GEO India 2018

PaperID **AU391**

Author **Piyush Gupta , Oil and Natural Gas Corporation Ltd , India**

Co-Authors **S. S. Rathore, G. C. Uniyal**

Multi-isotope dating of basement rocks from Cauvery Basin: Implication to crustal evolution of Peninsular India

Abstract

The Precambrian gneissic basement encountered in the drilled wells of Onshore and Offshore Cauvery Basin has provided a unique opportunity to investigate their crustal evolution, through multi-isotope dating. Basement core samples of 05 wells in the Cauvery Basin have been dated through Rubidium–Strontium and Samarium–Neodymium dating techniques, which yielded Early to Mid Paleoproterozoic (2.3–2.1 Ga) ages for the basement in the northern part of the basin, and Late Mesoproterozoic (1.1 Ga) age for the basement in the southern part. The obtained ages are in agreement with the reported ages in the Madurai Block and point towards the presence of two crustal provinces (North and South Madurai Blocks) with substantially different crustal growth ages and tectonic histories within the Cauvery Basin, which is also evident from their crustal evolution paths based on Nd–Model ages. The geochronological constraints for the eastern extremity of Madurai Block (Cauvery Basin) established in this study, along with the previously reported ages have significant tectonic implications for the amalgamation of Gondwana with respect to the Peninsular India and also point towards the presence of a tectonic-isotopic boundary separating Northern Madurai Block from the Southern Madurai Block in the basement of Cauvery Basin.

Introduction

Cauvery Basin is a peri-cratonic basin extending over 50,000 km^2 both onland and offshore up to 2000 m bathymetry with more than 6000 m pile of sediments belonging to Permian to recent age. The basin is located on the eastern extremity of the Southern Granulite Terrain and was formed as a result of fragmentation of the Gondwanaland during drifting of India–Sri Lanka landmass away from Antarctica/Australia continental plate in Late Jurassic/Early Cretaceous time. The basin is a proven Category-I petroliferous basin with several small oil and gas fields.

The basement of the basin, which is predominantly composed of the Precambrian rocks of Dharwars, Peninsular Granitic Gneiss and charnockites/khondalites of Madurai Block of Southern Granulite Terrain (SGT) (Meert et al., 2010), still remains unscathed in terms of its geochronological constraint and crustal evolutional history. The SGT is effectively constituted of polydeformed, poly-metamorphosed (Santosh et al., 2006; Teale et al., 2011; Plavsa et al., 2015, Bhutani et al., 2007) and exhumed granulite facies lower-crustal rocks e.g. charnockites, khondalites and other high-grade metamorphic rocks with intrusions of granitic rocks (Ravindra Kumar, 2005). Genetically SGT is believed to have been formed by the accretion of number of high-grade metamorphic blocks (Meert et al., 2010). The geological history of the Cauvery Basin began with the rejuvenation of rifting, i.e., creation of a new rift basin during Late Jurassic and Early Cretaceous times. The initial rifting caused the formation of NE-SW horst-graben features. As a result, it is configured morphologically into six half-graben blocks trending in NE-SW separated by horsts (Nagendra and Reddy, 2017).

In this paper, we attempt to resolve the geochronological constraints of the eastern part of Madurai Block encountered in the basement of Cauvery Basin and establish a genetic linkage of the crustal domain with the rest of Southern Granulite Terrain through Rb-Sr and Sm-Nd dating.

Materials and Methods

The basement samples from 04 onshore wells i.e. Kattimedu–A, Narimanam–M, Mattur-H and Mattur-I and one offshore well PH–M–A were taken up for the study (Fig. 1). From the bulk samples, about 100 g of homogenized samples were taken and powdered to less than 75 microns. For the Rb–Sr and Sm–Nd isotope studies, about 100 mg of whole-rock samples were precisely weighed in Teflon® beakers and a mixture of double-distilled HF + HNO_3 + $HClO_4$ was added to the beakers. For isotope dilution technique, known quantity of pre-calibrated isotope tracer solution (mixed Rb–Sr and Sm–Nd spike solutions) were added to the mixture.

The samples were digested in high pressure steel bombs at a temperature of 150°C for about >24 hours. Subsequently, the samples were dried on hot plate and second round of acid treatment was done with mixure of HNO_3+HCl to obtain clear solutions. The final solutions were then made in 2N HCl. The sample aliquots were passed through ion exchange columns. The Rb and Sr were eluted with 2.5N HCl whereas the REE were eluted in 6N HCl. The REE were then passed through secondary ion exchange columns for separation of Sm and Nd fractions.

The isotopic analysis Rb, Sr, Sm and Nd was carried out on Thermal Ionization Mass Spectrometer (TIMS) as per in-house procedure (Rathore et al., 2010). The measured Sr and Nd isotopic ratios were normalized to the values of 0.1194 ($^{86}Sr/^{88}Sr$) and 0.7219 ($^{146}Nd/^{144}Nd$), respectively. During the analyses, the reference standards i.e. SRM-987 for Sr and JNDi for Nd were analysed to monitor the stability and accuracy of the measurements.

Results

The petrographic study indicates hornblende gneiss to be the most common basement lithology, encountered in 03 wells, Kattimedu–A, Narimanam–M and PH–M–A, and chlorite-biotite-schist and garnet-biotite schist in other two studied wells, Mattur-H and Mattur-I, respectively. The results of Rb–Sr and Sm–Nd whole-rock and minerals geochronology have been summarized in Table 1 and Fig. 2:

Nd Isotopic ratios and model ages

A neodymium model age is an estimate of the age of "crustal formation" which represents the time when the crustal block was first created by mantle-derived magmatism. The calculated Nd model ages effectively provide a simplistic estimate of the time a sample (= proxy for the crust in a region) has been separated from its (modelled) mantle source, typically depleted mantle. This approach is most useful for magmatic rocks, especially felsic magmatic rocks, but has been used for all rock types (McCulloch and Wasserburg, 1978).

In the present study, the Rb-Sr and Sm-Nd isochrones have defined protolith ages in two major groups, viz., ~2200–2300 Ma and ~1150 Ma. Further, the Rb-Sr whole rock-mineral (biotite) ages yielded from three wells fall in the geological age bracket of ~450–500 Ma, which suggests the isotopic re-equilibration/ re-setting during the metamorphic episode at ~500 Ma. The Nd isotopic ratios were calculated at the protolith ages, i.e. ~2200–2300 Ma and ~1150 Ma, and at the metamorphic resetting at ~500 Ma, for respective locations (Fig. 3).

The $\varepsilon Nd_{(t)}$ values calculated from the older protolith of hornblende gneiss (t=2200–2300) studied from well Kattimedu-A and Narimanam-M fall in the narrow range of –1.4 to –9.5. The $\varepsilon Nd_{(t)}$ values of the schists calculated at t=2190 (wells Mattur-H and Mattur-I) are more towards positive, being –2.5 to +6.9, with exception of two samples (–8.8 and –11.1). The hornblende gneiss with younger protolith age (well PH-M-A) yield positive $\varepsilon Nd_{(t)}$ values (t=1143) and lie in the narrow range of +0.3 to +4.1. When calculated at the metamorphic resetting age (t=450), the $\varepsilon Nd_{(t)}$ values of the studied samples range from –30.5 to –20.7 (Fig. 3).

The depleted mantle model ages (T_{DM}) for the older hornblende gneisses range from 2.6 to 3.3 Ga, while those of the schists range from 2.0 to 3.4 Ga. The T_{DM} of the younger hornblende gneiss, however, exhibit narrower range of 1.3 to 1.5 Ga, which is substantially younger compared to other samples. Evolution of Nd isotope ratios with time, starting from the separation of source material from the depleted mantle, also indicates that the younger gneisses had a different path, compared to the evolution paths of the older hornblende gneisses and schists, the paths of which are overlapping in nature and point towards a common source in the mantle reservoir (Fig. 3).

Discussions

Hornblende gneisses and biotite schists studied from the basement cores of wells situated towards the north (Wells Kattimedu-A, Narimanam-13 and Mattur-I) have provided the protolith ages of 2173±91 Ma, 2307±63 Ma and 2190±98 Ma, respectively. The offshore well towards the south (well PH-M-A), on the other hand, has yielded the emplacement age of 1143±29 Ma, which is significantly younger compared to the other locations (Fig. 4).

Table 1. Results obtained from the Multi-isotopic (Rb–Sr and Sm–Nd) dating of drilled core samples.

Sl. No.	Well	Structure	Core Depth (m)	Lithology	Crystallization ages obtained (Ma)	Metamorphic ages obtained (Ma)
1	Kattimedu-A	Nagapattinam Sub-basin	2593-2595.25	Hornblende gneiss	2173±91 (Rb-Sr)	443±29 (Rb-Sr WR+ minerals)

3	MTR-H	Kumbakonam Ridge	2102.5-2105	Granite gneiss, Chlorite schist	-	487±9 (Rb-Sr WR+ minerals)
4	MTR-I	Kumbakonam Ridge	1700-1703	Garnet biotite gneiss	2190±98 (Rb-Sr)	457±16 (Rb-Sr WR+ minerals)
5	NRM-M	Karaikal High	2227.5-2229.7	Hornblende gneiss	2307±63 (Sm-Nd)	-
6	PH-M-A	Ramnad Palk Sub-basin	3386-3389	Hornblende gneiss	1143±29 (Rb-Sr)	-

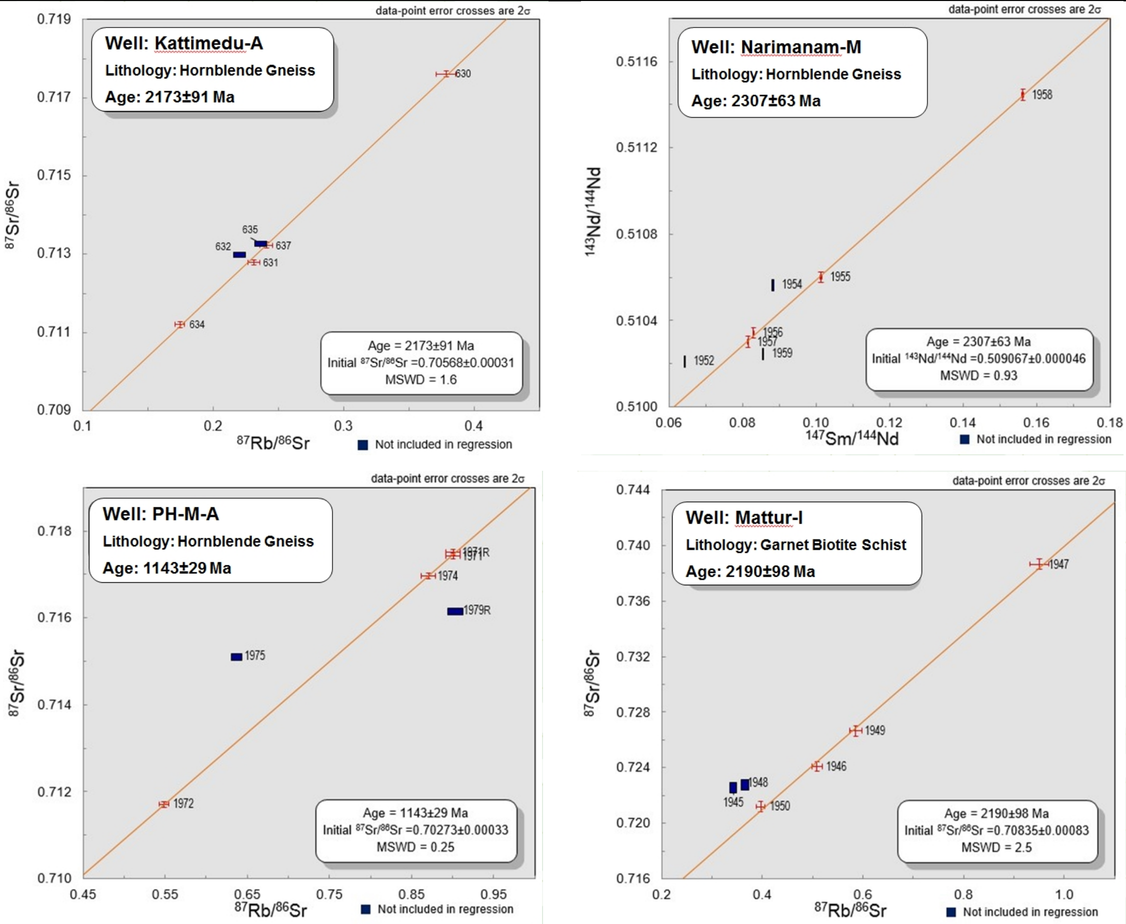

Fig. 2: Rb–Sr and Sm–Nd Whole-rock isochron ages from studied wells of Cauvery Basin

Previous studies have reported Paleoarchaean to Paleoproterozoic ages from the Northern Madurai Block, and Mesoproterozoic to Neoproterozoic ages from the Southern Madurai Block (Collins et al., 2007; Teale et al., 2011; Plavsa et al., 2012; Li et al., 2017).

Plavsa et al. (2014) reported Archean to Paleoproterozoic (3.2–1.7 Ga) zircons in metasedimentary rocks from the northern part of Madurai Block whereas zircons from the southern part of the Madurai Block in their study show Mesoproterozoic to Neoproterozoic provenance (1.1–0.65 Ga, with major peak at ca.1.02, 0.95, 0.78, 0.74, 0.67 Ga). Plavsa et al. (2012) reported crystallization ages of charnockites at 2689±26 Ma and 2521±13 Ma from the north of the Madurai Block (either close to, or north and west of the KKPT).

Mesoproterozoic to Neoproterozoic crystallization ages of 1007±23 Ma for orthopyroxene-garnet-bearing granitic gneiss, and 798±22 Ma and 781±8 Ma for charnockites, was also reported from the southeast of the Madurai Block without any evidence of older Archaean protoliths (Plavsa et al., 2012). Collins et al. (2007) reported similar detrital population (ca. 2700, 2260, 2100, 1997 Ma) from the Madurai Block. These data show similar age distribution with those from our studied samples in the Eastern part of Madurai Block.

These results strongly suggest the presence of two crustal provinces (North and South Madurai Blocks) with substantially different crustal growth ages and tectonic histories within the Madurai Block. By contrast, the metasedimentary rocks of the Madurai Block have shown a premoninantly Archean to Paleoproterozoic provenance (3.2–1.7 Ga) in the northern part of the Madurai Block and a largely late Mesoproterozoic to Neoproterozoic provenance (1.1–0.65 Ga) in the southern part of the Madurai

Block (Plavsa et al., 2014), which also holds for the eastern extremity of Madurai Block buried under the Phanerozoics of Cauvery Basin fill, as evident from the Rb-Sr and Sm-Nd ages in the study area (Fig. 4).

The evidence of two different crustal sources in the studied eastern part of Madurai Block is also exhibited by the Nd isotope evolution through time for the studied hornblende gneisses and biotite schists (Fig. 3) as the Nd evolution path for the younger gneisses (well PH-M-A) is significantly different from the older gneisses and schists (Wells Kattimedu-A, Narimanam-M, Mattur-H and Mattur-I). A crustal source with a longer residence time is also reflected in depleted mantle model ages (TDM) of 2.0–3.5 Ga of the studied gneisses and schists in the northern part of the studied area, as compared with ~1.5 Ga TDM calculated in the south.

The demarcation between the two crustal provinces have been represented as an isotopic boundary proposed by Plavsa et al. (2012), dividing the North and South Madurai Blocks on the basis of Sm-Nd WR and U-Pb age data as well as crustal residence ages, and is defined as a broad zone south of the Karur-Kambam-Painavu-Trichur (KKPT) lineament, appearing as a southerly dipping series of seismic reflectors (Rajendra Prasad et al., 2007) (Fig. 5a). Similar E-W oriented shear zones have also been observed in the basement of Cauvery Basin occurring as individual bands of 250m to 400m thick, continuous from the basin boundary to offshore causing intense fracturing near basement top, based on morphotectonics, field data, GIS-based image analysis and collateral seismic data (Mazumder et al., 2015) (Fig. 5b). These observed shear zones can be interpreted as the eastward continuation of the5delineation between northern and southern Madurai Blocks, in the basement of Cauvery Basin.

The findings of this study, along with the previously reported ages have significant tectonic implications for the amalgamation of Gondwana, as Peninsular India was located at the central domain of Gondwana assembly surrounded by Madagascar, Africa, Sri Lanka, East Antarctica and Australia (Collins et al., 2014). The similarity of northern Madurai Block metasedimentary rocks with those of the Trivendrum Block (Collins et al., 2007), Itremo Group in central Madagascar (Cox et al., 1998, 2004), Androyen and Graphite Groups in southeast Madagascar (Collins et al., 2012), and also the Highland Complex in Sri Lanka (Kröner et al., 1987) have suggested a common source region of these terranes. Further, Plavsa et al. (2014) proposed that these terranes represent a Paleoproterozoic depositional sequence on the eastern margin of the Congo-Tanzania-Bangweulu Block (Fig. 6 of Plavsa et al., 2014).

Conclusions

The Rb–Sr and Sm–Nd whole-rock and mineral dating of basement rocks from the Cauvery Basin, coupled with previously reported geochronological data, suggest the presence of two different crustal sources in the studied eastern part of Madurai Block. This observation has been substantiated with Nd-evolution data through time, which reflected a longer residence time in depleted mantle model ages (2.0– 3.5 Ga) for the studied gneisses and schists in the northern part of study area, as compared with the younger ~1.5 Ga model ages calculated in the southern part of the basement in the Cauvery Basin.

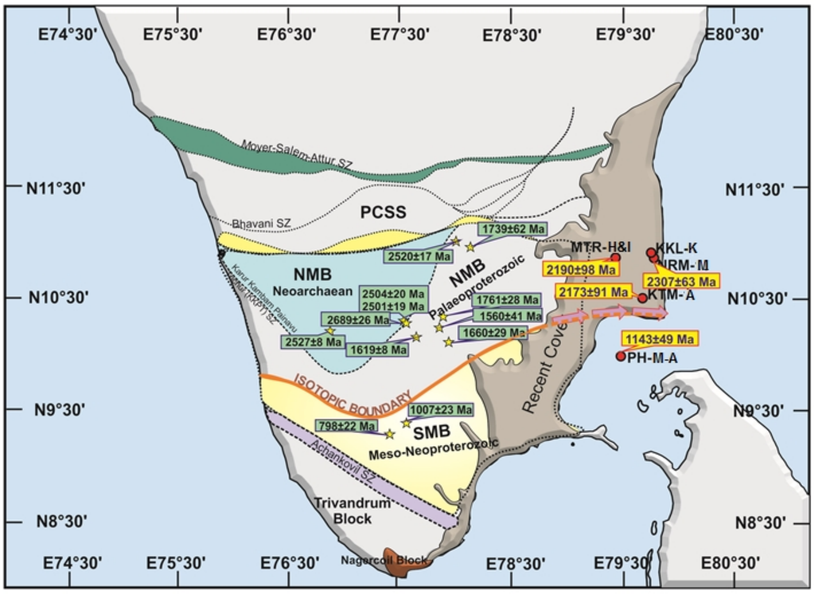

Fig.4: Obtained ages and extension of the proposed isotopic boundary (Plavsa et al., 2012) dividing North and South Madurai Block in the alluvium covered area towards further east

Fig. 5: (a) Block diagram showing seismic profile across the proposed isotopic boundary (Rajendra Prasad et al., 2007) (b) Structural highs at basement level (SH) correlating with surface geomorphic highs (GH), associated with E-W trending faults in the basement of Cauvery Basin (Mazumder et al., 2015)

The study of basement in the Cauvery Basin, which represents the eastern extremity of Madurai Block, has brought out new emplacement and metamorphic ages of the unexposed study area for the first time. These Rb-Sr and Sm-Nd ages, along with the depleted mantle Nd model ages, have largely improved the understanding of crustal evolution of North and South Madurai Blocks in the eastern part of the domain in the Southern Granulite Terrain of Peninsular India.

Acknowledgements

The authors thank Dr. Harilal, ED-HOI-KDMIPE for his permission to present the paper in the conference. We thank Shri Shekhar Srivastava, GM-Head, Geology for useful suggestions which have improved the manuscript. The views ex **a** sed in the paper are tho **b** f the authors and not necessarily of the organization they belong to.

References

Bhutani, R., Balakrishnan, S., Nevin, C. G. and Jeyabal, S., 2007, Sm-Nd isochron ages from Southern Granulite Terrain, South India: Age of protolith and metamorphism: Geochimica et Cosmochimica Acta, v. 71(15), pp. A89-A89.

Collins, A.S., Clark, C., and Plavsa, D., 2014, Peninsular India in Gondwana: The tectonothermal evolution of the Southern Granulite Terrain and its Gondwanan counter parts: Gondwana Research, v. 25, pp. 190–203.

Collins, A.S., Kinny, P.D., and Razakamanana, T., 2012, Depositional age, provenance and metamorphic age of metasedimentary rocks from southern Madagascar: Gondwana Research, v. 21, pp. 353–361.

Collins, A.S., Santosh, M., Braun, I., and Clark, C., 2007, Age and sedimentary provenance of the Southern Granulites, South India: U-Th-Pb SHRIMP secondary ion mass spectrometry: Precambrian Research, v. 155, pp. 125–138.

Cox, R., Armstrong, R.A., Ashwal, L.D., 1998, Sedimentology, geochronology and provenance of the Proterozoic Itremo Group, central Masagascar, and implications for pre-Gondwana palaeogeography, Journal of Geological Society, London, v. 155, pp. 1009-1024.

Cox, R., Coleman, D.S., Chokel, C.B., DeOreo, S.B., Collins, A.S., Kröner, A., De Waele, B., 2004, Proterozoic tectonostratigraphy and paleogeography of central Madagascar derived from detrital zircon U-Pb age populations, Journal of Geology, v. 112, pp. 379-400.

Directorate General of Hydrocarbon, Sedimentary Basins and categories: Cauvery Basin, http://www.dghindia.org

Kröner, A., Williams, I.S., Compston, W., Baur, N., Vithanage, P.W., Perera, L.R.K., 1987, Zircon ion microprobe dating of high grade rocks in Sri Lanka. Journal of Geology, v. 95, pp. 775-791.

Li, S. S., Santosh, M., Indu, G., Shaji, E. and Tsunogae, T., 2017, Detrital zircon geochronology of quartzites from the southern Madurai Block, India: Implications for Gondwana reconstruction, *Geoscience Frontier,* v. **8,** pp. 851-867.

Mazumder, S., Tep, B. and Pangtey, K. K. S., 2015, A remote sensing and GIS based integrated approach for identifying promising areas for basement exploration in Cauvery Basin, SPG-Jaipur-2015.

Meert, J.G., Pandit, M.K., Pradhan, V.R., Banks, J., Sirianni, R., Stroud, M., Newstead, B., and Gifford, J., 2010, Precambrian crustal evolution of Peninsular India: A 3.0 billion year odyssey: Journal of Asian Earth Sciences, v. 39, p. pp. 483–515.

Nagendra R. and Reddy A. N., 2017,Major geologic events of the Cauvery Basin, India and their correlation with global signatures A review, Journal of Palaeogeography, v. 6(1), pp. 69-83

Plavsa, D., Collins, A.S., Foden, J.F., Kropinski, L., Santosh, M., Chetty, T.R.K., Clark, C., 2012, Delineating crustal domains in Peninsular India: age and chemistry of orthopyroxene- bearing felsic gneisses in the Madurai Block, Precambrian Research, v. 198-199, pp. 77-93.

Plavsa, D., Collins, A.S., Payne, J.L., Foden, J., Clark, C., Santosh, M., 2015, The evolution of a Gondwanan collisional orogeny: a structural and geochronological appraisal from the Southern Granulite Terrane, South India, Tectonics, v. 34, pp. 820-857.

Rajendra Prasad, B., Kesava Rao, G., Mall, D.M., Koteswara Rao, P., Raju, S., Reddy, M.S., Rao, G.S.P., Sridher, V., Prasad, A.S.S.S.R.S., 2007, Tectonic implications of seismic reflectivity pattern observed over the Precambrian Southern Granulite Terrain, India, Precambrian Research, v. 153 (1–2), pp. 1–10.

Rathore, S.S., Rajeev Kumar, Uniyal, G.C. and Bansal M., 2010, Establishment of Ultra Clean Chemistry Laboratory, Standardization of Rb-Sr columns, Commissioning/Installation of new Thermal Ionization Mass Spectrometer (TIMS) and Standardization of spikes, Unpub. ONGC Report.

Ravindra Kumar, G. R., 2005, Lithology and Metamorphic Evolution of Granulite-Facies Segments of Kerala, Southern India, Journal of Geological Society of India, V. 66, pp. 253-254

Santosh, M., Morimoto, T., Tsutsumi, Y., 2006, Geochronology of the khondalite belt of Trivandrum Block, southern India: electron probe ages and implications for Gondwana tectonics, Gondwana Research, v. 9, pp. 261-278.

Teale, W., Collins, A.S., Foden, J., Payne, J.L., Plavsa, D., Chetty, T.R.K., Santosh, M., Fanning, M., 2011, Cryogenian (~830 Ma) mafic magmatism and metamorphism in the northern Madurai Block, southern India: a magmatic link between Sri Lanka and Madagascar? Journal of Asian Earth Sciences, v. 42, pp. 223-233.