Proceedings of the IGCP-440 and LEGENDS International Symposium and Field Workshop on "The Role of Sri Lanka in Rodinia and Gondwana Assembly and Break-up", March-April 2003, Centenary Publication, Geological Survey & Mines Bureau, Sri Lanka, (K.V.W. Kehelpannala, Ed.) pp. 13-17

What Happened to India and Sri Lanka during the Proterozoic?

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Introduction

Most of Peninsular India and Sri Lanka expose Precambrian crust which was formed, reworked and consolidated during several major orogenic events (see review in Braun and Kriegsman, 2002). Recent geochronological data revealed that peak metamorphism in the Proterozoic part of southern India, south of the Bhavani Shear Zone, and in Sri Lanka occurred during the Pan-African orogeny c. 610 – 520 Ma ago. High-grade metamorphism reached ultra-high temperature conditions, followed by slow cooling and uplift.

The Southern Granulite Terrain (SGT) of India

The Proterozoic part of the SGT is subdivided into the Madurai Block (MB) in the north and the Kerala Khondalite Belt (KKB) in the south. The MB covers the largest portion of the SGT and represents a composite mid- to lower crustal domain, bounded to the north by the Bhavani Shear Zone. Its western part is made up of charnockites and enderbites, whereas in the lowlands to the east hornblende-biotite gneisses, quartzo-feldspathic biotite gneisses and granites predominate. Within the Kerala Khondalite Belt (KKB), three units are distinguished: the Ponmudi and Nagercoil Units in the central and southern domains; and a northern domain, here called the Achankovil Unit (AU), which displays striking differences in Nd model ages and is roughly identical with the Achankovil Shear Zone of previous authors.

In the Nagercoil Unit massive charnockite, enderbite and mafic granulite of predominantly magmatic origin constitute the dominant lithologies. The Achankovil and Ponmudi Units form the largest metasedimentary sequences of the SGT and consist predominantly of migmatitic garnet-biotite gneisses and pelitic granulites, with subordinate cordierite gneisses, marbles, quartzites and granites. After pervasive early Pan-African deformation (D_1), the high grade gneissic layering became refolded during two regionally separated phases of upright folding (D_{2a}: NNW-trending, D_{2b}: NE-trending) and was then reworked in W to WNW trending higher strain zones. In the KKB upright to inclined folds tighten northwards and become isoclinal in the AU. This lineament is characterised as a higher strain zone dominated by flattening with a reverse component (Cenki and Kriegsman, under review).

Late Archaean to Mid-Proterozoic Nd (TDM) model ages suggest that the Pan-African event in the SGT was essentially a period of crustal reworking (Bartlett *et al.*, 1998 and refs. therein). Late Archaean and Palaeoproterozoic crustal growth has been suggested on the basis of U-Pb zircon upper concordia intercept ages and single zircon evaporation ages (op. cit.; Ghosh, 1999 and refs. therein). Model ages for rocks from the Achankovil Unit range between 1.6 and 1.3 Ga (Bartlett et al., 1998 and refs. therein). Although recent geochronological studies point to a polyphase magmatic and metamorphic evolution of the SGT, the available data only allow to discriminate Palaeoproterozoic and Neoproterozoic age populations. The emplacement of alkali granitic and carbonatitic magmas between 800 Ma and 516 Ma probably represents the only important episode of Neoproterozoic crustal growth in the Southern Granulite Terrain (compilation in Rajesh and Santosh, 1996*b*; Schleicher et al., 1998; Ghosh, 1999). A U-Pb upper concordia intercept age of 987 ± 65 Ma, a Pb-Pb zircon age of 796 ± 1 Ma for (gneissic) granites and a mean $^{206}Pb/^{238}U$ SHRIMP monazite age of 791 ± 17 Ma for a khondalite sample (Ghosh, 1999) are in good agreement with the intrusion age of the Sevattur carbonatite (Schleicher et al., 1998). These data may indicate a widespread and previously unrecognized thermal and magmatic event in the SGT.

P-T estimates indicate ultra-high temperature (UHT) metamorphism and maximum pressures of 10 - 12 kbar in parts of the Kodaikanal Massif (Satish-Kumar, 2000). In the KKB a P-T gradient with systematically increasing pressures and temperatures from 5 kbar/750°C in the central part of the Ponmudi Unit up to 8 – 9 kbar/1000 °C towards the Cardamom Hills and the Nagercoil Unit is reported (Chacko et al., 1996; Nandakumar and Harley, 2000). The recognition of a final stage of isothermal decompression in both crustal domains, may be taken as evidence for their common metamorphic evolution during the Pan-African Orogeny.

Crustal Terrains of Sri Lanka

Similarities in lithology, structural style, age and degree of high-grade metamorphism have led to the suggestion that the lower crustal terrains of the SGT can be correlated with the high-grade complexes of Sri Lanka. The crystalline basement of Sri Lanka is distinguished into four units: the Highland Complex (HC), the Wanni Complex (WC), the Kadugannawa Complex (KC) and the Vijayan Complex (VC) (Cooray, 1994). The KC is now considered be part of the Wanni Complex (Kehelpannala, 1991, 1997). Among these, the Wanni and the Highland Complex seem to be the most promising to have experienced a joint tectono-metamorphic evolution with the SGT. The Highland Complex (HC) consists for about 50% of metasedimentary rocks and 50% of meta-igneous gneisses.

The Wanni Complex (WC) consists predominantly of migmatized gneisses of igneous and sedimentary parentage. Major differences with the HC are: (i) metabasic gneisses and pure marbles are virtually absent, (ii) cordierite is more abundant, and (iii) Nd model ages of 2.0-1.0 Ga (Milisenda et al., 1988; Liew et al., 1991) and intrusion ages of 790-750 Ma (Kröner and Jaeckel, 1994) to 1100 Ma - 1000 Ma (Kröner et al., 1994, 2003) are significantly younger than those in the HC (Model ages: 2 –3 Ga; U-Pb zircon ages: 3.5 Ga – 0.45 Ga). Zircon lower concordia intercepts and concordant monazite ages lie in the range 610-550 Ma in the Highland Complex, which probably reflects the time of regional high-grade metamorphism. Lower concordia intercept ages in the Wanni Complex range between 590-540 Ma (Hölzl et al., 1994; Kröner et al., 1994). Maximum pressures decrease from about 9-10 kbar in the central and eastern part of the HC, including the Kataragama outlier, to about 5-6 kbar in western Sri Lanka (Schumacher and Faulhaber 1994). The maximum temperature decreases in the same direction from about 830° to 680°C.

Discussion

The SGT of India shows abundant characteristics in common with the HC and WC of Sri Lanka. Both crustal domains consist of meta-igneous (charnockites, enderbites) and metasedimentary rocks, the latter predominantly comprising metapelites and –psammites. Nd model ages between 3.0 Ga and 2.0 Ga, together with U-Pb zircon upper concordia intercept and single zircon evaporation ages of 2.2 Ga – 1.8 Ga, indicate crustal growth during Archaean and Palaeoproterozoic times, whereas the Neoproterozoic is predominantly characterized by crustal reworking. High- to ultra-high temperature conditions during Pan-African orogeny have been deduced for both units followed by isobaric cooling from peak-metamorphic temperatures and subsequent near-isothermal decompression (Raase 1998; Kriegsman and Schumacher, 1999; Satish-Kumar, 2000; Cenki et al., 2002 and references therein). A similar pressure gradient as in the SGT is recognized in the granulites of the HC with a high-pressure (> 9 kbar) domain in its central part and a significant drop down to 5 – 6 kbar towards the southwestern edge (Schumacher and Faulhaber, 1994). This suggests that (parts of) the Madurai Block can be correlated with the high-pressure domains of the HC while the southwestern part of the HC may be linked with the Ponmudi and Nagercoil Units of the KKB.

Strongly migmatitic cordierite-garnet-(orthopyroxene-)gneisses are abundant in the northwestern Achankovil Unit and display similar textural and compositional features as their counterparts in southwestern Sri Lanka. Mesoproterozoic Nd model ages (1.6 – 1.3 Ga) in these and other rocks from the AU may point to a genetic relationship with the WC. Yet, unless more petrological, isotope and geochronological data are available, such interpretations must remain speculative.

The Rodinia Connection

U-Pb zircon ages of 2.30 Ga – 1.85 Ga and 0.61 Ga – 0.55 Ga in rocks of the HC of Sri Lanka record Palaeoproterozoic sediment provenance and/or magmatism as well as Pan-African high-grade metamorphism and associated magmatism (Hölzl et al., 1994), respecttively. This age distribution is identical with that of the SGT (2.50 Ga - 1.85 Ga and 0.61 Ga – 0.52 Ga) and indicates that both complexes formed part of the East African Orogen. Several Grenville-ages have recently been reported from the SGT (Ghosh, 1999; Santosh et al., 2003) which could be related to orogenic processes during the formation and break-up of Rodinia.

The Southern Granulite Terrain and Sri Lanka in the Gondwana Context

Sri Lanka is commonly shown juxtaposed to the Lützow-Holm Bay in a more northerly position with respect to southern India than at present (e.g., Kriegsman, 1995; Fitzsimons, 2000; Collins and Windley, 2002). U-Pb zircon crystallization ages of orthogneisses from the Vijayan and the Wanni Complexes between 1100 Ma and 1000 Ma (Hölzl et al., 1994; Kröner et al., 1994; Kröner and Jäckel, 1994; Kröner et al., 2003) correspond with published data from the Maud province (compilation in Fitzsimons 2000) and thus would imply that these two complexes of Sri Lanka formed part of west Gondwana. Ages between 790 Ma and 770 Ma (Hölzl et al., 1994), recognized in orthogneisses of the Wanni Complex, represent a stage of early Pan-African magmatism, possibly related to extensional tectonics. As Kröner (2001) reports subduction-related magmatism in the Mozambique Belt in this time interval, the Wanni Complex could represent a coeval back-arc basin. Similar ages have been recently obtained from alkali rocks and carbonatites from the northeastern part of the SGT (~800 Ma; Schleicher et al.,

1998) as well as from granitic gneisses and (alkali) granites of the Madurai Block (770 – 570 Ma; compilation in Rajesh and Santosh, 1996*b*; Ghosh, 1999).

Kröner et al. (2000) used the absence of early and middle Neoproterozoic ages (820–640 Ma) in the SGT, which are widespread in central Madagascar (Kröner et al., 2000), as main argument against a link between the Proterozoic parts of Madagascar and southern India. However, further studies could very well reveal the occurrence of a widespread early Neoproterozoic event in southern India. Recently, chemical dating of zircon and monazite from rocks along a N-S traverse through the Proterozoic part of the SGT yielded abundant ages between 1.0–0.8 Ga and could serve as an additional argument for a Grenvillian imprint in the Madurai Block (Santosh et al., 2003). The relevance of these data, however, has to be tested by U-Pb dating.

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