources. This study reveals that the detrital zircon records of the charnockites of VC of Sri Lanka have Neoproterozoic detritus and correlate with the Neooproterozoic Molo Group metasedimentary succession of Madagascar. It was suggested that the Itremo Group and the Molo Group were sourced from the eastern Africa (Cox et al., 2004; Fitssimons and Hulscher, 2005). Eastern Africa contains potential protolith source rocks for all the detrital age peaks obtained in this study from VC metasedimentary charnockites of Sri Lanka. In the Kibaran belt of eastern Africa Mesoproterozoic protoliths were dated at ~ 1.4 Ga (Kokonyangi, 2004) and Neoproterozoic magmatic rocks of central Madagascar were dated (Handke et al., 1999; Kröner et al., 2000) and Neoproterozoic rocks were dated from the Mozambique belt (Kröner et al., 2003). I here suggest that VC metasedimentary charnockites have derived protolith sources from central Madagascar and eastern Africa.

4.5.3 Age of metamorphism

The concordia plot of metamorphic rims (Fig.4.5) shows that the Highland Complex and Vijayan Complex was subjected to Edaicaran - Cambrian regional metamorphism between about 515 Ma to 600 Ma. Fig.4.4 also shows that the event of partial melting proceeded and continued into Cambrian (~448 Ma) and new detrital zircon grains had formed from the partial melts.

4.6 Conclusions

The concordia and probability density plots of this study clearly reveal for the first time that parent materials of Sri Lankan charnockites have two different geological origins. The two central HC charnockite samples clearly show metaigneous origin whilst the sample from the VC show metasedimentary origin. The upper intercepts of two metaigneous charnockites show primary intrusive ages ~1.82 to 1.85 Ga. These ages are consistent with ages of igneous intrusions to HC metasediments reported by Kröner et al. (1987). The metasedimantary charnockite sample shows deposition in the late

Neoproterozoic after ~640 Ma with major detrital peaks occurring at 640 Ma, 830 Ma, and 920 Ma. The detrital signatures of the VC metasedimentary charnockite sample best fit the current basement ages (1.0 to 1.1 Ga) of the Vijayan Complex (VC) of Sri Lanka and give sedimentary provenance of VC rocks. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources. I here suggest that VC metasedimentary charnockites have derived detritus from protolith sources of central Madagascar and eastern Africa. On the basis of the interpretation of the results of this study it is interpreted and suggested that the sediments of the HC were deposited in a deep basin and which most probably existed as a deep oceanic basin of an orogenic belt since 1.9 to 2.0 Ga (as indicated by the maximum age of deposition of HC metaquartzites in the chapter 2) and concordant and discordant intrusions of parent magmas of HC charnockitic gneisses and charnockites took place around ~ 1.85 Ga into the HC sedimentary make up in Paleoproterozoic time. The charnockitization of granitic intrusions occurred during ultra high temperature regional metamorphism to form HC charnockites.

Acknowledgements

The authors wish to thank the University of Adelaide for the providing adequate laboratory facilities for sample preparation and U-Pb zircon dating. Dr. Benjamin Wade of Adelaide Microscopy is especially thanked for assistance during LA-ICPMS analysis. My Ph.D colleagues, Diana Plavsa, Jade Anderson, Frank Robinson of the Department of Earth Sciences are also thanked. Prassana. Dharmapriya is thanked for improving figures in Corel draw and Moditha Kodikaraarachchi of the Department of Geology, University of Peradeniya is thanked for his assistance in petrographic photography. Dasith Bandara Wewegama, a third year undergraduate in Medicine, the University of Adelaide is thanked for all the encouragements and helps.

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Supplementary Table 4.1

Analysis_#	Pb207/U235	1σ	Pb206/U238	1σ	rho	Concordancy	Pb207/Pb206	1σ	Pb206/U238	1σ
817										
1c	3.49329	0.08268	0.24253	0.00367	0.63934426	60	1350	39.31	805.1	11.53
2c	0.81604	0.01319	0.10024	0.00127	0.783843416	62	1437.3	83.33	892.3	18.76
3c	0.79387	0.01226	0.09672	0.00125	0.836859683	70	1204.6	55.49	843.7	12.8
4c	1.54807	0.04372	0.13984	0.00226	0.572252192	73	1550.9	36.5	1127	16.07
5c	2.89861	0.07781	0.21423	0.00355	0.617308755	77	894.6	60.45	690.8	11.24
6c	3.11877	0.05391	0.22245	0.00315	0.81920418	78	1656	28.21	1294.8	16.62
7c	3.56716	0.07105	0.24322	0.00342	0.705968509	79	1748	58.08	1374	22
8c	3.49602	0.11398	0.23755	0.00422	0.544882264	79	1794.1	80.27	1410.4	30.6
9c	0.83028	0.01416	0.10132	0.00142	0.821777955	79	1589.7	48.39	1251.3	18.83
10c	2.76997	0.11052	0.20979	0.0042	0.501763073	79	1672	47.78	1326.7	22.55
11c	4.1306	0.1176	0.27708	0.0047	0.595797255	80	1543	72.93	1227.7	22.39
12c	4.26128	0.0864	0.27764	0.00415	0.73721199	81	1738.5	33.93	1403.4	17.71
13c	1.852	0.08359	0.14845	0.00334	0.49848595	82	1707.1	42.3	1399.8	19.04
14c	1.58657	0.0352	0.13303	0.00203	0.687801346	82	1689.5	44.2	1388	23.24
15c	4.19874	0.09754	0.27325	0.00445	0.701029141	82	1746.1	39.8	1437.3	21.94
16c	3.98956	0.12836	0.27472	0.00501	0.566816835	83	781	47.43	645	10.38
17c	3.76908	0.11706	0.25955	0.00464	0.575603973	85	1823	37.85	1557.3	22.54
18c	2.53228	0.0563	0.19104	0.00297	0.699254822	87	1719.4	52.96	1487.5	23.74
19c	1.07462	0.03405	0.11312	0.00194	0.541252775	87	632.4	28.95	548	21.25
20c	4.2065	0.0806	0.28039	0.00422	0.785481176	87	1822.1	33.1	1579.5	20.93
21c	0.84663	0.01831	0.10164	0.0016	0.727881423	88	1784.8	35.94	1571.7	22.77
22c	4.73301	0.16213	0.30463	0.00578	0.553897248	89	1705.6	92.61	1520.1	34.16
23c	4.11076	0.12039	0.28345	0.00494	0.595089373	89	1767.9	49.83	1576.6	23.74
24c	3.84369	0.21882	0.26593	0.00671	0.443217119	91	1720.2	55.3	1564.7	25.35
25c	4.16171	0.09876	0.2761	0.00451	0.688336609	91	1669.4	74.33	1526.1	29.3
26c	3.77608	0.17207	0.2671	0.00576	0.473243463	93	1844.9	55.83	1714.2	28.57

27c	0.92074	0.03486	0.10908	0.00213	0.515755778	94	1717.2	46.86	1608.7	24.79
28c	3.68737	0.09598	0.24978	0.00425	0.653683076	97	1690	73.83	1636.7	33.09
29c	0.94843	0.02577	0.10523	0.00178	0.622545784	98	1751.5	85.55	1720.7	36.63
30c	4.52753	0.23972	0.30595	0.00742	0.458047498	101	587.5	29.91	595.2	7.35
32c	3.2557	0.10409	0.22851	0.0043	0.58857067	102	614.6	38.76	624	9.37
33c	3.75684	0.19896	0.24457	0.00591	0.456290287	103	650.2	71.12	667.4	12.37
34c	4.134	0.20052	0.28903	0.00662	0.472202023	107	583.6	32.1	622.1	8.28
35c	3.45566	0.10479	0.24025	0.00447	0.613557533	108	570	32.78	615.8	7.42
818										
1c	4.66197	0.07993	0.29612	0.0042	0.827258449	90	1867.3	27.28	1672.1	20.87
2c	4.43604	0.07255	0.28901	0.00395	0.827258449	90	1821.5	26.03	1636.6	19.74
3c	0.86141	0.01737	0.09588	0.00137	0.827258449	90	779.7	39.64	590.2	8.04
4c	5.26367	0.09038	0.33367	0.00458	0.827258449	90	1871.2	27.7	1856.2	22.16
5c	5.15169	0.09908	0.33038	0.00481	0.827258449	90	1849.8	31.83	1840.2	23.33
6c	3.97149	0.11089	0.26497	0.00433	0.827258449	90	1779.5	49.79	1515.2	22.04
7c	5.18024	0.23108	0.3261	0.00735	0.827258449	90	1884.9	80.86	1819.5	35.73
9c	0.65157	0.01345	0.08747	0.00135	0.827258449	90	372.2	42.78	540.5	8.03
10c	0.85726	0.02078	0.1052	0.00165	0.827258449	90	571.2	49.3	644.8	9.61
12c	3.26388	0.08858	0.23581	0.00406	0.827258449	90	1630.1	48.03	1364.9	21.16
14c	5.74824	0.1934	0.36263	0.00668	0.827258449	90	1879.8	59.25	1994.6	31.6
13c	0.82666	0.01673	0.1	0.00146	0.827258449	90	602.1	39.1	614.4	8.55
17c	0.76587	0.04281	0.09311	0.0024	0.461131453	96	599.2	117.07	573.9	14.15
18c	4.81432	0.13591	0.30748	0.00516	0.461131453	96	1855.2	45.73	1728.3	25.44
19c	5.08525	0.18517	0.32213	0.00585	0.461131453	96	1870	60.23	1800.1	28.54
20c	4.16707	0.16058	0.29091	0.00593	0.461131453	96	1696.8	64.77	1646.1	29.6
22c	2.04961	0.09226	0.16507	0.00357	0.461131453	96	1424.6	79.12	984.9	19.74
25c	0.83274	0.0332	0.09656	0.00189	0.461131453	96	691.3	80.37	594.2	11.12
26c	5.7068	0.19143	0.3522	0.00634	0.461131453	96	1914	53.09	1945.1	30.21
27c	0.91238	0.03316	0.10802	0.00205	0.461131453	96	643.5	69.77	661.3	11.92

28c	5.37913	0.1739	0.33536	0.00606	0.461131453	96	1895.6	50.92	1864.3	29.27
29c	5.90971	0.22947	0.36438	0.00709	0.461131453	96	1917.5	61.72	2002.9	33.49
30c	5.13544	0.13211	0.33191	0.00562	0.461131453	96	1835.1	39.13	1847.6	27.21
31c	3.95421	0.22672	0.31301	0.00892	0.461131453	96	1468	106.34	1755.5	43.78
32c	0.96496	0.05516	0.1085	0.0026	0.461131453	96	750.3	105.65	664	15.12
2r	0.74298	0.01962	0.09126	0.00135	0.560184934	99	569.7	30.77	563	6.93
4r	0.66684	0.01703	0.08478	0.0013	0.600422467	106	494	64.42	524.6	8.04
5r	0.78104	0.10618	0.08886	0.00439	0.363403216	75	734.2	44	548.8	7.71
12r	0.75941	0.02495	0.09365	0.00161	0.523267614	103	561.1	70.08	577.1	9.5
18r2	0.8147	0.02934	0.09981	0.00192	0.534151903	107	571.6	72.64	613.3	11.25
19r	0.74426	0.01837	0.08873	0.00142	0.648385636	87	632.4	48.74	548	8.39
20r	0.76594	0.02392	0.08502	0.00152	0.572474389	67	783.8	61.74	526	9.03
21r	0.82071	0.0396	0.09158	0.00208	0.47071413	74	762.6	94.98	564.9	12.29
27r	0.83707	0.02936	0.09854	0.00185	0.535260132	92	658.7	66.17	605.8	10.83
31r	0.88278	0.03128	0.09593	0.00188	0.553081518	72	819.2	65.04	590.5	11.09
923										
1c	0.91599	0.04853	0.10927	0.00209	0.361015447	63	643.4	89.72	407.2	8
2c	0.77085	0.03399	0.09111	0.0016	0.398265464	65	818.3	165.32	534	13.24
3c	0.74082	0.0236	0.09135	0.00144	0.494828421	67	645.1	69.35	432.7	6.76
4c	0.60324	0.02504	0.07608	0.0013	0.411650507	73	867.2	113.91	630	12.33
5c	0.58548	0.01987	0.06943	0.00112	0.475318868	74	969.2	222.78	720.1	24.52
6c	0.79074	0.05278	0.09372	0.00207	0.330904283	82	571.5	47.65	471.1	6.84
7c	0.79026	0.06465	0.08636	0.00223	0.315641211	83	667.3	163.95	553.3	13.09
8c	0.96171	0.05446	0.10266	0.00211	0.362950743	83	900.3	117.37	750.8	15.18
9c	1.09263	0.05481	0.11904	0.00229	0.383491624	84	606.7	112.42	508.2	9.74
10c	0.91468	0.04918	0.10444	0.00207	0.368624453	86	652.4	91.93	562.1	9.46
11c	1.19403	0.037	0.12617	0.00164	0.419470341	88	824.9	100.98	725	13.19
12c	0.67926	0.06989	0.08203	0.00265	0.313974345	88	726.3	109.84	640.4	12.08
14c	0.61796	0.01519	0.07582	0.00114	0.611679128	89	646.4	139.05	577.5	12.18

15c	0.84609	0.02596	0.10003	0.00158	0.514800182	90	611.8	81.49	553.3	9.32
16c	0.82525	0.0461	0.09743	0.00193	0.354608559	91	704.5	105.83	639.6	11.66
17c	0.68592	0.07631	0.08605	0.00267	0.278902495	91	524.3	238.23	477.6	14.69
18c	0.61347	0.07073	0.0769	0.00245	0.276330877	92	654.1	115.03	599.3	11.33
20c	0.93159	0.07467	0.10776	0.00268	0.310281497	92	596.9	98.76	551.1	9.86
21c	0.76364	0.06132	0.08962	0.00221	0.307095786	92	728.2	111.2	672.9	13.34
22c	0.90446	0.04737	0.1043	0.002	0.366126924	93	511	88.41	472.7	7.79
23c	0.73624	0.03516	0.08926	0.00167	0.391769057	94	887.1	88.7	831.6	14.88
24c	0.99977	0.03436	0.11365	0.00191	0.489002267	94	692.5	154.83	652.9	16.52
25c	0.74444	0.03003	0.08962	0.00157	0.434279252	94	651.7	61.44	614.6	9.28
26c	0.72114	0.04658	0.09038	0.00193	0.330601693	94	734.5	66.97	693.9	11.05
27c	1.30509	0.06195	0.13769	0.00263	0.40239493	95	698	161.67	659.7	15.58
28c	0.86416	0.06657	0.10334	0.00252	0.316553913	95	759.9	144.32	722	16.74
29c	0.82717	0.03355	0.09936	0.00176	0.436720256	95	604.4	152.37	575.5	13.3
30c	1.05361	0.07964	0.11851	0.0029	0.323736474	95	724.5	129.97	690.9	14.92
31c	0.99418	0.06779	0.11313	0.00258	0.334457783	99	614.9	76.43	610.7	10.35
32c	0.54993	0.02685	0.06521	0.00132	0.414593848	100	923.6	176.71	920.7	25.87
33c	0.96466	0.05554	0.11002	0.0023	0.363098614	100	560.9	65.94	563.5	8.48
35c	0.77341	0.05868	0.09339	0.00226	0.318953771	101	628.8	154.29	634	14.7
36c	1.16066	0.13956	0.11819	0.00425	0.299055817	102	523.4	230.27	532.1	15.85
37c	0.85084	0.08254	0.10526	0.00298	0.291834299	102	559.4	152.71	571.9	13.79
38c	1.48966	0.14885	0.15353	0.00463	0.301804741	106	632.7	111.16	668.5	12.13
39c	0.92945	0.08303	0.10659	0.00284	0.298258529	107	523.1	133.93	557.8	11.39
40c	0.75267	0.06118	0.09277	0.00234	0.310315475	109	536	137.27	583.2	13.56
41c	0.75786	0.05607	0.09468	0.0023	0.328343192	117	550.3	192.95	645.2	17.4

The Chapter 5 of the thesis has been published in the International Journal of Geoscience Frontiers (2014), http://dx.doi.org/10.1016/j.gsf.2014.03.009. This paper was written and submitted based on the data that the candidate had derived based on his laboratory work carried out at the University of Adelaide. The candidate and first author had also contributed in plotting of graphs and analysis of geochronological data and subsequent sharing of editing the draft level paper.

Chapter 5 – Evolving provenance in the Proterozoic Pranhita-Godavari Basin, India

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This paper, Amarasinghe et al., was published in the International Journal of Geoscience Frontiers (DOI;10.1016/J.gsf.2004.03.009)

Abstract

The Pranhita-Godavari Basin in central eastern India is one of the Proterozoic "Purāna" basins of cratonic India. New geochronology demonstrates that it has a vast depositional history of repeated basin reactivation from the Palaeoproterozoic to the Mesozoic. U-Pb laser ablation inductively coupled plasma mass spectrometry dating of detrital zircons from two samples of the Somanpalli Group – a member of the oldest sedimentary cycle in the valley – constrains its depositional age to ∼1620 Ma and demonstrates a tripartite age provenance with peaks at ∼3500 Ma, ∼2480 Ma and ∼1620 Ma, with minor age peaks in the Eoarchaean (∼3.8 Ga) and at ∼2750 Ma. These ages are consistent with palaeocurrent data suggesting a southerly source from the Krishna Province and Enderby Land in East Antarctica. The similarity in the maximum depositional age with previously published authigenic glauconite ages suggest that the origin of the Pranhita-Godvari Graben originated as a rift that formed at a high angle to the coeval evolving late Meosproterozoic Krishna Province as Enderby Land collided with the Dharwar craton of India. In contrast, detrital zircons from the Cycle III Sullavai Group red sandstones yielded a maximum depositional age of 970 ± 20 Ma and had age peaks of ∼2550 Ma, ∼1600 Ma and then a number of Mesoproterozoic detrital zircons terminating in three analyses at ∼970 Ma. The provenance of these is again consistent with a southerly source from the Eastern Ghats Orogen and Antarctica. Later cycles of deposition include the overlying Albaka/Usur Formations and finally the late Palaeozoic to Mesozoic Gondwana Supergroup.

Keywords
LA-icpms; U-Pb zircon geochronology; Godavari; Purāna; Gondwana

5.1. Introduction

Cratonic India hosts large unmetamorphosed and only mildly deformed Proterozoic sedimentary successions, with minor pyroclastic and volcanic rocks. These basins include the Vidhyan, Chhattisgarh, Indravati, Cuddapah, Bhima, Khariar and Pranhita-Godavari basins and are collectively known as the Purāna basins (Fig.5. 1)(Holland, 1906). Traditionally, they have been interpreted as having formed contemporaneously (Chaudhuri et al., 1999), but recent U-Pb detrital zircon (Malone et al., 2008, Bickford et al., 2011a; Bickford et al., 2011b and Mukherjee et al., 2012; Chaudhuri et al., unpublished data), palaeomagnetic (Gregory et al., 2006;Malone et al., 2008 and Gregory et al., 2009) and ^{40}Ar-^{39}Ar glauconite studies (Conrad et al., 2011) have shown that this is a considerable oversimplification. Work over the last decade has established that different Purāna basins opened at different times, but the upper age limits of major depositional sequences are largely unconstrained, impeding the evaluation of their global significance. The question of the upper age limit of Purāna sequences, and the possibility of their continuity into the late Neoproterozoic or into the Cambrian has been debated for a long time, though recently, U-Pb ages from tuffs sampled from the Chhattisgarh and Indravati basins has led to a new hypothesis suggesting closure of at least these Purāna basins at c. 1000 Ma (Bickford et al., 2011a and Mukherjee et al., 2012), coinciding with orogenesis in the Eastern Ghats (Korhonen et al., 2011) and the central Indian tectonic zone (Bhowmik et al., 2012).

5.2. Geological setting

The pre-Gondwana 'Purāna' basin of the Pranhita-Godavari Valley is preserved in, and may well have developed as, a major rift extending for about 450 km, from the Eastern Ghats Belt in the southeast to the Central Indian Tectonic Zone (CITZ) in the northwest (Fig. 5.1). Although previous workers had suggested that the Proterozoic sedimentary rocks in the basin were likely to be the preserved relics of a much larger basin

(Ramakrishnan and Vaidyanathan, 2008), sedimentological studies by Chaudhuri et al. (2012) demonstrated that the rocks were deposited largely within the present rift boundaries. The rift developed along the NW–SE trending Karimnagar Orogenic Belt, which delineates a Neoarchaean granulite belt between the Dharwar and Bastar cratonic nuclei. The Pranhita-Godavari Valley preserves records of multiple Proterozoic rifts, as well as a Gondwana rift, opening and closing along the same zone where Purāna formations occur as several structural inliers within the younger Gondwana rift system. The Gondwana outcrops occur primarily as a linear belt along the axial part of the Valley, separating Purāna outcrops into two belts (Fig. 5.2). Both Purāna and Gondwana outcrop belts maintain similar depositional and structural trends (Chaudhuri et al., 2012), and Purāna formations can be lithostratigraphically correlated across the valley into several unconformity-bound sequences (Chaudhuri, 2003 and Chaudhuri et al., 2012). The sequences, by turn, can be classified into at least three 1st or 2nd order depositional cycles (Fig. 5.3), each bounded by regional unconformities. The unconformity–bound cycles, representing major basin formation events, are stacked one above, generating a megasequence where basins are considered as genetic units rather than simply as a geographical unit (Whittaker et al., 1991). The cycles are characterized by very distinctive sets of lithologic attributes indicating deposition under highly variable modes and tempos of sediment generation, sediment supply and creation of accommodation space.

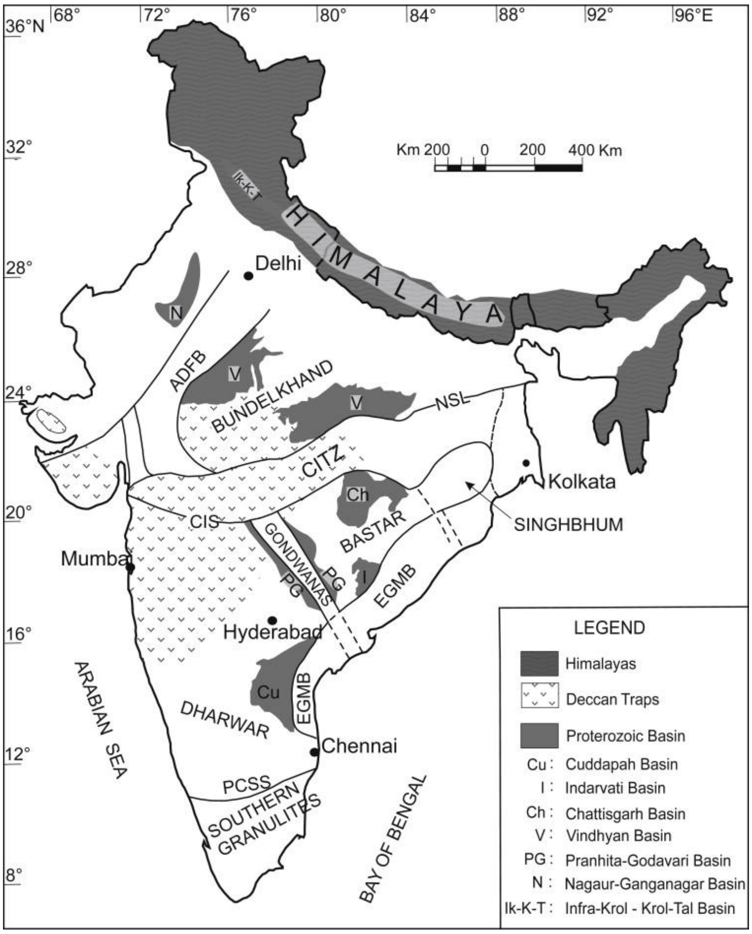

Fig.5.1. Map of India highlighting the main cratons, the Proterozoic orogens and the Proterozoic to early Palaeozoic so-called Purāna basins. ADFB – Aravalli–Delhi Fold Belt; NSL – Narmada–Son Lineament: CIS – Central Indian Suture; CITZ – Central Indian Tectonic Zone; EGMB – Eastern Ghats Mobile Belt; PCSS Palghat-Cauvery Shear System (modified from Vijaya Rao and Reddy, 2002).

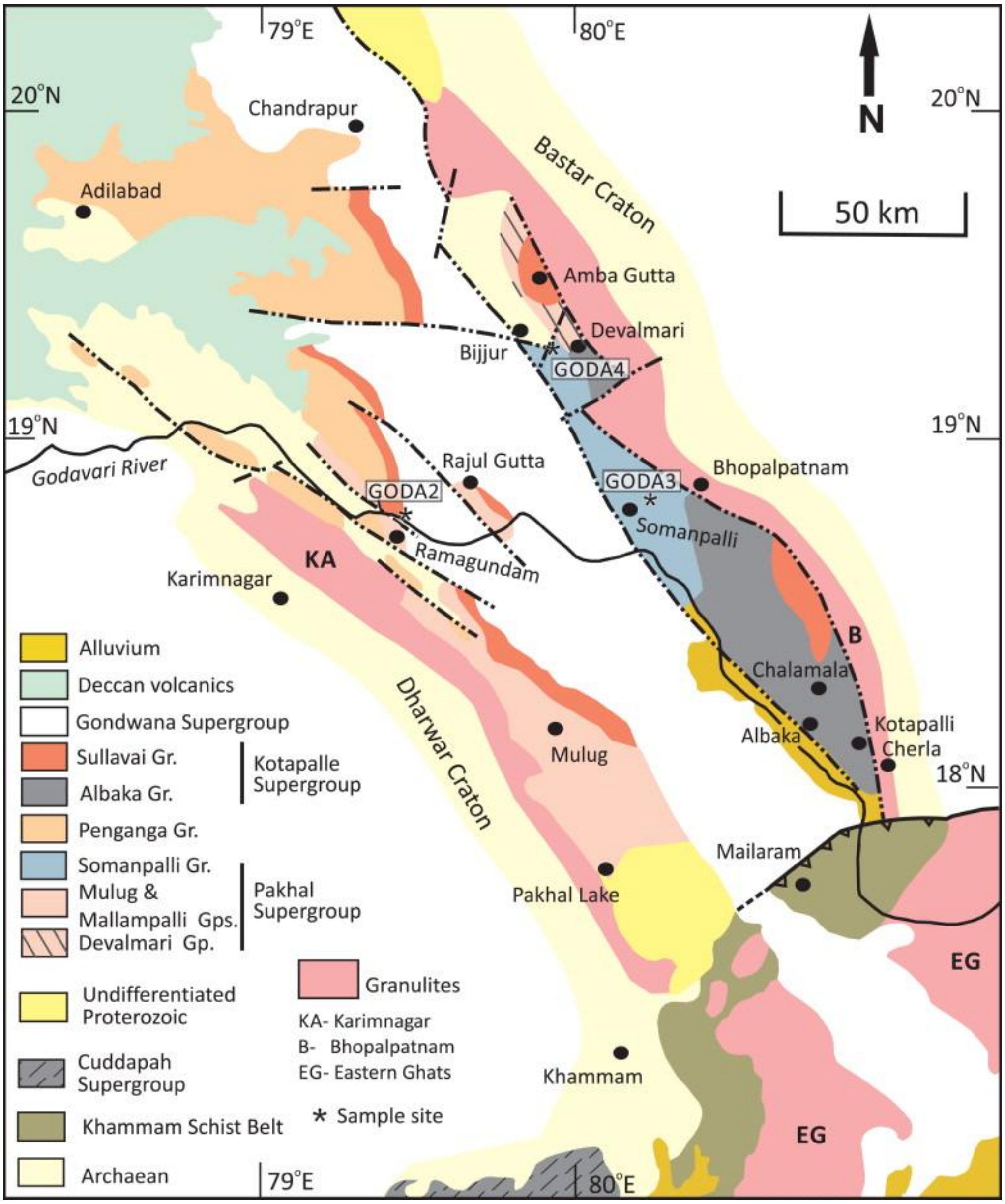

Fig.5. 2. Generalized geological map of the Pranhita-Godavari Valley showing distribution of the Purāna sequences and of the Permian–Mesozoic Gondwana Supergroup. The basin occurs along the join of the Bastar and Dharwar cratons, and is bounded on the SW (west) and on the NE (east) by Karimnagar and Bhopalpatnam Granulite belts, respectively. Locations of the samples analysed for isotopic age of detrital zircon are shown.

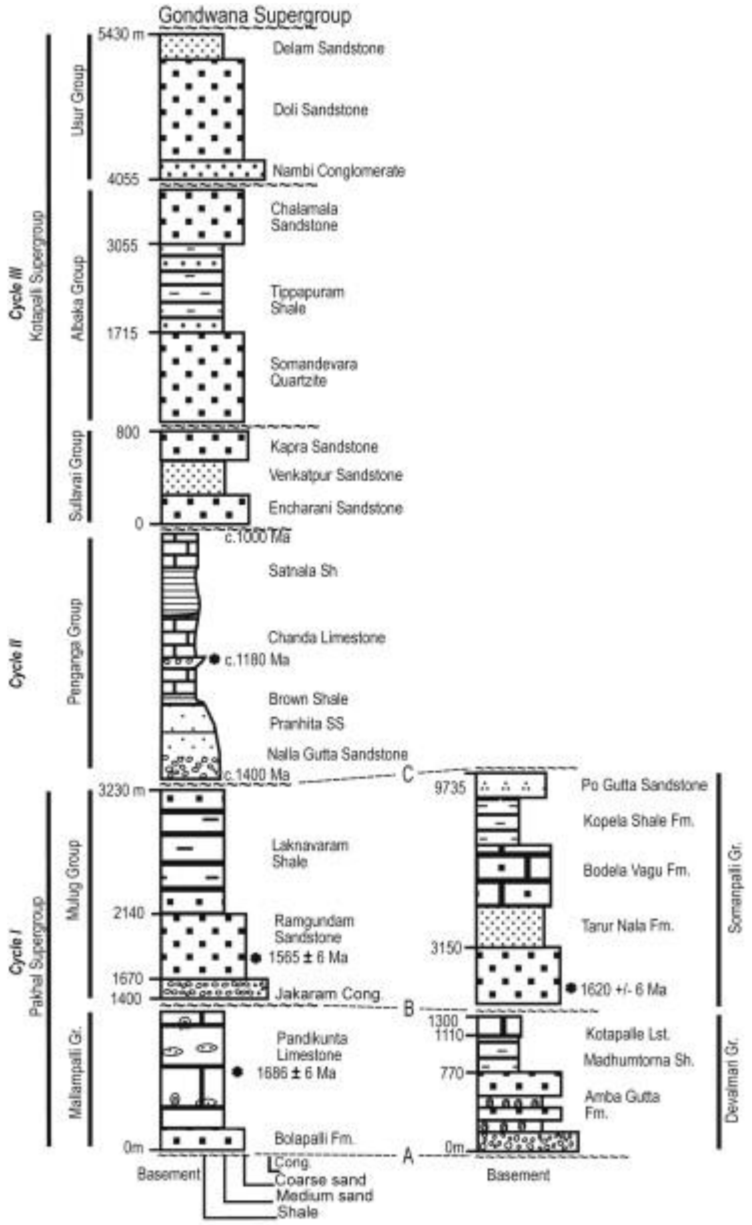

Fig.5.3. Composite stratigraphic column for the Purāna succession in the Pranhita-Godavari Valley. Different unconformity-bound sequences have been classified into three major cycles of sedimentation. The youngest Cycle consists of the Sullavai Albaka and Usur groups.

5.2.1. Cycle I

The Cycle I, or the basal cycle, comprises two smaller order unconformity–bound sequences, defined as groups, namely, the Mallampalli Group, which unconformably rests over crystalline basement, and the overlying Mulug Group. Equivalent Groups occur spatially separated on the east-side of the Valley, these are named the Devalmari and

Somanpalli Groups (Fig.5. 2 and Fig.5.3). The sedimentation age of the basal sandstone formation in these groups was constrained by $^{40}Ar/^{39}Ar$ dating of early authigenic glauconite grains by incremental heating technique on single grains (Conrad et al., 2011). Glauconites from Mallampalli sandstones yielded a plateau age of 1686 ± 6 Ma, whereas those from the Mulug and Somanpalli Groups yielded ages of 1565 ± 6 Ma and 1620 ± 6 Ma, respectively. The Mulug and Somanpalli Groups have been interpreted, on the basis of regional stratigraphic considerations, to have developed as two parallel belts within a protracted rift system. The former developed as a shallow tidal shelf deposit and the latter was deposited in a genetically related deep water slope and continental rise environment (Chaudhuri et al., 2012). Sedimentation in the shallow water–deep water couplet was terminated by contractional deformation (Ghosh and Saha, 2003), termed the Somanpalli orogenic belt by Chaudhuri et al., (2012). The age of basin inversion is not well constrained, but we consider that it coincides with the closure of Mulug–Somanpalli basin, and pre-dates deposition of the Penganga Group that overlies the Mulug Group above a major erosional unconformity.

The Mallampalli, Devalmari, Somanpalli and Mulug Groups are all characterized by mixed carbonate-siliciclastic assemblages, and the combined succession has been designated as the Pakhal Supergroup. The Pakhal Supergroup crops out primarily in the central and southwestern part of the Pranhita-Godavari Valley.

5.2.2. Cycle II

Cycle II comprises a major unconformity-bound sequence of mixed carbonate-siliciclastic rocks, designated the Penganga Group. The Penganga Group crops out mainly in the central and northern part of the Pranhita-Godavari Valley, and the basin had a northwesterly to northerly palaeoslope (Mukhopadhyay and Chaudhuri, 2003), contrasting with the underlying Pakhal Supergroup. The lower part of the Penganga succession comprises a thick fining-up succession of alluvial conglomerate-pebbly sandstone-coarse grained sandstone that grades upward into a succession of limestone and shale through a zone of quartz-arenite that was deposited in a tidal shelf environment. The outcrops of the carbonate-shale succession have been covered up by the Deccan volcanics (Fig. 5.2) in the northern part of the outcrop belt. However, it appears most likely that the outcrops extended further north–northwest beneath the volcanics, and connected down palaeoslope with open ocean situated along the present Central Indian Tectonic Zone.

The $^{40}Ar/^{39}Ar$ analysis of glauconites from a submarine-fan complex (Patranabis-Deb and Fukuoka, 1998) at the basal part of the carbonate assemblage did not yield any plateau age, but provided a provisional minimum age of c. 1200 Ma for initiation of carbonate sedimentation (Conrad et al., 2011), suggesting a much older age for opening of the Penganga Basin. The Penganga Group has been lithostratigraphically correlated with the combined succession of the c. 1400 to c. 1000 Ma Chandarpur and Raipur groups of the Chhattisgarh Basin (Mukhopadhyay et al., 2006 and Conrad et al., 2011), which is consistent with the provisional glauconite age.

5.2.3. Cycle III

The red sandstones of the Sullavai Group, along with the Albaka and Usur groups, constitute Cycle III. Sullavai sandstones unconformably overlie different formations of the Penganga Group, the Mulug Group and the Mallampalli Group in different parts of the Pranhita-Godavari Valley, attesting to the variable degree of uplift of fault blocks and erosion during the sub-Sullavai hiatus, exceeding several thousand metres at places. The stratigraphic relationship attests to deposition of the Sullavai Group in fault controlled basins, representing a probable Neoproterozoic rift cycle. The Sullavai red beds comprise different types of feldspathic and sub-feldspathic sandstones and were deposited in extensive fluvial and erg environments (Chakraborty, 1991, Chakraborty, 1999 and Chakraborty and Chaudhuri, 1993).

The stratigraphic position of the combined succession of the Albaka Group and the unconformably overlying Usur Group could not be uniquely constrained though field mapping. The siliciclastic assemblage unconformably overlies the folded succession of the Somanpalli Group, and are here considered to either be lateral equivalents of, or stratigraphic younger than, the Sullavai Group. The Albaka and Usur successions comprise extensive quartz-arenites and shales deposited in tide- and storm-dominated inner shelf environments. Though the stratigraphic position of the Albaka and Usur groups is uncertain, along with the Sullavai Group, the sequences collectively constitute a siliciclastic depositional system that was fundamentally different from the system represented by the carbonate-dominated, mixed carbonate-siliciclastic Pakhal or Penganga successions of late Palaeoproterozoic and Mesoproterozoic age.

5.3. U/Pb laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS)

Samples were crushed and sieved to obtain the 79 – 400 μm fraction. This fraction was then panned and zircon separates were extracted using the methylene iodide heavy liquids. The magnetic minerals were removed using a hand magnet and the remaining zircon separates were hand–picked and mounted in epoxy resin discs. Care was taken not to overly bias the zircons during picking by selecting zircon grains of all sizes, colours and shapes. Prior to analysis, zircons mounts were carbon coated and cathodoluminescence (CL) imaged on a Phillips XL20 SEM with attached Gatan CL at Adelaide Microscopy (University of Adelaide). Zircon grains were imaged using ∼16 mm working distance and accelerating voltage of 12 kV.

Zircon grains were analysed on a New Wave 213 nm Nd-YAG laser coupled with the Agilent 7500cs Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at Adelaide Microscopy (University of Adelaide). A 30 μm spot size was used with a typical pit depth of 30–50 μm. The isotopic ratios were monitored and corrected for drift and within–run U-Pb fractionation by repeated analyses of GEMOC GJ-1 standard zircon (published thermal ionization mass spectrometry normalizing ages of $^{207}Pb/^{206}Pb = 607.7 \pm 4.3$ Ma, $^{206}Pb/^{238}U = 600.7 \pm 1.1$Ma and $^{207}Pb/^{235}U = 602.0 \pm 1.0$ Ma, Jackson et al., 2004). Over the course of analytical sessions, a total of 79 analyses of the GJ-1 external standard yielded a weighted average $^{207}Pb/^{206}Pb$ age of 609 ± 13 Ma (2σ, MSWD = 1.4) and $^{206}Pb/^{238}U = 601.6 \pm 2.0$ Ma (2σ, MSWD = 0.5). Analysis of the Plešovice zircon standard (TIMS $^{206}Pb/^{238}U$ age = 337.13 ± 0.37 Ma, 95% confidence limits, Sláma et al., 2008) was performed to check for validity of the applied method during the analysis of unknowns. A total of 46 analyses of the Plešovice internal standard yielded weighted average ages of $^{206}Pb/^{238}U = 341.1 \pm 1.7$ Ma (2σ, MSWD = 1.4), showing the general accuracy of the operating conditions.

5.4. Stratigraphic location of samples

Samples are discussed from oldest to youngest.

5.4.1. Somanpalli Group (Indravati) – GODA 03

Two samples of the Tarur Nala Formation of the Somanpalli Group were collected over 50 km apart from each other. The formation consists of a coarsening-up succession of black shale-mudstone-siltstone with a thin interval of mass flow ash-tuffs and greywackes. Sample GODA3 was collected from a channel-filling greywacke along the right bank of the Indravati River at N18°47′39″, E80°17′49″. The Somanpalli Group forms part of the Pakhal Supergroup, the first stratigraphic cycle in the Pranhita-Godavari Valley (Fig. 5.2).

5.4.2. Somanpalli Group (Biijur) – GODA 04

Sample GODA4 was also collected from a channel-filling greywacke from the Somanpalli Group. However, this sample was collected over 150 km away from sample GODA3 near the town of Biijur at N19°15′43″, E79°55′52″.

5.4.3. Sullavai Group – GODA 02

Sample GODA2 was from the stratigraphically overlying Sullavai Group that unconformably overlie different formations of the Penganga Group, the Mulug Group and the Mallampalli Group in different parts of the Pranhita-Godavari Valley (Fig. 5.2). The Sullavai Group forms Cycle III in the stratigraphy of the Pranhita-Godavari Valley, and, to date, there are no geochronological data on this Group.

Sample GODA2 was collected near the town of Ramagundam at N18°47′18″, E79°27′45″. The sample was collected from the Mancheral Quartzite Formation, at the base of the Sullavai Group. This formation is interpreted to represent alluvial plain to braided plain deposits. The sample was collected from the stratigraphically highest part of the formation.

5.5. Results

U/Pb LA-ICPMS results are presented in Table 5. 1. U-Pb results are presented in Fig. 4a–d. Ages for individual analyses are quoted at the 1σ level, whereas averages and intercept ages are quoted at a 2σ level.

Table 5.1.U-Pb isotopic data of zircons from the Somanpalli and Sullavai Groups.

Analysis	Isotope ratios					Concordancy	Ages (Ma)			
	$^{207}Pb/^{235}U$	1σ error	$^{206}Pb/^{238}U$	1σ error	rho		$^{207}Pb/^{206}Pb$	1σerror	$^{206}Pb/^{238}U$	1σerror
GODA-3 Somanpalli Group (Indravati)										
c1	24.02543	0.31589	0.51212	0.0068	0.990211	73	3663.3	15.33	2665.7	29.01
c2	31.14818	0.41482	0.69689	0.00934	0.993675	95	3589	15.69	3408.9	35.48
c3	8.02924	0.12929	0.2551	0.00376	0.915349	48	3040.5	20.93	1464.7	19.3
c4	10.44264	0.15898	0.46322	0.0064	0.907529	98	2491.5	21.39	2453.7	28.19
c5	26.16163	0.35826	0.65348	0.0089	0.994544	95	3418.9	16.53	3241.8	34.68
c6	28.07308	0.38526	0.68898	0.00941	0.99522	98	3446.2	16.49	3378.7	35.92
c7	10.97492	0.15046	0.48355	0.00657	0.99107	102	2502.9	17.74	2542.7	28.54
c8	8.51858	0.17323	0.41957	0.00633	0.741897	98	2313.6	32.2	2258.5	28.75
c9	3.96478	0.05888	0.28622	0.00393	0.924579	99	1632.1	22.25	1622.6	19.72
c10	3.07136	0.04251	0.2254	0.00308	0.987271	82	1601.6	19.74	1310.4	16.2
c11	19.17574	0.27139	0.54143	0.00754	0.983982	86	3227.2	17.42	2789.4	31.54
c12	37.56824	0.50651	0.74169	0.01021	0.979408	95	3780.3	15.17	3576.8	37.8
c13	8.56743	0.14383	0.37508	0.00561	0.890923	82	2515.1	23.08	2053.2	26.29
c14	20.30643	0.28924	0.53877	0.00769	0.997934	84	3325.4	16.4	2778.3	32.23
c15	29.51943	0.46516	0.71074	0.01038	0.926813	100	3476.2	20.8	3461.2	39.13
c16	9.56794	0.16075	0.4413	0.00637	0.859158	97	2425.9	24.46	2356.5	28.47
c17	12.78181	0.18017	0.47063	0.00663	0.99941	89	2800.7	17.11	2486.3	29.05
c18	28.59132	0.41963	0.68745	0.00983	0.974272	97	3478.3	17.82	3372.9	37.54
c19	29.06652	0.62702	0.67476	0.0119	0.817541	94	3535.5	30.29	3324.2	45.81
c20	29.30716	0.40573	0.70377	0.00976	0.998261	99	3480.2	16.47	3434.9	36.92
c21	10.72389	0.16767	0.45704	0.00664	0.929204	95	2559.3	21	2426.5	29.36
c22	11.86836	0.17372	0.47414	0.00685	0.987018	94	2667	18.05	2501.7	29.95
c23	26.17397	0.36512	0.61659	0.0087	0.988652	88	3510	15.76	3096.4	34.71
c24	8.36424	0.12925	0.40545	0.00584	0.932119	94	2341.3	20.89	2194.1	26.78
c25	10.47062	0.18004	0.46795	0.00696	0.864994	100	2479.9	24.35	2474.6	30.59
c26	3.84819	0.06676	0.28355	0.00409	0.831446	101	1594.8	27.38	1609.2	20.56
c27	20.53321	0.29376	0.53866	0.00782	0.985471	83	3343.1	15.85	2777.8	32.78

Analysis	Isotope ratios					Concordancy	Ages (Ma)			
	$^{207}Pb/^{235}U$	1σ error	$^{206}Pb/^{238}U$	1σ error	rho		$^{207}Pb/^{206}Pb$	1σerror	$^{206}Pb/^{238}U$	1σerror
c28	10.67181	0.15807	0.47966	0.00674	0.94867	102	2470.1	19.7	2525.8	29.34
c29	10.79262	0.15392	0.46638	0.00654	0.983263	97	2536.5	18.04	2467.7	28.75
c30	25.2052	0.38481	0.64376	0.00956	0.972697	95	3386.1	17.32	3203.8	37.48
c31	3.82712	0.07444	0.28452	0.00432	0.780615	102	1578.3	31.38	1614.1	21.66
c32	13.06326	0.20058	0.49869	0.00727	0.94944	95	2742.3	19.61	2608.1	31.27
c33	3.90216	0.06119	0.28265	0.00401	0.904732	99	1626.7	23.38	1604.7	20.18
c34	30.5559	0.44586	0.72742	0.01063	0.998517	101	3493.5	16.14	3523.8	39.69
c35	26.65449	0.38015	0.66898	0.00961	0.992829	97	3412.1	16.05	3301.9	37.14
c36	29.00178	0.4216	0.66436	0.00969	0.99668	92	3553.5	16.23	3284.1	37.54
c38	26.99308	0.49194	0.65298	0.01024	0.860479	93	3470	25.27	3239.8	39.92
c39	3.88457	0.06064	0.2838	0.00408	0.92094	100	1610.3	22.72	1610.5	20.48
c40	21.70823	0.30765	0.59435	0.00846	0.995645	92	3275.9	16.04	3007	34.22
c41	28.4643	0.4126	0.76894	0.01099	0.985999	112	3297.1	16.82	3676.9	40.04
c42	27.59632	0.40362	0.6658	0.00962	0.987893	95	3473.2	16.77	3289.6	37.24
c43	9.98568	0.16749	0.44977	0.00667	0.884146	97	2466.1	23.23	2394.2	29.65
c44	10.21408	0.15633	0.46006	0.00666	0.945838	99	2466.1	19.87	2439.8	29.42
c45	3.88587	0.05777	0.28349	0.00407	0.965701	100	1612.8	20.58	1608.9	20.45
c46	9.97639	0.14691	0.45573	0.00655	0.976013	99	2442.2	18.44	2420.7	29.02
c47	14.20642	0.27577	0.51893	0.00827	0.820983	96	2813.5	27.49	2694.6	35.1
c48	29.50629	0.47616	0.70127	0.01058	0.934893	98	3496.3	19.96	3425.5	40.09
c49	17.84503	0.25299	0.5033	0.00717	0.995162	81	3229.4	16.17	2628	30.75
c50	17.3355	0.24777	0.52105	0.00746	0.998281	86	3128.6	16.49	2703.6	31.61
c51	26.57026	0.38264	0.65191	0.00939	0.999808	94	3448	16.26	3235.6	36.64
c52	33.71633	0.49715	0.74922	0.01088	0.984855	100	3600.7	16.95	3604.6	40.1
c54	29.4346	0.5135	0.70969	0.01125	0.90866	100	3474.1	22.38	3457.3	42.43
c55	10.36442	0.21695	0.47374	0.00792	0.798676	102	2441.5	30.94	2499.9	34.66
c56	10.99424	0.15727	0.34183	0.00475	0.97141	62	3077.7	17.75	1895.5	22.8
c57	21.52084	0.31622	0.57769	0.0082	0.966026	89	3308.5	17.74	2939.3	33.5
c58	7.24459	0.10738	0.28172	0.00394	0.943559	59	2713.4	19.38	1600	19.83
c59	4.92593	0.07668	0.26768	0.00386	0.926355	71	2145	21.28	1529	19.64
GODA-4 Somanpalli Group (Biijur)										
c1	32.51028	0.44076	0.41231	0.0057	0.980687	50	4438.2	14.66	2225.5	26.04
c2	4.65223	0.06558	0.1563	0.00219	0.993974	32	2950.7	17.62	936.2	12.23
c3	3.731	0.06124	0.27196	0.00394	0.882635	96	1616	25.95	1550.7	19.99
c4	31.03092	0.48089	0.74527	0.01135	0.982723	103	3481.9	19.8	3590.1	41.91
c5	26.55893	0.38536	0.68231	0.00989	0.998984	99	3377.7	17.63	3353.2	37.9

Analysis	Isotope ratios					Concordancy	Ages (Ma)			
	$^{207}Pb/^{235}U$	1σ error	$^{206}Pb/^{238}U$	1σ error	rho		$^{207}Pb/^{206}Pb$	1σerror	$^{206}Pb/^{238}U$	1σerror
c6	16.78621	0.23674	0.43696	0.00622	0.990764	70	3357.6	16.68	2337	27.89
c7	24.04752	0.36976	0.62192	0.00939	0.981932	93	3368.2	19.62	3117.6	37.34
c8	4.03365	0.08585	0.27845	0.00451	0.761005	92	1719.4	36.63	1583.6	22.72
c9	10.78981	0.17585	0.48833	0.00738	0.927287	104	2462.5	23.09	2563.5	31.95
c10	20.80844	0.29454	0.40629	0.00586	0.981394	58	3801.6	16.06	2197.9	26.84
c11	12.83635	0.18493	0.4071	0.00589	0.995753	72	3047.9	17.44	2201.6	26.97
c12	22.46666	0.32837	0.52337	0.00771	0.992155	77	3532.9	17.31	2713.4	32.63
c13	28.38545	0.43878	0.70351	0.01097	0.991322	100	3432.8	16.72	3434	41.52
c14	11.27464	0.18284	0.46718	0.00711	0.938462	95	2608.7	22.2	2471.2	31.25
c15	13.54869	0.20564	0.51545	0.00766	0.979111	97	2749.9	18.76	2679.8	32.58
c16	7.67399	0.12501	0.24111	0.00373	0.949664	45	3061.6	22.23	1392.5	19.39
c17	25.91503	0.38797	0.64164	0.00968	0.992345	93	3434.1	16.21	3195.4	38.01
c18	8.16028	0.12392	0.28543	0.00422	0.973591	56	2891.9	20.49	1618.6	21.18
c19	11.11052	0.16449	0.27982	0.00419	0.988712	47	3407.4	15.56	1590.5	21.12
c20	8.41135	0.12442	0.34336	0.00507	0.998237	72	2632.9	17.59	1902.8	24.31
c21	11.43437	0.20361	0.50353	0.00802	0.894463	105	2506.7	25.59	2628.9	34.4
c22	35.64645	0.53538	0.78729	0.01187	0.996162	104	3610.3	15.99	3743.4	42.82
c23	24.21476	0.36215	0.59353	0.00897	0.989597	87	3449.3	15.77	3003.7	36.28
c24	33.1939	0.51018	0.67446	0.01039	0.997713	89	3737.2	16.24	3323.1	39.99
c25	10.41069	0.17337	0.46701	0.00739	0.950219	100	2473.1	22.48	2470.5	32.46
c26	13.56717	0.206	0.34492	0.00539	0.971645	56	3390.3	15.65	1910.3	25.84
c27	8.70211	0.12664	0.39781	0.00597	0.969723	88	2441.3	16.8	2159	27.55
c28	6.2896	0.09126	0.20512	0.00307	0.969454	40	2997.7	16.05	1202.8	16.44
c29	31.12613	0.45496	0.72494	0.01097	0.965925	100	3527.9	16.14	3514.5	41
c30	10.43797	0.15442	0.4684	0.00706	0.981521	100	2472.3	17.67	2476.6	31.01
c31	29.95877	0.43521	0.72047	0.01085	0.964631	101	3477.9	15.56	3497.8	40.67
c32	30.84217	0.4423	0.44804	0.00645	0.99616	56	4239.2	15.6	2386.5	28.71
c33	9.89421	0.15392	0.46041	0.00712	0.99408	101	2412.5	19.99	2441.4	31.41
c34	16.18132	0.23644	0.43169	0.00622	0.986078	70	3317.5	17.08	2313.3	28.01
c35	29.66077	0.42995	0.70627	0.01067	0.959493	99	3492.8	15.69	3444.4	40.32
c36	16.00487	0.22775	0.41315	0.00616	0.954406	66	3367.8	15.16	2229.3	28.11
c49	21.83041	0.34622	0.58194	0.00935	0.98709	89	3317.2	17.31	2956.6	38.11
c50	13.91691	0.22947	0.5254	0.00832	0.960396	99	2759.7	21.33	2722	35.16
c51	26.99824	0.41195	0.63604	0.00998	0.97244	90	3510.1	15.53	3173.4	39.32
c52	20.82108	0.31579	0.43345	0.00675	0.973936	63	3701.8	15.22	2321.2	30.35
c53	7.4909	0.11021	0.29437	0.00443	0.977635	62	2693.6	16.4	1663.3	22.07

Analysis	Isotope ratios					Concordancy	Ages (Ma)			
	$^{207}Pb/^{235}U$	1σ error	$^{206}Pb/^{238}U$	1σ error	rho		$^{207}Pb/^{206}Pb$	1σerror	$^{206}Pb/^{238}U$	1σerror
c54	19.41508	0.30097	0.45424	0.00716	0.983459	69	3521.6	16.17	2414.1	31.76
c55	25.24094	0.38009	0.57822	0.00847	0.972768	83	3557	17.98	2941.5	34.6
c56	21.48119	0.3148	0.49387	0.00732	0.988731	73	3549.6	16.97	2587.4	31.59
c57	41.32114	0.604	0.7824	0.01172	0.975811	97	3843.2	15.35	3725.8	42.39
c58	13.14144	0.19636	0.38161	0.00569	0.997889	65	3183.9	18.2	2083.8	26.55
c59	11.26762	0.17324	0.48728	0.00746	0.995736	101	2534.2	18.65	2558.9	32.32
c60	20.73576	0.32428	0.5503	0.00865	0.99491	85	3327	16.89	2826.4	35.95
GODA-2 Sullavai Group										
c1	3.78188	0.07628	0.27683	0.00417	0.746827	98	1607.7	33.16	1575.4	21.07
c2	1.66874	0.04937	0.16275	0.0026	0.53998	92	1052.1	56.91	972	14.4
c3	14.05869	0.2107	0.49314	0.00712	0.963363	90	2880.8	18.65	2584.2	30.75
c4	7.00423	0.11797	0.23618	0.00351	0.882374	46	2947.7	23.58	1366.8	18.3
c7	2.01403	0.06464	0.19346	0.0032	0.515375	105	1082.3	61.79	1140.1	17.29
c8	5.12309	0.1077	0.31279	0.00476	0.723886	91	1938.4	34.53	1754.4	23.36
c9	3.91106	0.22925	0.22483	0.00582	0.441625	64	2045.6	103.38	1307.3	30.63
c10	4.45709	0.08314	0.30434	0.00457	0.805005	99	1735.7	29.23	1712.8	22.57
c11	2.56596	0.05789	0.17199	0.00264	0.680373	58	1769.3	38.25	1023.1	14.51
c12	10.99549	0.18307	0.46287	0.00668	0.866792	95	2581.3	23.98	2452.2	29.43
c14	6.55692	0.10291	0.26909	0.00395	0.93528	59	2622.4	20.32	1536.2	20.09
c15	10.6016	0.17617	0.46698	0.00695	0.895625	99	2504.1	22.6	2470.3	30.56
c16	1.7928	0.2667	0.18407	0.00819	0.299095	115	948.5	285.24	1089.2	44.58
c17	7.7564	0.13789	0.39759	0.0061	0.863022	96	2245.7	25.09	2157.9	28.15
c23	5.56252	0.08737	0.26008	0.00383	0.937564	62	2403.1	20.49	1490.2	19.6
c24	1.59766	0.0368	0.16275	0.00252	0.672227	101	962.7	42.44	972	13.96
c26	3.93717	0.06541	0.28486	0.00417	0.881139	99	1630.1	24.67	1615.8	20.92
c27	11.30919	0.18242	0.48455	0.00718	0.918639	100	2552	21.17	2547.1	31.16
c29	3.9208	0.08259	0.28829	0.00428	0.704793	102	1601.3	35.66	1633	21.42
c30	10.95185	0.18146	0.45495	0.00676	0.896788	93	2603.9	22.18	2417.2	29.96
c31	11.37097	0.19625	0.49386	0.00743	0.871712	102	2529	23.77	2587.4	32.07
c32	11.76188	0.21674	0.49649	0.00765	0.836158	101	2577	26.14	2598.7	32.94
c33	11.26714	0.1912	0.48102	0.00719	0.880829	99	2559.8	23.24	2531.7	31.28
c34	4.27257	0.07537	0.14184	0.00213	0.851278	29	2971.8	24.63	855.1	12.01
c35	3.62141	0.06769	0.18398	0.00277	0.805494	48	2263.5	27.87	1088.7	15.1
c36	9.83326	0.15236	0.38452	0.0057	0.956715	78	2704.8	19.06	2097.4	26.54
c37	10.60831	0.22757	0.47113	0.00766	0.757913	100	2492.9	32.44	2488.5	33.55
c39	11.70832	0.18833	0.42256	0.00627	0.922474	80	2837.3	20.7	2272.1	28.4

Analysis	Isotope ratios					Concordancy	Ages (Ma)			
	^{207}Pb/^{235}U	1σ error	^{206}Pb/^{238}U	1σ error	rho		^{207}Pb/^{206}Pb	1σerror	^{206}Pb/^{238}U	1σerror
c40	11.14465	0.22685	0.48127	0.00757	0.772742	100	2541.6	30.59	2532.8	32.93
c41	2.61041	0.0611	0.22808	0.00353	0.661234	104	1273.9	41.55	1324.4	18.55
c42	5.94814	0.10312	0.26836	0.00403	0.866215	62	2468.1	24.28	1532.5	20.47

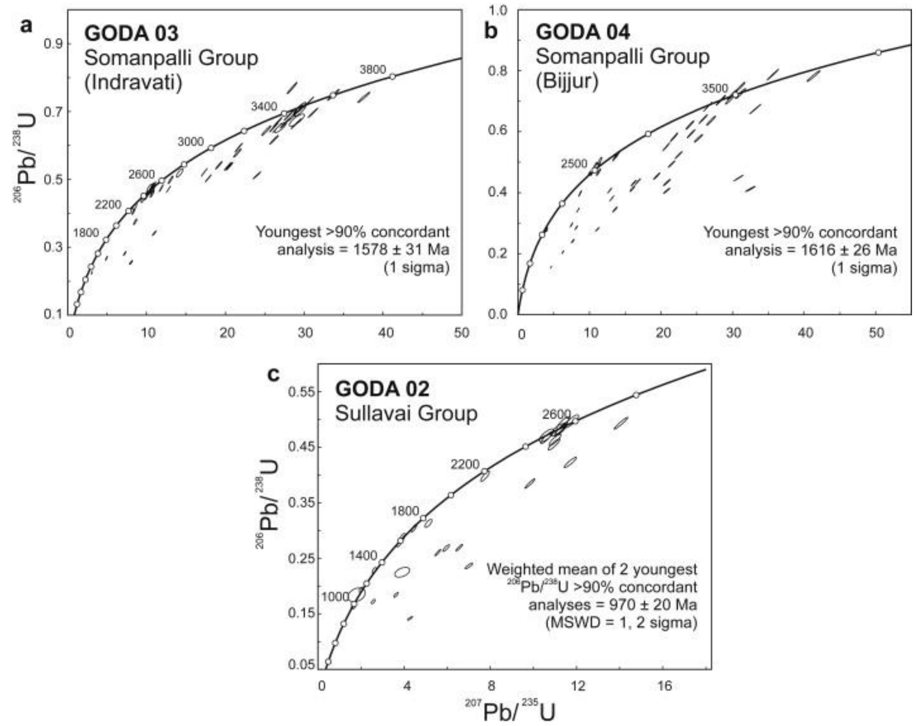

Fig. 5.4. U-Pb LA-ICPMS zircon concordia plots. (a) Concordia plot for all detrital zircon U-Pb data from sample GODA 03 of the Somanpalli Group from the Indravati River. (b) U-Pb detrital zircon data from sample GODA 04 of the Somanpalli Group from near the town of Bijjur. (c) U-Pb detrital zircon data from sample GODA 02, an arenite from the Sullavai Group.

5.5.1. Somanpalli Group (Indravati) – GODA 03

Sixty analyses of sixty grains yielded forty two >90% concordant analyses (Fig.5. 4 and Fig.5. 5). Of the near-concordant analyses, a lone analysis provided a^{207}Pb/^{206}Pb age of 3780 ± 15 Ma. Nineteen other analyses yielded Eoarchaean to Palaeoarchaean ages between 3680 Ma and 3200 Ma, with a probability distribution maximum at ca. 3480 Ma. A second age population of sixteen analyses lies between

2900 Ma and 2300 Ma, with a probability density distribution maximum of ca. 2470 Ma (Fig.5. 5a). The youngest six >90% concordant analyses yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1613 ± 19 Ma (MSWD = 0.55). This age is interpreted as the maximum depositional age of this sandstone.

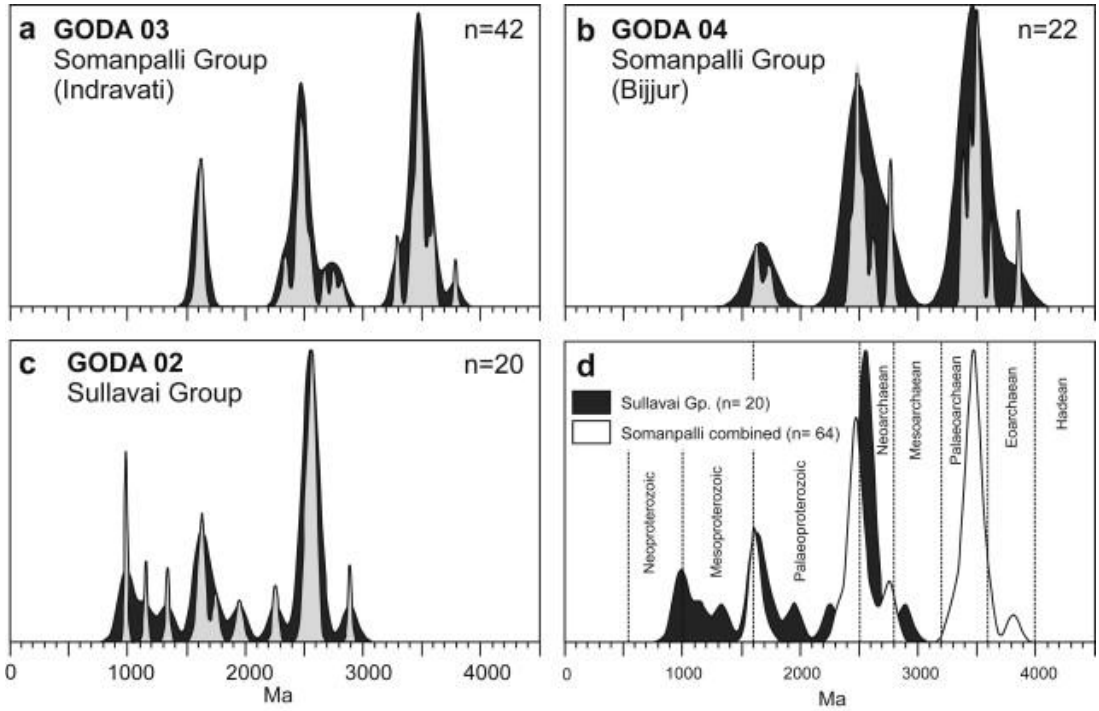

Fig. 5.5. Greater than 90% concordant U-Pb LA-ICPMS zircon data plotted as probability density (light grey) and kernel density estimation (dark grey) plots (in a–c). (a) Sample GODA 03, Somanpalli Group from the Indravati River; (b) GODA 04, Somanpalli Group from Biijur; (c) GODA 02, Sullavai Group arenite; (d) kernel density estimation plots of all the data, the Sullavai Group data and the combined Somanpalli Group (samples GODA 03 and 04). Plots constructed using software DENSITYPLOTTER (Vermeesch, 2012). Data older than 1400 Ma are plotted as $^{207}Pb/^{206}Pb$ ages, whilst those younger than 1400 Ma are plotted as $^{206}Pb/^{238}U$ ages.

5.5.2. Somanpalli Group (Biijur) – GODA 04

Despite the distance between the two Somanpalli Group samples, the age-provenance of the two greywackes is similar. Seventy analyses were performed, but only twenty two were within 10% of concordance. One lone analysis yielded a $^{207}Pb/^{206}Pb$ age of 3843 ± 15 Ma, whilst another ten analyses produced $^{207}Pb/^{206}Pb$ Eoarchaean to Palaeoarchaean ages between 3650 Ma and 3300 Ma (Fig.5. 4 and Fig.5. 5). These analyses clustered around a probability density distribution maximum of ca. 3500 Ma.

Nine analyses yielded $^{207}Pb/^{206}Pb$ ages between 2800 Ma and 2350 Ma, with a maximum at ca. 2480 Ma (Fig. 5.5b). Two isolated >90% concordant analyses yielded $^{207}Pb/^{206}Pb$ ages of 1719 ± 37 Ma and 1616 ± 26 Ma. This latter age is interpreted as the maximum age of deposition, and is within error of that from sample GODA 03.

5.5.3. Sullavai Group – GODA 02

Sample GODA2 only yielded thirty analyses, of which twenty were within 10% of concordance. The oldest analysis provided a $^{207}Pb/^{206}Pb$ age of 2881 ± 19 Ma, whereas nine analyses yielded ages between 2600 Ma and 2450 Ma. A weighted mean of these analyses produced an age of 2547 ± 27 Ma (MSWD = 2). Six near-concordant analyses yielded $^{207}Pb/^{206}Pb$ ages between 2300 Ma and 1580 Ma. The youngest three of these yielded a weighted mean age of 1622 ± 29 Ma (MSWD = 0.14). Isolated analyses yielded $^{206}Pb/^{238}U$ ages of ca. 1320 Ma and ca. 1140 Ma (the $^{206}Pb/^{238}U$ age is quoted for analyses younger than 1600 Ma as with increasing youth, these ages are increasingly more precise than $^{207}Pb/^{206}Pb$ ages). The two youngest grains yielded near-identical $^{206}Pb/^{238}U$ ages of ca. 972 Ma. A weighted mean of these two yields an interpreted maximum depositional age of 972 ± 20 Ma.

5.6. Discussion

5.6.1. Constraints on the age of deposition of the Purāna sediments in the Pranhita-Godavari Valley

The two maximum depositional ages of the Somanpalli Group samples of 1613 ± 19 Ma and 1616 ± 26 Ma overlap in error with the 1620 ± 6 Ma age of authigenic glauconite from the same Group (Conrad et al., 2011). This suggests that the age of deposition of this Cycle 1 sequence is now well constrained to ∼1620 Ma, at the end of the Palaeoproterozoic.

The maximum depositional age of the Sullavai Group arenite of 972 ± 20 Ma, confirms the relative youth of the siliciclastic Cycle III in the Pranhita-Godavari Valley. This suggests that the Sullavai Group was deposited between this age and the Permian age of the basal Gondwana Supergroup. The overlying Albaka Group has been suggested to contain Cambrian detrital zircons (Chaudhuri et al., unpublished data), but this is yet to be fully published. Whether the Sullavai Group was deposited directly before the Albaka Group, or forms an older Neoproterozoic succession is unknown.

5.6.2. Provenance of the Pranhita-Godavari Valley Proterozoic-Palaeozoic sedimentary rocks

The distinct tripartite age peaks of the Somanpalli Group samples at ∼3500 Ma, ∼2480 Ma and ∼1620 Ma suggests a source with similar-aged zircons exposed at the surface at ∼1620 Ma (either as distinct rocks, or as recycled zircons from previous sedimentary cycles). The minor peaks at ∼3800 Ma and ∼2750 Ma are also quite distinctive. Presently, the Somanpalli Group crops out against the eastern Dharwar and Bastar cratons and the Karimnagar Orogenic Belt (Fig.5.1 and Fig.5.2). Veevers and Saeed (2009) studied detrital zircons from the Permian to Jurassic Gondwana Supergroup overlying the Purāna sequences in the Pranhita-Godavari Valley. Their study provides an interesting comparison to this one and allows us to examine the changing provenance of the region over 1.5 billion years of Earth history.

Veevers and Saeed (2009) suggested that the Permian–Jurassic of the Pranhita-Godavari Valley were sourced from a drainage system that originated in Antarctica in the region of the Gamburtsev Subglacial Mountains. A qualification to this was the presence of 2900–3470 Ma detritus in Triassic samples. They suggested that these originated in cratonic India – either the Dharwar Craton, or from the Karimnagar Orogenic Belt. Available data from the Karimnagar Orogenic Belt, however, does not support the presence of rocks of suitable antiquity (Santosh et al., 2004). The Western Dharwar Craton does contain rocks of suitable age, but the Eastern Dharwar Craton, the province adjacent to the Pranhita-Godavari Valley, does not (Jayananda et al., 2013). Small enclaves of Palaeoarchaean rocks have been found within the Bastar Craton (Ghosh, 2004) that may explain some of the ∼3500 Ma detritus. Possible Indian Eoarchaean sources that might match the minor ∼3800 Ma detritus are difficult to find. In the adjacent part of Antarctica, however, protoliths of up to ∼3800 Ma have been recorded in the Napier Complex (Harley and Black, 1997) and the Ruker Terrane further south has granitoids and orthogneisses with protoliths of up to ∼3500 Ma (Mikhalsky et al., 2001 and Boger et al., 2008). Rare detrital zircons of up to ~3500 Ma are also seen in Triassic to Recent sediments and sedimentary rocks of this part of Antarctica (Veevers and Saeed, 2008 and Veevers and Saeed, 2011). We therefore suggest that these characteristic ancient zircons provide a good fingerprint back to a source in Enderby Land, East Antarctica for the Somanpalli Group (Fig. 5.6).

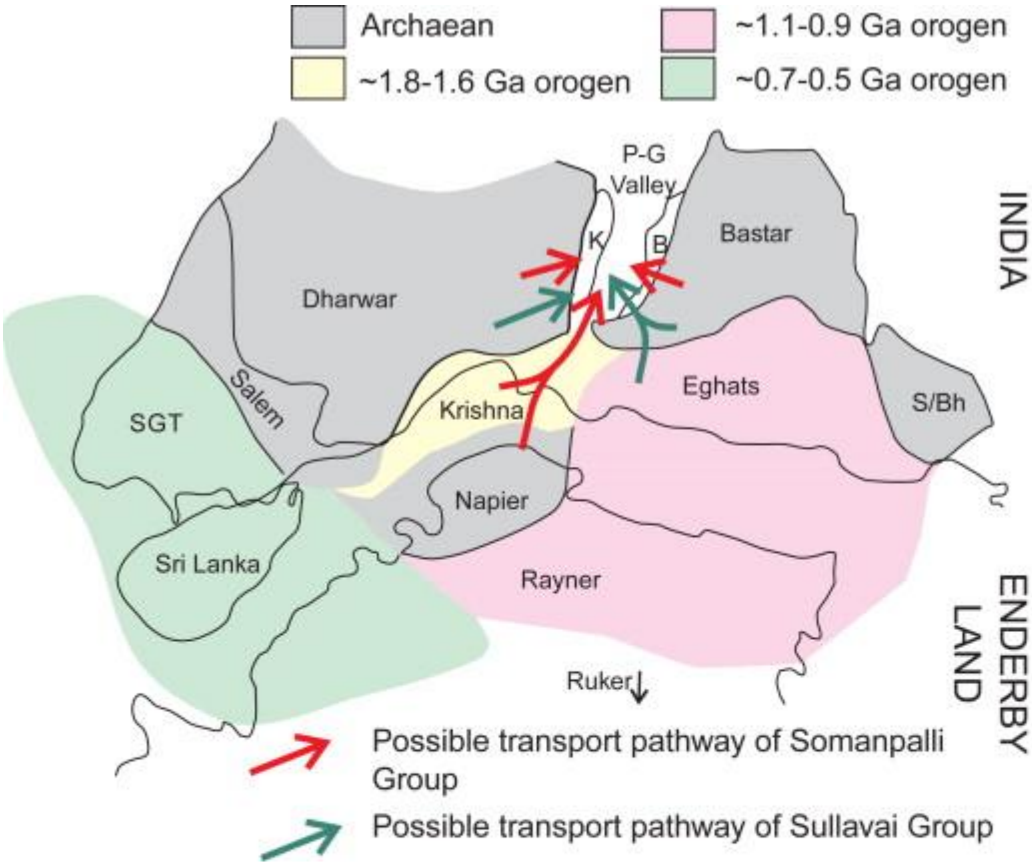

Fig. 5.6. Reconstruction of SE India and Enderby land in Antarctica after the ~1580 Ma collision between the two along the Krishna Province of the southern Eastern Ghats (Henderson et al., 2014). Possible sediment transport pathways of the Somanpalli and Sullavai Groups are highlighted. After Veevers and Saeed (2009). Dharwar = Dharwar craton, Bastar = Bastar Craton, S/Bh = Singbhum Craton, Eghats = Eastern Ghats Orogen, Krishna = Krishna Province, Napier = Napier Complex, Rayner = Rayner Complex, Salem = Salem Block, SGT = Southern Granulite Terrane, K = Karimnagar Granulite Belt, Ruker = Ruker Terrane, B = Bhopalpatnam Granulite Belt, P-G Valley = Pranhita-Godavari Valley.

Rocks and detritus between ~2750 Ma and ~2480 Ma are found in Enderby Land (Harley, 2003) and other proximal parts of Antarctica and form common detrital components in Antarctica and in the post-Permian of the Pranhita-Godavari Valley (Veevers and Saeed, 2008; Veevers and Saeed, 2009; Veevers and Saeed, 2011 and Veevers and Saeed, 2013). In contrast, zircons of the third major age-source,

~1620 Ma, are common in orthogneisses and charnockites from the southern Eastern Ghats region – the Krishna Province (Henderson et al., 2014). The Somanpalli Group, therefore appears to be sourced consistently from the south, from rocks similar in age to those from the Napier Complex of Enderby Land and from the Krishna Province that stitched together the terranes in the latest Palaeoproterozoic (Fig. 5.6). Possible components from the adjacent late Archaean Indian cratons cannot be ruled out – and may represent part of the ~3500 Ma and ~2480 Ma peaks.

The Sullavai Group shares the latest Archaean/earliest Palaeoproterozoic age peak with the Somanpalli Group, although the age-maximum is slightly older in the Sullavai Group (2547 ± 27 Ma). The Sullavai Group age spectra also lack the >3.0 Ga zircons that are so well represented in the Somanpalli Group (Fig.5.4 and Fig.5.5), although, admittedly, the data are limited. The late Palaeoproterozoic zircon age peak is also seen in the Sullavai Group detritus, but unlike the Somanpalli Group, Mesoproterozoic zircons are also common and continue down to ~970 Ma. This early Neoproterozoic age for the youngest detrital zircons in the Sullavai Group is consistent with a source from the Eastern Ghats Orogen, where extensive high-grade metamorphism and voluminous charnockite magmatism occurred at this time (Korhonen et al., 2011).

5.7. Conclusions

The Somanpalli Group is sourced from rocks that are consistent with those found in the Enderby Land in East Antarctica, and from the Krishna Province. They were deposited on a northward dipping palaeoslope and were deposited at ~1620 Ma. The similarity in the maximum depositional age and the published glauconite age suggests that the Somanpalli Group was deposited in a foreland setting (similar to that suggested byGupta, 2012)—in the foreland to the coeval Krishna Province—that involved the collision of Enderby Land with the Dharwar Craton (Henderson et al., 2014). The high angle of the Pranhita-Godavari Valley to the Krishna Province (Fig. 5.6), suggests that the basin may have formed as a rift valley in the orogenic foreland, similar to the Rhine Valley in the foreland of the Cenozoic Alps (Şengör et al., 1978).

The Neoproterozoic (to possibly Palaeozoic) Sullavai Group represents renewed deposition in the same basin, but this time demonstrates a different source region that contains the Eastern Ghats Orogen, to the northeast.

Modern detrital zircon geochronology is demonstrating the antiquity and history of pulsed subsidence in this part of India, demonstrating a billion-year scale of basin rejuvenation.

Acknowledgements

Professor Asru Chauduri tragically died whilst this manuscript was in draft stage. His drive, enthusiasm and rapier-like wit are lost to a grieving community of researchers. The research was initiated with the financial support of the Indian Statistical Institute, Kolkata, and was developed to completion with the financial support extended to AKC by the Council of Scientific and Industrial Research, Government of India to work as an Emeritus Scientist (Grant No. 21(0578)/03/EMR-II), and Department of Science and Technology, Government of India under the research project on a DST-funded project (Grant No.SR/S4/ES–210/2006). ASC is funded by Australian Research Council grant #FT120100340 and Australia–India Strategic Research Fund project #ST030046. ASC and UA's contributions form TRaX Record #289. This is also a contribution to IGCP Project #628 – The Gondwana Map. We gratefully acknowledge all the funding organizations. We are thankful to the Presidency University, Kolkata and the Indian Statistical Institute for extending office facilities to us for completing the work. Saibal Gupta and Abhijit Basu are thanked for constructive reviews.

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Chapter 6 - Overall Discussion

This research study has been carried out with a main aim of unraveling geological origin and Paleotectonic position of the island of Sri Lanka based a study of age and provenance of metasedimentary rocks of island's three main crustal units, the Wanni Complex (WC), Highland Complex (HC) and Vijayan Complex (VC). Detrital zircon grains of metaquartzites of the Highland Complex (HC) and Wanni Complex (WC), leucosemes and paleosomes of migmatites of the Wanni Complex (WC) and charnockites of the Highland Complex (HC) and the Vijayan Complex (VC) and sedimentary rocks of the Pranhita-Godavari rift basin of central east India were dated for age, provenance and maximum age of deposition of sediments. The results of U-Pb zircon LaICPMS age determinations are very sound and interesting. In this study the nature of concordia plots and probability density didtribution plots is also used as a 'geochronological' method to discriminate between igneous and sedimentary protoliths of high grade metamorphic rocks, specifically leucosomes and paleosomes of migmatites of the WC and charnockites of HC and VC of Sri Lanka. The interpretation of data and results of this study has found answers not only to the knowledge gaps on understanding geological origin and paleotectonic position of the island of Sri Lanka but also about the nature and history of original sedimentary basins of WC, HC, and VC of Sri Lanka, the probable basement rock materials of WC, HC and VC, the probable protolith source areas of WC, HC and VC and Pranhita-Godavari sedimentary basins, the maximum age of deposition of sediments deposited in WC and VC shallow continental basins as well as in the deep HC basin of orogenic belt and also Pranhita-Godavari rift basin of India. The study has also answered questions such as whether the WC and HC are two different crustal domains or not as well as whether the WC-HC boundary is adequately accurate or not. When the age and sedimentary provenance data of mataquartzites of WC and HC, leucosomes and paleosomes of migmatites of WC and chharnockites of HC and VC are analyesd and interpreted as a combined analysis to find answers to current research questions and it can be described as follows.

All the metaquartzite samples of HC and near boundary WC of Sri Lanka contain clear records for a considerable Paleoproterozoic to Neoarchaean to Mesoarchaean detrital grain input into their original sedimentary constitution. The maximum age of deposition of HC metaquartzites can be approximately constrained at ~ 2000 Ma. The depositional age for the protoliths for these samples is constrained approximately between ~2000 Ma and ~550 Ma (between the youngest reliable detrital zircon grain and the age of regional metamorphism). However, one metaquartzite sample of the western WC yielded Neoproterozoic detritus and mixed with older Paleoproterozoic to Neoarchaean detritus. Existence of younger and older age mixtures in one rock indicates that WC and HC terranes existed adjacent to each other since early Neoproterozoic. The western WC shallow continental basin may have received sedimentary detritus either from the HC terrane or east African protolith sources. The WC and HC metaquartzites represent two different successions /systems of sediments deposited in two different basins. The results of age and provenance show that near boundary metaquartzites should be belonging the HC terrane. All these indicate that the current tentative WC-HC boundary which was established based on Sm-Nd model ages is not adequately accurate and the exact boundary could exist further westwards and further geochronological research is needed to accurately re-establish the WC-HC geological boundary.

When attempting to locate protolith sources for the WC and HC of Sri Lanka, the Indian sources lack Paleoproterozoic sources for the neighbouring WC and HC metaquartzies and it is suggested that protoliths to WC and HC terranes of Sri Lanka may be sourced from non-Indian sources and based on relating to available geochronological data it is interpreted that source regions of WC and HC were in east Africa.

The concordia and probability density plots of this study clearly reveal for the first time that parent materials of leucosome portions of WC migmatitic gneisses are metasedimentary. Detrital cores of leucosomes of migmatitic gneiss rock samples from WC yielded >90% concordant $^{206}Pb/^{238}U$ ages that generally range from ~700 Ma to 1150 Ma. The WC migmatitic gneisses generally show maximum age of deposition at ~700 Ma compared to the maximum age of deposition of HC to be ~2000 Ma and parent sediments for HC deposited after ca. 1900 to 2000 Ma (Amarasinghe et al. 2011) and also results of chapter 2 of this thesis. This reveals and confirms that WC and HC of Sri Lanka are two different crustal domains with different geological origins and histories. It is first time reported that the two paleosome samples show metaigneous characteristics based on a concentrated detrital point or cluster on the concordia plot and yielding Mesoarchean (2.85-3.0 Ga) concordant ages. I suggest that the paleosome portions of WC migmatitic gneisses most probably represent the Mesarchaean igneous continental crustal block type basement rock materials on which Neoproterozoic to Mesoproterozoic WC metasediments were deposited in shallow basins as indicated by the fact that metasedimentary supracrustal rocks are subordinately and dispersedly abundant in the WC compared to the HC. This also reveals that paleosome portions and leucosome parts of WC migmatitic gneisses represent two different materials of a continental block. The leucosomes of migmatitic gneisses of the WC of Sri Lanka record a mixture of predominent late Mesoproterozoic to Neoproterozoic protolith sources. I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older paleosome metaigneous Mesoarchean re-worked cratonic continental crustal basement material to form WC migmatitic gneisses and migmatites.

The detrital signatures of leucosomes of WC migmatitic gneisses best fit the combined basement ages of Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources. It further reveals that both the metasedimentary leucosome portions of migmatitic gneiss rocks and metaquartzites of western WC of of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. The WC of Sri Lanka is here interpreted as the welded and continuous terrane of the Southern Madurai Block of South India before the assembly of Gondwana. I here suggest that metasedimentary sequences of WC of Sri Lanka, metasedimentary sequences of HC of Sri Lanka, Southern Indian sequences, and Malagasy sequences represent different parts of either shallow continental sedimentary basins or deep orogenic belt basins which existed since Paleoproterozoic to late Mesoproterozoic to Neoproterozoic.

The concordia and probability density plots of this study clearly reveal for the first time that parent materials of Sri Lankan charnockites have two different geological origins. The two central HC charnockite samples clearly show metaigneous origin whilst the sample from the VC shows metasedimentary origin. The upper intercepts of two metaigneous charnockites show primary intrusive ages ~1.82 to 1.85 Ga. These intrusive ages confirm and support that the deep orogenic belt basin of HC existed since Paleoproterozoic, ~ ca. 2000 Ma. These ages are also consistent with ages of igneous intrusions to HC metasediments reported by Kröner et al. (1987). The metasedimantary charnockite sample shows deposition in the late Neoproterozoic after ~640 Ma with major detrital peaks occurring at 640 Ma, 830 Ma, and 920 Ma. The detrital signatures of the VC metasedimentary charnockite sample best fit the current basement ages (1.0 to 1.1 Ga) of the Vijayan Complex (VC) of Sri Lanka and give sedimentary provenance of VC rocks. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources. I here suggest that VC metasedimentary charnockites have derived detritus from protolith sources of central Madagascar and eastern Africa.

6.3

On the basis of the interpretation of the results of this study it is interpreted and suggested that the sediments of the HC were deposited in a deep basin and which most probably existed as a deep oceanic basin of an orogenic belt since 1.9 to 2.0 Ga (as indicated by the maximum age of deposition of HC metaquartzites in the chapter 2) and concordant and discordant intrusions of parent magmas of HC charnockitic gneisses and charnockites took place around ~ 1.85 Ga into the HC sedimentary make up in Paleoproterozoic time. The charnockitization of granitic intrusions occurred during ultra high temperature regional metamorphism to form HC charnockites.

This study reveals that the metaquartzites of HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metasedimentary (metaquartzites of western WC and leucosomes of migmatites of WC) rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. Although the HC of Sri Lanka is correlated to both Trivandrum Block and Northern Madurai Block of South India, only the Trivandrum Block shows geological similarity and similar orogenisis to the HC of Sri Lanka. It is here interpreted that HC is the south eastern continuation of the Trivandrum Block of South India in the Gondwana super continent. This study reveals that WC and HC are two different crustal domains and WC represents a continental block welded to Southern Madurai Block of South India and supracrustal HC represents an orogenic belt deep basin.

I here suggest based on the results that the paleotectonic position of Sri Lanka would be south east of South India as shown in the Fig.6.1 and the WC is interpreted to be the welded and continuous terrane of the Southern Madurai Block (SMB) of South India as well as Trivandrum Block is the continuation of HC of Sri Lanka and it is also somewhat consistent with what was suggested by Teale et al. (2011), Plavsa et al. (2014b) and Collins et al, (2014) except this study links HC to Trivandrum Block and WC to SMB. It is also here suggested that paleosome materials of WC migmatites represent the older reworked Mesoarchaean continental cratonic basement on which a thin pile of WC sedimentary succession was deposited. The study of age and provenance of metaquartzites and metasedimentary leucosomes of WC migmatitic gneisses clearly show a correlation between the WC of Sri Lanka with Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources.

The acidic, mafic, ultramafic magmatism reported in the VC of Sri Lanka is interpreted as continental arc type and similarly the Cryogenian felsic magmatism reported in the WC is also suggested as continental arc type and the Paleoproterozoic HC basement
was an oceanic crust and which had subducted underneath the welded Southern Madurai Block-WC continental block along the sutures of WC-HC boundary and HC-VC boundary marking the closure of the ancient south Mozambique ocean.

Partial melting continued up to ~ 490 Ma. I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older paleosome igneous cratonic basement materials to form WC migmatitic gneisses. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.

Sri Lanka's paleotectonic position could be south east of south India as shown in the Fig.6.1 before Gondwana being amalgamated in Ediacaran-Cambrian and the HC of Sri Lanka and Trivandrum Block of South India formed in a collisional orogeny associated with subsequent granulite facies ultra high temperature regional metamorphism during the assembly of Gondwana in the Ediacaran-Cambrian.

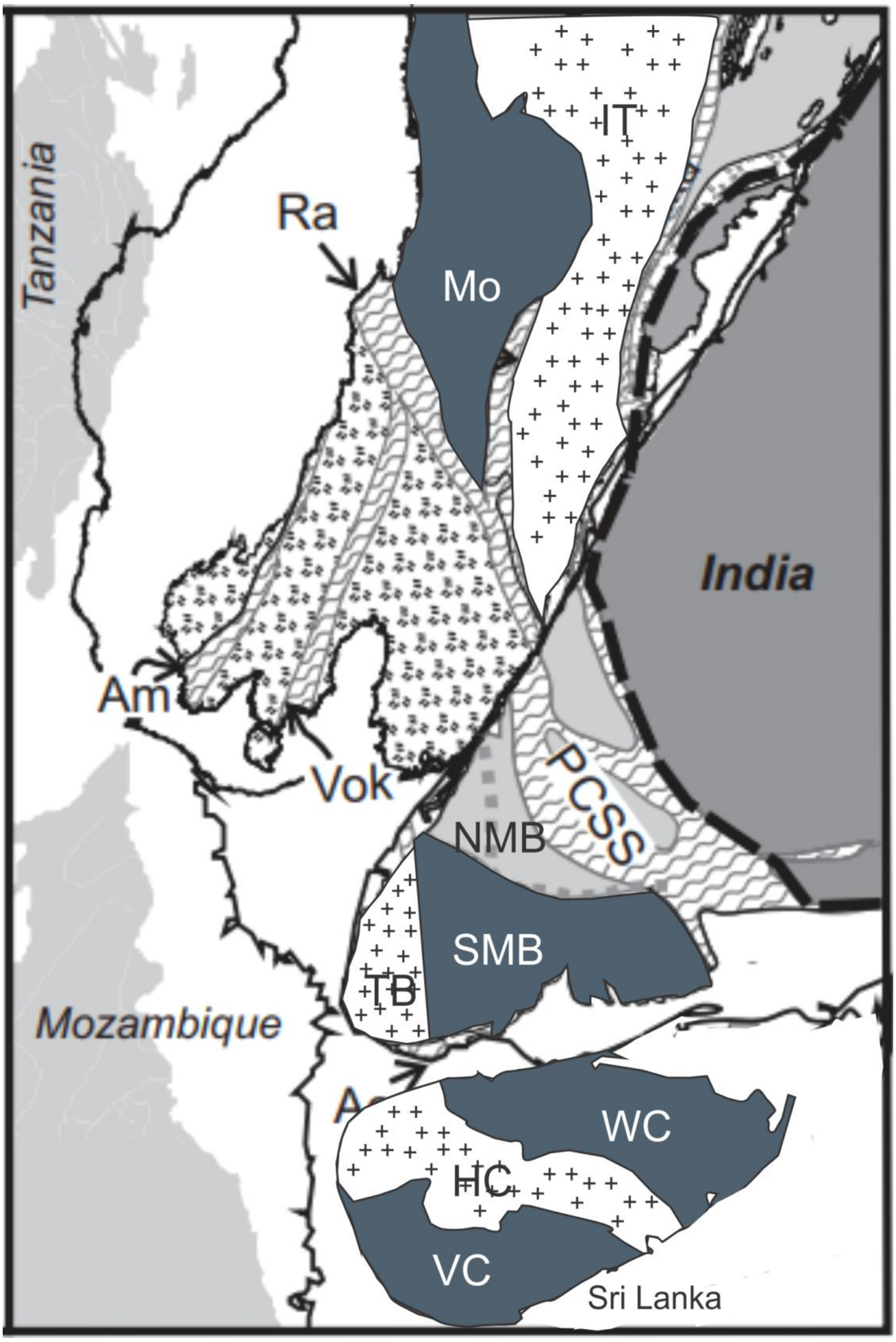

Fig.6.1 Paleotectonic position of island of Sri Lanka within Gondwana super continent determined based on age, provenance and maximum age of deposition of metasedimentary rocks (Modified after Gondwana Reconstruction, Lawver et al.1998 and Teale et al.2011). A- Archancovil shear zone; HC-Highland Complex; PCSS= Palghat-Cauvery Shear Zone System; Ra-Ranotsara shear zone; VC-Vijayan Complex; WC- Wanni Complex.

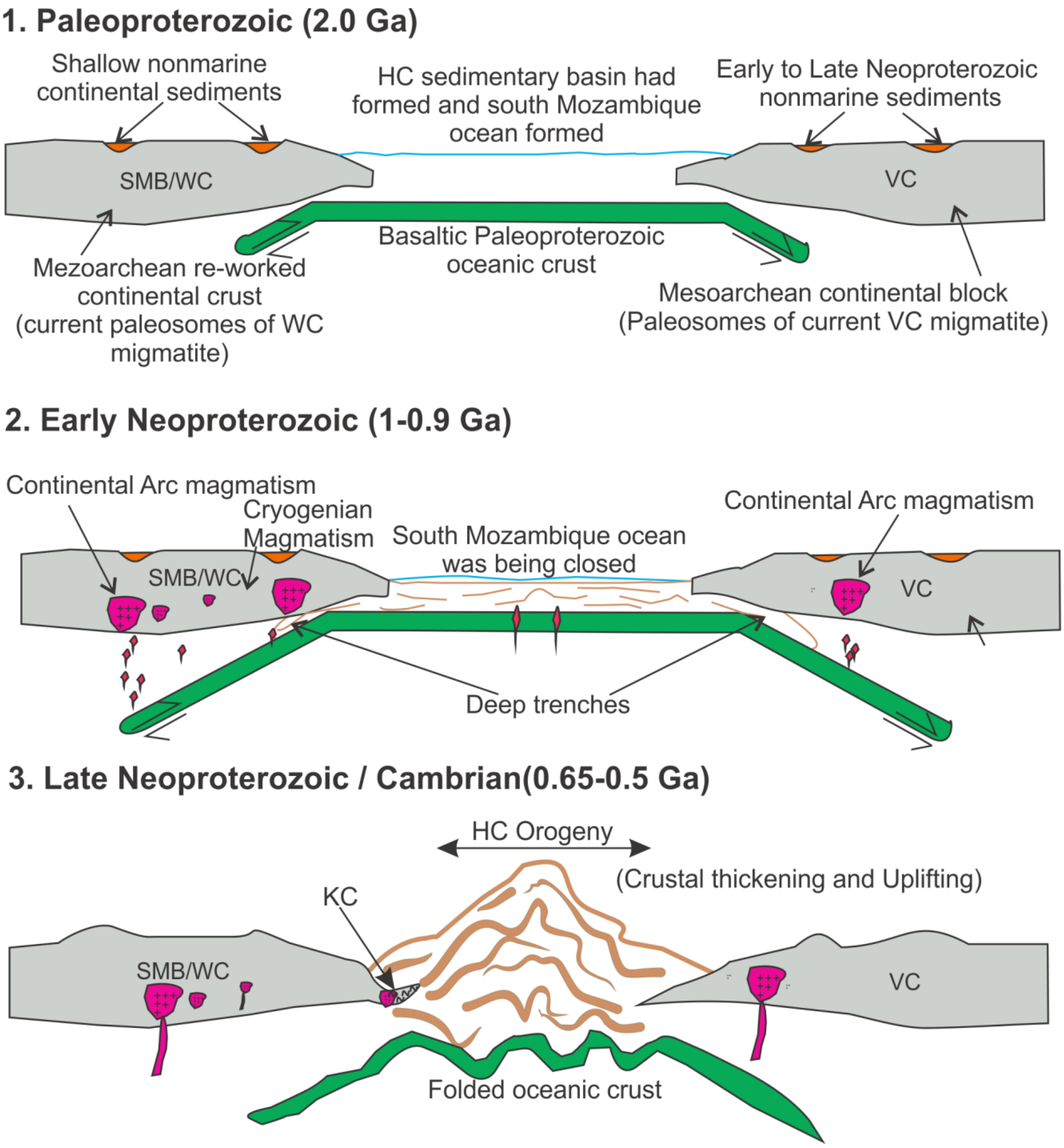

Fig.6.2 Plate tectonic cartoon model illustrating the origin of the island of Sri Lanka occurred due to double subduction of HC oceanic crust underneath WC and VC continental Blocks and collisional 'HC orogeny' and closure of south Mozambique ocean in Late Neoproterozoic to Cambrian (see text for details). KC is interpreted to have formed from ductile deformation and migmatisation of WC Mesoarchaean continental basement materials. WC- Wanni Complex, HC- Highland Complex, VC- Vijayan Complex, KC- Kadugannawa Complex SMB- Southern Madurai Block.

The field information and difference in grade of metamorphism show that HC rocks were subjected to relatively deeper burial into lower crust and greater uplifting from the lower crust level than the WC rocks during orogenesis. I suggest a 'HC orogeny" and this had taken place in late Neoproterozoic when WC and VC continental blocks had collided with the deep basin of HC orogenic belt when oceanic crust of the HC orogenic belt subducted underneath the WC and VC continental blocks to form two continental arcs (Fig.6.2). This study reveals that boundaries of WC-HC and HC-VC are suture zones alone which subduction of HC oceanic crust had taken place. I also suggest that Cryogenian magmatism in the Madurai Block of South India and Wanni Complex of Sri Lanka is interpreted to form an extensive arc magmatic province within the Southern East African

Orogen that can be traced from central Madagascar, through southern India to the Wanni Complex of Sri Lanka and this interpretation is consistent with what was suggested for Madurai Block by Teal, et al, 2011. I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Trivandrum Block and Southern Indian Madurai Block sequences, and Malagasy sequences represent different parts of either sedimentary basins of continental blocks or orogenic belt basins.

This suggestion is somewhat consistent with the paleotectonic position of Sri Lanka which was suggested by Teale et al. (2011), Plavsa et al., 2014 (b), and Collins et al 2014 (Fig.2,11). But the results of this age and provenance study pinpoint that Trivandrum Block of South India was probably the continuation of the HC of Sri Lanka and WC of Sri Lanka was the continuation of Southern Madurai Block of South India. In addition to that the Kadugannawa Complex (KC) lies close to the WC-HC boundary in the HC terrane and it is interpreted that KC was formed during the collisional orogeny of HC from basement materials of the WC (As shown in the Fig.6.2, the results of the chapter 3 show that basement materials of WC are found to be Mesoarchaean paleosomes of WC migmatites) and shallow continental sediments (as shown in chapter 3 these sediments probably became leucosome partial melts of WC migmatites) of the WC after being subject to intense ductile deformations to form KC 'arena' structures or doubly plunging synform structures. This province is interpreted to have formed above a south/west dipping subduction system as the south Mozambique ocean was subducted underneath the Neoproterozoic continent Azania (Teale et al., 2011).

This shows that the Highland Complex and Wanni Complex (WC) of Sri Lanka had been formed in two different sedimentary systems before the assembly of Gondwana. In a plate tectonic model of the origin of Sri Lanka, it is suggested that the HC of Sri Lanka was formed together with the Trivandrum Block of Southern India and Itremo Group of central Madagascar as a single orogenic mountainous terrane of the ancient micro continent Azania which was uplifted after the HC basement oceanic crust had subducted underneath the WC and VC continental blocks of Sri Lanka, Southern Madurai Block of India and Molo Group of Madagascar. The island of Sri Lanka had subsequently rotated anticlockwise after separating from the Mainland India after late Cretaceous period.

In the comparison of data and results of age, provenance and source areas of protoliths of Southern Madurai Block of India (SMB), HC and WC of Sri Lanka with those of sediments of Pranhita-Godavari rift basin of central south east India it is found that South Indian terranes and Sri Lankan terranes were sourced from east African igneous protolith sources whilst the Pranhita-Godavari rift basin was sourced from the Eastern Ghats orogen of East India and Antarctica. Based on this result is interpreted here that Southern Granulite Terrane of India and Sri Lankan terranes were not clearly parts of mainland cratonic India until the latest Neoproterozoic. Further, though it existed in the sourrounding environment, the thick sedimentary pile of Pranhita-Godavari rift basin was not deep buried and subject to high grade regional metamorphism similar to terranes of Southern Granulites of India and high grade terranes of Sri Lanka.

On a very general level this study has investigated how Sri Lanka fits into Gondwana super continent reconstructions. The ages of the detrital zircons in the metasedimentary rocks of all the geological units of Sri Lanka have been used to constrain the possible provenance that supplied the detritus. The same technique is applied to the Pranhita-Godavari basin in the heart of Peninsular India, to compare the sources in roughly coeval sedimentary basins that were separated by an ancient ocean called Mozambique Ocean. This study has also used a ‘geochronological’ method to discriminate between igneous and sedimentary protoliths of high grade metamorphic rocks, specifically charnockites of the HC and the VC and leucosomes and paleosomes of migmatites of the WC.

This study has also examined the nature of contact between the HC and the WC and about the accuracy of current WC-HC boundary, whether the WC and the HC are two distinct terranes or not, the possible nature of WC and HC sedimentary basins, what could be the possible basement materials of WC and HC basins and possible geological origin of the island of Sri Lanka during the assembly of Gondwana super continent. The above techniques have been found to be effective in determining the outcomes up to the point of understanding the possible geological origin of Sri Lanka and sampling along traverse lines is found to be the most methodological for this condition and had also helped to understand the difference between the WC and HC terranes and the accuracy of the current WC-HC boundary. What could be done in the future as further research is sampling more rock samples further westwards along the traverse lines in the western WC terrane as well as sampling further eastwards into the VC terrane to deeper understand the age and sedimentary provenance of WC and VC crustal domains. The study has proved that isotopes can be used as accurate tracers of provenance.

Chapter 7– Conclusions

On the basis of this study following conclusions can be made:

- All the metaquartzite samples of WC and HC of Sri Lanka contain clear records for a considerable Paleoproterozopic to Neoarchaean to Mesoarchaean detrital grain input into their original sedimentary constitution with the youngest <10% discordant core analyses in all the nine samples range from 1500 Ma to 2000 Ma. The maximum age of deposition of all the eight samples of near boundary WC and HC except the S814 collected at Maradankadawela can be approximately constrained at ~2000Ma. The depositional age for the protoliths for these samples is constrained approximately between ~2000Ma and ~550 Ma (between the youngest reliable detrital zircon grain and the age of regional metamorphism). However, one metaquartzite sample which was collected at Maradankadawela in the western WC yielded Neoproterozoic detritus and mixed with older Paleoproterozoic to Neoarchean detritus. It is interpreted that existence of younger and older age mixtures in one rock indicates that WC and HC terranes existed adjacent to each other in early Neoproterozoic but WC meta sediments were deposited in shallow basins of a continental block and HC metaquartzites represents a different succession of sediments deposited in a basins of an orogenic belt. It is here also suggested that the current tentative WC-HC boundary which was established based on Sm-Nd model ages is not accurate and the true boundary between the two units must be further westwards. Systematic further geological and geochronological research is needed to accurately re-establish the WC-HC geological boundary.

- The S0814, Maradankadawela (western WC) metaquartzite sample indicates that this rock derived sedimentary detritus from Paleoproterozoic to Neoarchaean sources as well as Neoproterozoic protolith sources as age mixtures. Further, the leucosomes of WC metasediments show the maximum age of deposition ~700 Ma (chapter 3) against the

- HC metaquartzites show maximum age of deposition ~ 1900 to 2000 Ma (chapter 2).This enables to make a conclusion that WC and HC of Sri Lanka are two distinct terranes or crustal domains and the WC represents of a shallow basin of a continental block and the HC represents a deep basin of an orogenic belt which existed adjacent to each other since early Neoproterozoic times. The near WC-HC boundary metaquartzites of the WC derived Paleoproterozoic to Neoarchean detritus probably from the adjacent HC terrane as well as from the east African protolith sources but deposited in the Neoproterozoic.

- When attempting to locate protolith sources for the WC and HC of Sri Lanka, the Indian sources lack Paleoproterozoic sources for the neighbouring WC and HC metaquartzites and it is suggested that protoliths to WC and HC terranes of Sri Lanka may be sourced from non-Indian sources.

- This study reveals that the metasedimentary rocks of the HC of Sri Lanka are correlated with the Trivandrum Block and Northern Madurai Block of South India and the Itremo Group of Madagascar whilst metasedimentary rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Southern Indian Madurai Block sequences, and Malagasy sequences represent either different parts of basins of different continental blocks or basins of orogenic belts. I also suggest that the Sri Lanka's paleotectonic position could be south east of south India before Gondwana being amalgamated in Ediacaran-Cambrian (Fig.2.12).It was possible to determine this paleotectonic position for Sri Lanka after interpreting the results of chapter 2 and chapter 3 because the chapter 2 has indicated that the continuation of the Trivandrum Block was the HC tarrane and the continuation of the Southern Madurai Block was the WC of Sri Lanka. My suggestion is broadly consistent with the Paleotectonic position of Sri Lanka which was suggested by Plavsa et al. (2014b), Teale et al.(2011) and Collins et al. (2014) but the HC of Sri Lanka is connected to the Trivandrum Block of South India and the Southern Madurai Block was connected to the WC of Sri Lanka.

- The field geological information and difference in grade of metamorphism show that HC rocks were subjected to relatively deeper burial into lower crust and greater uplifting from the lower crust level than the WC rocks during orogenesis. This shows that the Highland Complex and Wanni Complex were two distinct terranes which collided with each other and the island of Sri Lanka had been formed in a collisional orogeny during the assembly of Gondwana. It is interpreted that the WC sediments were deposited in shallow basins of a continental block whilst HC sediments were deposited in a deep basin of an orogenic belt. It is concluded that WC and HC are two distinct crustal domains which were welded together during Ediacaran-Cambrian due to collisional orogeny and high grade metamorphism.

- The U-Pb ages of metamorphic rims of zircon grains from both WC and HC are found to be between ~600 Ma and 550 Ma. A weighted mean of all rim data yields an age of 545.1 ± 9.7 Ma, supporting an age of Ediacaran-Cambrian metamorphism similar to that found in adjacent areas of Southern India and other Gondwanan terranes.

- The LaICPMS U-Pb zircon isotopic data from three near boundary WC metaquartzites and five HC metaquartzites demonstrate dominant Mesoarchaean to Neoarchaean to Paleoproterozoic detrital input into the metasedimentary make up and original sediments to the WC and HC metaquartzites were deposited between ~2000 Ma and 515 Ma, whereas a sample from the western WC collected at Maradankadawela (S814) was deposited in Neoproterozpoic times. This rock contains detritus with >90% concordant detrital peaks at 813.5 ± 11 Ma, 964 ±14 Ma and mixed with Paleoproterozoic to Neoarchaean detrital grains up to 2700 Ma.

- The concordia and probability density plots of this study clearly reveal for the first time that parent materials of the leucosomes of WC migmatitic gneisses are metasedimentary. Detrital cores of leucosomes of migmatitic gneiss rock samples from WC yielded >90% concordant $^{206}Pb/^{238}U$ ages that generally range from ~700 Ma to 1150Ma. The leucosomes of WC migmatitic gneisses generally show maximum age of deposition at ~700 Ma. It is first time reported that the two paleosome samples (S0804 and S0807) also show metaigneous characteristics and Mesoarchaean to Neoarchaean (2.85- 3.0 Ga) age and Paleosomes of WC migmatites have been discovered in this study to be the Mesoarchaean cratonic continental basement material of the WC shallow basins of a continental block. It is suggested that the paleosome portions of WC migmatitic gneisses probably represent the basement reworked continental crustal material on which Neoproterozoic to Mesoproterozoic WC metasediments were deposited. The two leucosome samples of migmatitic gneisses from Dombawela and Leeniwehera also show sedimentary origin and late Mesoproterozoic to Neoproterozoic provenance (1.1 to 0.65 Ga) . This also reveals that paleosome portions and leucosome parts of WC migmatitic gneisses represent two different materials. Collectively, leucosomes of the migmatitic gneisses of the WC of Sri Lanka record a mixture of predominent late Mesoproterozoic to Neoproterozoic protolith sources. The detrital signatures of leucosomes of migmatitic gneisses of WC migmatitic gneisses best fit the combined basement ages of Southern Madurai Block of India and the Molo Group of Madagascar and derivation of sedimentary detritus probably from East African protolith sources. It reveals that the metasedimentary leucosome portions of migmatitic gneiss rocks of the WC of Sri Lanka are correlated with the Southern Madurai Block of South India and the Molo Group of Madagascar. It is here suggested that metasedimentary sequences of WC of Sri Lanka, metasedimentary sequences of HC of Sri Lanka, Southern Indian sequences, and Malagasy sequences represent different parts of neighbouring basins of continental blocks or sedimentary orogenic belts. It is here suggested that the paleotectonic position of Sri Lanka would be south east of South India as described in the chapter 2 with a most probable link between the HC of Sri Lanka and the Trivandrum block of South India and it is broadly consistent with what was suggested by Plavsa et al. (2014) and Teale et al. (2011). I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older metaigneous Meoarchaean basement materials (Paleosomes) to form WC migmatitic gneisses.

- Partial melting continued up to ~490 Ma. I here suggest that during regional metamorphism the younger sedimentary succession of the WC was mainly partially melted and mixed with the older Mesoarchaean paleosome materials of cratonic re-worked continental basement to form WC migmatitic gneisses. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.

- The concordia and probability density plots of this study clearly reveal for the first time that parent materials of Sri Lankan charnockites have two different geological origins. The two central HC charnockite samples clearly show metaigneous origin whilst the sample from the VC show metasedimentary origin. The upper intercepts of two metaigneous charnockites show primary intrusion ages ~1.82 to 1.85 Ga. The metasedimantary charnockite sample shows deposition in the late Neoproterozoic after ~640 Ma with major detrital peaks occurring at 640 Ma, 830 Ma, and 920 Ma. The detrital signatures of the VC metasedimentary charnockite sample best fit the current basement ages (1.0 to 1.1 Ga) of the Vijayan Complex (VC) of Sri Lanka and give sedimentary provenance of VC rocks. It reveals that VC metasediments derived sedimentary detritus from early to late Neoprotorozoic protolith sources. I here suggest that VC metasedimentary charnockites have derived protolith sources probably from central Madagascar and eastern Africa. The metamorphic rims show that regional metamorphism occurred between 500 Ma to 550 Ma.
- The age and provenance study of sedimentary rocks of Pranhita-Godavari rift valley of India indicates that the Somanpalli Group is sourced from rocks that are consistent with those found in the Enderby Land in East Antarctica, and from the Krishna Province. They were deposited on a northward dipping palaeoslope and were deposited at ∼1620 Ma. The similarity in the maximum depositional age and the published glauconite age suggests that the Somanpalli Group was deposited in a foreland setting (similar to that suggested by Gupta, 2012) in the foreland to the coeval Krishna Province that involved the collision of Enderby Land with the Dharwar Craton (Henderson et al., 2014). The high angle of the Pranhita-Godavari Valley to the Krishna Province (Fig.5.6), suggests that the basin may have formed as a rift valley in the orogenic foreland, similar to the Rhine Valley in the foreland of the Cenozoic Alps (Şengör et al., 1978).

The Neoproterozoic (to possibly Palaeozoic) Sullavai Group represents renewed deposition in the same basin, but this time demonstrates a different source region that contains the Eastern Ghats Orogen, to the northeast. The study also reveals that the Pranhita-Godavari Basin in central eastern India was mainly sourced from both the Eastern Ghats orogen and Antarctica unlike Sri Lankan terranes were sourced from East Africa. This is probably supporting the interpretation that Southern Granulite Terrane of India and Sri Lanka were not part of mainland cratonic India until Ediacaran-Cambrian times.

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- Based on this study a platetectonic model for the geological origin of the island of Sri Lanka is suggested as follows: The age and provenance data of this study clearly reveals that WC and VC had younger and similar ages compared to the HC of Sri Lanka. HC is clearly an orogeny. In order to occur an orogeny, two adjacent crustal blocks/plates need essentially to collide and the oceanic crust of the central deep basin of an orogenic belt needs to subduct underneath the two continental crustal blocks. This interpretation is supported by occurrence of Cryogenian plutonic igneous bodies (eg., Thonigala granite, Ambagaspitiya granite) in the western WC terrane as well as occurrence of acidic, mafic to ultramafic igneous intrusive bodies in the VC of Sri Lanka indicating subduction and arc magmatitic precesses in the Neoproterozoic. It is suggested that WC and VC were two continental blocks and the HC was a deep sedimentary basin of an orogenic belt. They had come closer in the late Neoproterozoic and collided and the oceanic crust of the HC had subducted underneath the Mesoarchaean basement paleosome materials of continental blocks, the WC and VC. On the basis of results of this study it is interpreted that the WC was already welded to the Southern Madurai Block of South India prior to collide with the HC and the HC and the Trivandrum Block of South India was a single and deep basin of an orogenic belt connected to the ancient micro continent Azania which resulted in final closure of the south Mozambique ocean during Ediacaran-Cambrian. The north eastern Mozambique ocean was simultaneously closed along the suture of Palghat-Cauvery Shear Zone Systyem (PCSS) of peninsular India. To form Sri Lanka the WC and VC continental blocks with deposited shallow sediments collided with the HC-Trivandrum Block deep basin of an orogenic belt to occur a collisional orogeny (‘HC Orogeny’).

- The HC had deeper buried and metamorphosed under granulite facies PT
- conditions, The WC and VC were not deep buried and but metamorphosed under upper amphibolites facies conditions, HC subsequently was uplifted slowly in the Cambrian as an orogeny. There was a clear 'HC orogeny' during the Ediacaran-Cambrian when the Gondwana supercontinent was assembled. A part of the WC was undergone ductile deformation and penetrated into the HC along the WC-VC boundary and was intensely deformed to form the Kadugannawa Complex (KC) doubly plunging synform structures during the HC orogeny. Igneous charnockitic intrusions to the HC had taken place between 1900 Ma to 2000 Ma. WC migmatites were formed from partial melting of shallow continental sedimentary sequences and mixing with the reworked Mesoarchaean paleosome basement rock materials of the WC. The paleosome part of WC migmatites was the most probable reworked continental basement rock material on which WC sediments were deposited in the Neoproterozoic. The island of Sri Lanka had subsequently rotated anticlockwise after separating from the Mainland India after late Cretaceous period.
- I also suggest that Cryogenian magmatism in the Madurai Block of South India and Wanni Complex of Sri Lanka is interpreted to form an extensive arc magmatic province within the southern East African Orogen that can be traced from central Madagascar, through southern India to the Wanni Complex of Sri Lanka and my interpretation is consistent with that was suggested for Madurai Block by Teal, et al. (2011). I here suggest that metasedimentary sequences of WC and HC of Sri Lanka, Trivandrum Block and Southern Indian Madurai Block sequences, and Malagasy sequences represent different parts of basins of different neighbouring continental blocks or orogenic belts. Sri Lanka's paleotectonic position could be south east of south India before Gondwana being assembled in Ediacaran-Cambrian and the HC of Sri Lanka and Trivandrum Block of South India formed in a collisional orogeny as a continuous mountainous belt during the assembly of Gondwana in the Ediacaran-Cambrian. This province is also interpreted to have been formed above a south/west dipping subduction system as the south Mozambique Ocean was subducted underneath the Neoproterozoic continent Azania (Teale et al., 2011). This shows that the Highland Complex and Wanni Complex (WC) of Sri Lanka had been formed in the Neoproterozoic from distinct one continental block and

- a deep basin of an orogenic belt during the assembly of Gondwana. In the model of the origin of Sri Lanka, it is suggested that the HC of Sri Lanka was formed together with the Trivandrum Block of Southern India and Itremo Group of central Madagascar as a single orogenic mountainous terrane of the ancient micro continent Azania which was uplifted when the WC and VC of Sri Lanka, Southern Madurai Block of India and Molo Group of Madagascar collided with this belt of orogenesis along a sutures in the Mozambique ocean.

- The study of three near WC-HC boundary metaquartzite rock samples collected in the present WC terrane indicate similar age and provenance to HC of Sri Lanka. It is concluded that the current WC-HC boundary is not accurate enough as it was established based on Sm-Nd modal ages and those three WC metaquartzite samples should be belonging to the HC terrane and the true boundary between the two units must be further westward and WC-HC boundary is to be re-established based on further studies.