GEO India 2018

PaperID **AU288**

Author **shakti singh rathore , oil& natural gas corp. ltd (ONGC) , India**

Co-Authors **Piyush Gupta and G. C. Uniyal**

Geochronological and genetic constraints of Mannar Volcanics, Cauvery Basin, India

Abstract

The Gulf of Mannar Sub-Basin of the Cauvery Basin has witnessed several volcanic activities in the form of doleritic intrusives within the Lower and Upper Cretaceous sediments, which have been reported in almost all the drilled wells in the Sub-Basin, both towards the Indian side as well as the Sri Lankan side. Furthermore, several Late Cretaceous mafic dykes have been reported from Huliyardurga, Karnataka and two regional dykes from, Kerala region of South-western India, along with the volcanics from St. Mary Islands and SE and SW Madagascar, which bear petrogenetic linkage with the reported intrusive activity in the Mannar Sub-Basin. In this paper, geochronological and genetic constraints have been established for the doleritic intrusives, through $^{40}Ar–^{39}Ar$ dating of core samples from well GM-E-A, and Sr-Nd isotopic correlation of dolerites encountered in other wells in the sub-basin with reported volcanic activity in the subcontinent during the Late Cretaceous. The study has brought out the $^{40}Ar–^{39}Ar$ emplacement age of 89.1±0.6 Ma for the dolerites encountered in well GM-E-A, which along with Sr-Nd isotopic signatures of other studied core and cutting samples, establishes their geochronological and genetic linkage with the Marion hotspot activity ~90 Ma, making them direct manifestations of India-Madagascar separation during Upper Cretaceous.

Introduction

The evolution of any sedimentary basin is closely interlinked with global tectonics. Identification of various thermo-tectonic episodes, therefore, is of paramount importance in the formation of a comprehensive basin evolutionary model. Since geochemical and isotopic characteristics of the basement as well as intrusive rocks provide the fingerprints of various paleogeological processes associated with the basin formation and evolution, it is necessary to carry out in detail the multi-isotopic geochronological and geochemical studies of these rocks.

Gulf of Mannar Sub-Basin constitutes the south eastern offshore part of Cauvery Basin, the southern most of the Mesozoic rift basins along the east coast of India. Late Jurassic fragmentation of eastern Gondwanaland into India, Antarctica, and Australia had initiated the formation of Mesozoic rift basins on the eastern continental margin of India including Cauvery Basin (Rana et al., 2008; Rao et al., 2010; Premarathne et al., 2013). Numerous deep extensional faults developed in NE-SW direction during rifting had initiated active subsidence that resulted in the formation of graben and horst blocks which subdivided the Cauvery Basin into many sub-basins including Gulf of Mannar (Rao et al., 2010).

In Cauvery Basin, the Mannar Sub-Basin, which is the southern-most of the Mesozoic rift basins existing along the eastern continental margin of India and lying between Indian coast and Sri Lanka, has witnessed several volcanic activities in the form of doleritic intrusives within the Turonian sediments. These are seen in almost all the drilled wells in the Gulf of Mannar, both towards the Indian side as well as the Sri Lankan side, but have not been reported from any of the other sub-basins of Cauvery Basin.

Bearing an important possible significance related to the break-up of Greater India and Madagascar, core/cutting samples of these doleritic intrusives encountered in the drilled wells of Mannar Sub-Basin have been taken up for the $^{40}Ar–^{39}Ar$ age dating and Sr–Nd isotopic characterization study, with the objective to establish their geochronological constraint, as well as investigate their petrogenesis and source, to establish a possible linkage of these emplacements with known thermo-tectonic episodes prevailing in the vicinity of the subcontinent during the Cretaceous period.

Geological History

The Cauvery Basin covers an area of 150,000 sq. km comprising onland 25,000 sq. km and shallow offshore areas 30,000 sq. km. In addition, there is about 95,000 sq. km of deep-water offshore areas in the Cauvery Basin. The Cauvery Basin is a pericratonic rift basin, under category I and is divided into a number of sub-parallel horsts and grabens, trending in a general NE-SW direction. It is bounded on the west by the Western Ghats, on the east and south by the Eastern Ghats and on the north by the ridges separating it from the Tungabhadra (Krishna) and Pennar Basins (Source: DGH India).

Mannar sub-basin of the Cauvery Basin is the southern-most of the Mesozoic rift basins existing along eastern continental margin of India and lies between Indian coast and Sri Lanka. Initial rifting in the Cauvery Basin took place during lower Mid-Cretaceous (Pre-Albian and Albian) and led to the establishment of NNE-SSW trending horst-graben architecture (Rao et al., 2010; Rana et al., 2008).

However, the horst and graben tectonics, so characteristic of the Cauvery Basin is absent in Gulf of Mannar and the entire basin had remained a broad graben throughout its history between the outcropping Sri Lanka and Indian Peninsular massifs. Baillie et al. (2003) has suggested the Mannar Basin to have been developed during, at least, two periods of rifting and associated continental breakup as part of the multiphase breakup of Gondwana during the Mesozoic. Due to similarities in origin, geological structure and stratigraphy, Baillie et al. (2003), Rao et al. (2010) and Premarathne (2011), have considered it to be a sub basin of the Cauvery Basin.

Curray (1984) opined that the first rifting between India, Sri Lanka and Antarctica occurred through the Cauvery–Palk Strait–Gulf of Mannar zone but this rift did not progress into the sea floor spreading stage. Instead, the break occurred between Sri Lanka and Antarctica, as a result the Cauvery – Palk Strait – Gulf of Mannar Basin became a failed rift or aulacogen of Late Jurassic to Early Cretaceous age. It appears that during the beginning of the Late Cretaceous, active tectonism was prevalent in the Cauvery Basin with subsidence all over the basin. This was accompanied by extensive lava flows and igneous activity (Curray, 1984).

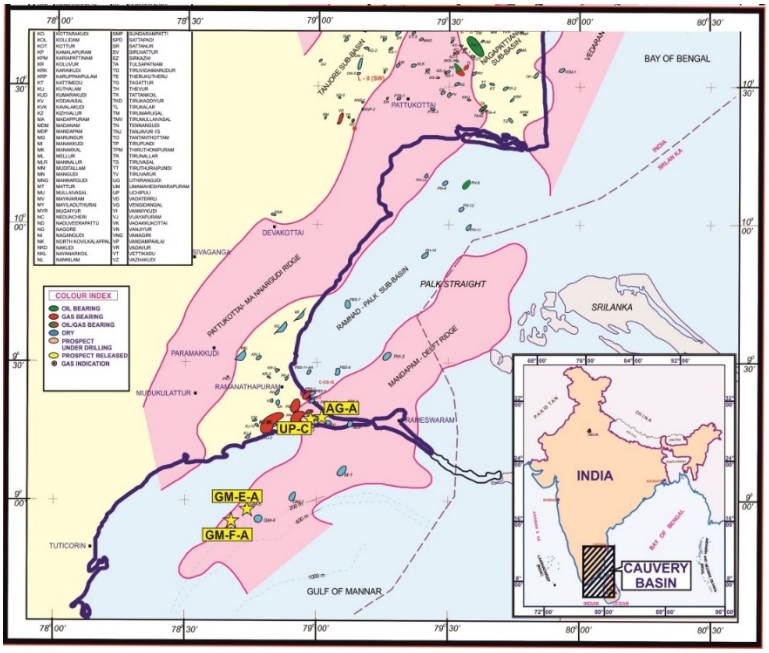

Fig. 1: Location of studied wells in Mannar Sub-Basin, Cauvery Basin

At least six offshore wells and four onshore wells, drilled mainly in the northern low area, encountered dolerite intrusives. These intrusives are confined within the Andimadam Formation towards the northern part and Bhuvanagiri Formation towards the southern part of the sub-basin (Uppal et al., 2017). This igneous activity is also reported in wells Pearl-1 and Barracuda G1/1 in the Sri Lankan side of Mannar sub-basin (Premarathne et al., 2013). In the present study, we attempt to provide the geochronological constraint and petrogenetic history of these intrusive bodies through ^{40}Ar–^{39}Ar dating and Sr-Nd isotopic characterization, respectively, in the studied core and cutting samples encountered in drilled wells.

Materials and Method

Conventional cores/ cutting samples of 04 wells (Fig. 1) were taken up for the ^{40}Ar–^{39}Ar dating and Sr–Nd isotopic studies for genetic characterization. The core samples of well GM-E-A and GM-F-A were attempted for Ar-Ar dating. However, the GM-E-A dolerite sample yielded meaningful plateau age.

For the ^{40}Ar–^{39}Ar studies the selected samples were powdered to 60–80 mesh size and about 600–700 mg of homogenized powder of each sample was used for neutron irradiation. The 523.2±0.9 Ma Minnesota Hornblende (MMhb–1) was used as a monitor (Renne et al., 1998). The whole rock powder samples and monitor along with pure CaF_2 and K_2SO_4 salts, which are used for correcting interfering isotopes produced from calcium and potassium, were filled in clean quartz vials.

The samples were irradiated for 140 hours at 1 MW power level in D4 (core) position of the APSARA reactor of BARC, Mumbai. This position receives maximum flux with minimum variation. The total flux received by the samples was about 10^{17} neutron/cm^2. Samples were then split into aliquots, weighed and wrapped in aluminium foils and loaded in the sample holder of the argon extraction system. Argon isotopic measurements were carried out on MM 1200 Noble Gas Mass Spectrometer as per the procedures set in-house (Rathore et al., 2003) in the Geochronology Laboratory, KDMIPE. The samples were heated in incremental steps starting from 600°C to fusion around 1400°C except the monitor, potassium and calcium salts, which were fused in a single temperature step. Measured isotopic ratios were corrected for the effects of mass discrimination and interfering isotopes produced during the irradiation i.e. $(^{40}Ar/^{39}Ar)_K$, $(^{39}Ar/^{37}Ar)_{Ca}$ and $(^{36}Ar/^{37}Ar)_{Ca}$. These ratios were deduced from K_2SO_4 and CaF_2 salts irradiated along with the samples. The horizontal fluence variation as measured by ^{58}Co activity of pure Ni wire enclosed with the samples were found to be less than 18% for the irradiation.

Apparent ^{40}Ar–^{39}Ar ages were calculated from the corrected isotopic ratios using the decay constants and isotopic ratios given by Steiger and Jager (1977). Total gas ages were computed for each sample by weighting with inverse variance of each temperature increment.

For Sr and Nd isotopic analysis, about 100 mg powder sample was digested in a mixture of acids as per the procedure detailed above. The Rb-Sr and Sm-Nd mixed spike was added to the sample prior to the dissolution to ensure complete mixing. The Sr and Nd elements were separated using ion exchange chromatography as per the in-house established procedure (Rathore et al., 2013).

The Sr and Nd isotopic ratios were measured using multicollector TRITON-TIMS. The measured Sr and Nd isotope ratios were corrected for mass fractionation by normalizing to $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$, respectively. Average blank levels were found to be within nanogram range for Sr and Nd. The results for the Sr and Nd standards were well within their reported values.

Results

One dolerite intrusive core sample from the well GM-E-A of Mannar Sub-Basin was able to yield ^{40}Ar–^{39}Ar age of 89.1±0.65 Ma. The sample was analysed in eight incremental steps. The analysed sample has not yielded a plateau; instead it has shown a saddle shaped spectrum indicating the presence of excess argon. The initial five temperature steps i.e. 600°C to 1000°C, comprising 50% ^{39}Ar release, have shown decreasing Ar–Ar ages. The next temperature step alone has contributed 43.7% of ^{39}Ar release but has yielded distinctly lower age. The next two temperature steps, though accounting for just 6.2% of total ^{39}Ar, have shown increasing trend. This type of spectrum, which is known as saddle shaped spectrum, is indicative of excess argon (Kaneoka, 1974; Lanphere and Dalrymple, 1976). In such type of spectrum, the minima of the spectrum marks the upper limit to the time of formation (Lanphere and Dalrymple, 1976). In the sample, the minima of the spectrum is 89.1±0.65 Ma which marks the upper limit to the time of emplacement of the doleritic intrusive activity in this area.

Dolerite samples from four wells, i.e. GM-E-A, GM-F-A, UP-C and AG-A, have been analyzed for Sr-Nd isotopic ratios. The $^{87}Sr/^{86}Sr_{(i)}$ ratios in the measured samples do not vary much, with variation form 0.7041 to 0.7088, thus ruling out the effect due to weathering and sea water alteration. Similarly, $\varepsilon_{Nd}(i)$ values also display a close-knit cluster ranging from +1.1 to +5.7 epsilon units (Fig. 3).

The Sr ratios and εNd values have been plotted on a $^{87}Sr/^{86}Sr_{(i)}$ vs. $\varepsilon Nd(i)$ diagram along with Sr-Nd data from St. Mary's Islands volcanics as well as those from Madagascar volcanics and Marion Island (Fig. 3) for comparison of isotopic signatures (Torsvik et. al., 2000; Mahoney et al., 1991; Le Roex et al., 2012).

The Sr ratios and ƐNd values of studied samples from Mannar dolerites, are similar to that of SE and SW Madagascar (Tholeiites, alkali basalts and mafic dykes), Marion Island and St. Mary Island volcanics, indicating that these dolerites have fundamental petrogenetic similarity with the latter volcanic events.

Discussions

During the beginning of the Late Cretaceous, active tectonism was prevalent in the Gulf of Mannar in Cauvery Basin with subsidence all over the basin (Rana et al., 2008). This was accompanied by extensive lava flows and igneous activity in the region. At least 10 wells were drilled in the northern low area, where dolerites were encountered. These intrusives are mainly confined within the Lower and Upper Cretaceous sediments (Uppal et al., 2017).

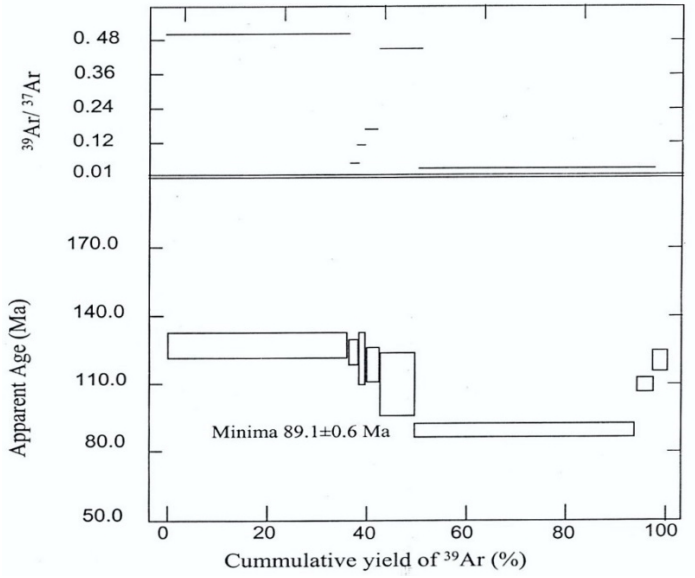

Fig. 2: ^{40}Ar–^{39}Ar age spectrum diagram of dolerite intrusive from well GM-E-A of Mannar Sub-Basin, Cauvery Basin

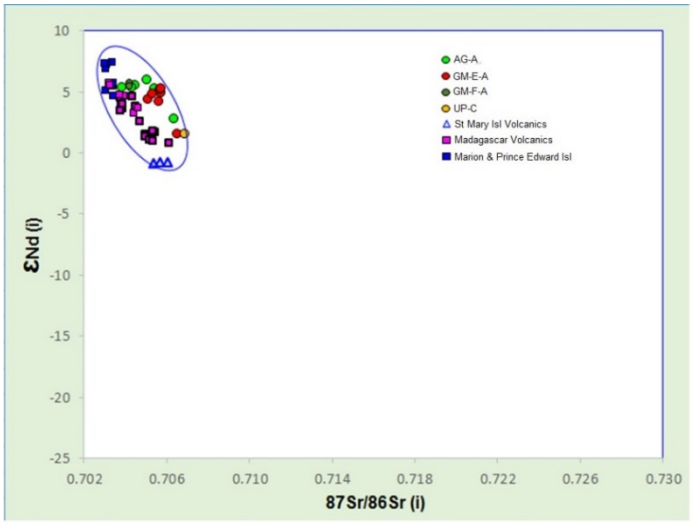

Fig. 3: $Ɛ_{Nd}$ vs. $^{87}Sr/^{86}Sr$ plot for dolerites from Mannar Sub-Basin, compared with published data for St. Mary Island, Madagascar volcanics and Marion-Prince Edward Islands (Data source: Torsvik et al., 2000; Mahoney et al., 1991; Le Roex et al., 2012)

The present study integrates the temporal and geochemical aspects of the intrusives encountered in the Gulf of Mannar, through the ^{40}Ar–^{39}Ar age dating of the intrusives as well as their genetic characterization based on Strontium-Neodymium isotopes. The ^{40}Ar–^{39}Ar dating of doleritic intrusives encountered in the well GM-E-A have yielded minima of the spectrum at 89.1±0.65 Ma which marks the upper limit to the time of emplacement of the doleritic intrusive activity in this area. Further, the

studied core was cut from the dolerite encountered in Andimadam (Lower Cretaceous) Formation, and yielded a Coniacian age (89.1±0.65 Ma), which suggests the intrusive activity to be younger and not related to the syn-rift phase in the Lower Cretacrous (Late Aptian 112 Ma; Nagendra and Reddy, 2017) in the Cauvery Basin. However, a few more dolerite samples from different wells need to be dated by Ar-Ar method to affirm this conclusion.

The Sr–Nd isotopic signatures from the intrusives encountered in four studied wells drilled in the Gulf of Mannar, namely GM-E-A, GM-F-A, UP-C and AG-A, have been correlated with the volcanic rocks reported from published literature. These include SE Madagasacar tholeiites and dykes, SW Madagascar alkali basalts and dykes, St. Mary Islands volcanics, and Marion Islands alkali basalts as well as rhyolites exposed between Vatomandry-Ilaka and Mananjary in eastern Madagascar (Torsvik et. al., 2000; Mahoney et al., 1991; Le Roex et al., 2012) and bring out the following interpretations for the emplacement of igneous activity (volcanics/intrusives) in the Gulf of Mannar in Cauvery Offshore:

a) A strong correlation of age has been observed in the dolerites encountered in well GM-E-A (89.1±0.65 Ma) with those of well Pearl-1, drilled further south east towards Sri Lanka(76.8 ± 4.5 Ma; Premarathne et al.,2013), Karnataka mafic dykes (90±1 Ma and 87.5±0.9 Ma; Kumar et al. 2001), St. Mary Islands (85.6±0.9 Ma and 91.2±0.2 Ma; Pande et al., 2001; Torsvik et. al., 2000, respectively) and Madagascar Volcanics (87.6±1.2 Ma; Storey et al., 1995).

b) On correlating the Sr-Nd signatures of dolerites from four studied wells along with those from SE Madagasacar tholeiites and dykes, SW Madagascar alkali basalts and dykes, St. Mary Islands volcanics and Marion Islands alkali basalts, they appear to show strikingly similar petrogenetic characteristics. This suggests that intrusives encountered in Gulf of Mannar wells have a common petrogenetic evolution as compared with former.

c) Similarity in Isotopic characters and age indicate that the doleritic emplacement in Mannar Sub-Basin of Cauvery Basin was as a result of Marion hotspot activity (~90 Ma) and has a direct relationship to India-Madagascar separation (Fig. 4).

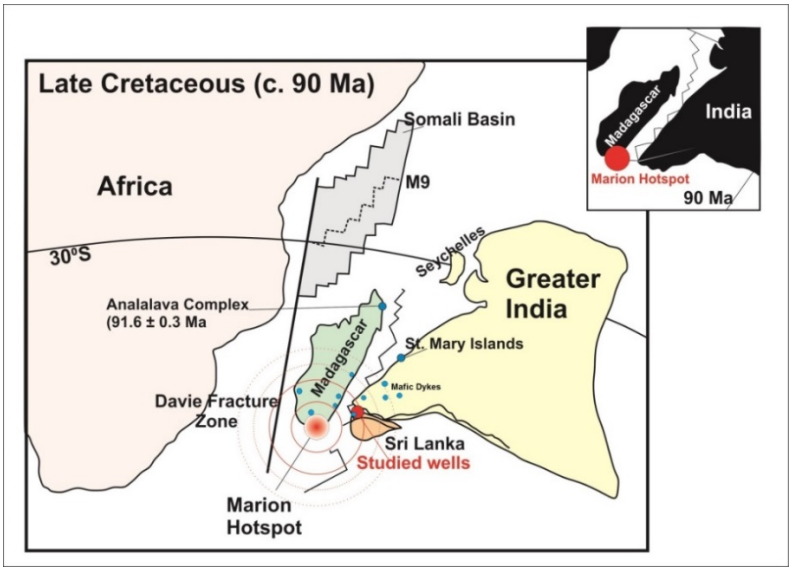

Fig. 4: Plate tectonic reconstruction (after Torsvik et al., 2000) showing the location of the Marion hotspot during ca. 90 Ma responsible for the emplacement of dolerite intrusives in Mannar Sub-Basin

Conclusions

^{40}Ar–^{39}Ar age and Sr–Nd isotopic signatures of the studied samples suggest that the dolerite intrusives encountered in the Mannar sub-basin in the Cauvery Basin were emplaced as a result of Marion hotspot activity (~90 Ma) and are direct manifestations of India-Madagascar separation during Upper Cretaceous. This is evident from a strong age correlation of Mannar volcanics with those of Madagascar, St. Mary Islands and mafic dykes of Karnataka, as well as Sr-Nd isotopic similarity of the studied dolerites with the volcanic rocks of south-eastern and southwestern Madagascar, St. Mary Island and Marion-Prince Edward Island, which are the present day manifestations of the Marion hotspot in SW Indian Ocean.

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 expressed in the paper are those of the authors and not necessarily of the organization they belong to.

References

Baillie, P. W., Shaw, R. D., Liyanaarachchi, D. T. P. and Jayaratne, M. G., 2003, A new Mesozoic sedimentary basin, offshore Sri Lanka. Proceedings of EAGA 64th Conference & Exhibition, Florence, Italy.

Curray, J. R. and Nara, J., 1984, Sri Lanka: is it a mid-plate platelet? Vol. 31, pp. 30-50.

Kaneoka, I., 1974, Investigation of excess argon in ultramafic rocks from Kola Peninsula by the $^{40}Ar/^{39}Ar$ method, Earth. Planet. Sci. Lett., vol. 22, pp. 145-156.

Kumar, A., Pande, K., Venkatesan, T. R. and Bhaskar Rao, Y. J., 2001, The Karnataka Late Cretaceous dykes as products of the Marion hot spot at the Madagascar- India breakup event: Evidence from ^{40}Ar-^{39}Ar geochronology and geochemistry, Geophy. Res. Lett., vol. 28, pp. 2715-2718.

Lanphere, M. A. and Dalrymple, G. B., 1976, Identification of excess ^{40}Ar by the $^{40}Ar/^{39}Ar$ age spectrum technique, Earth Planet. Sci. Lett., vol. 32, pp. 141-148.

Le Roex, A. P., Chevallier, L., Verwoerd, W. J. and Barends, R., 2012, Petrology and geochemistry of Marion and Prince Edward Islands, Southern Ocean: Magma chamber processes and source region characteristics, Journal of Volcanology and Geothermal Research, vol. 223, pp. 11-28.

Mahoney, J. J., Nicollet, C. and Dupuy, C., 1991, Madagascar basalts: tracking oceanic and continental sources, Earth Planet. Sci. Lett., vol. 104, pp. 350–363.

Pande, K., Sheth, H.C. and Bhutani R., 2001, ^{40} Ar-^{39}Ar age of the St. Mary's Islands volcanics, Southern India: Record of India-,Madagascar break-up on the Indian subcontinent, Proc. Indian Acad. Sci. (Earth Planet. Sci.), vol. 193, pp. 39-46.

Premarathne, D.M.U.A.K., 2011, Oil exploration in Sri Lanka and Sustainability of the Gulf of Mannar, Proc. of 27th Annual Sessions of the Geological Society of Sri Lanka, vol. 23.

Premarathne, D.M.U.A.K., Suzuki, N., Ratnayake, N. P., and Kularathne, E.K.C.W., 2013, A Petroleum System in the Gulf of Mannar Basin, Offshore Sri Lanka, Proceedings to 29th Technical Sessions of Geological Society of Sri Lanka, pp. 9-12.

Rana, M.S., Chakraborty, C., Sharma, R. and Giridhar, M., 2008, Mannar Volcanics - Implications for Madagascar Breakup, SPG 7th International Conference and Exposition on Petroleum Geophysics, P-358.

Rao, M. V., Chidambaram, L., Bharktya, D., Mala Janardhanan, 2010, Integrated Analysis of Late Albian to Middle Miocene Sediments in Gulf of Mannar Shallow Waters of the Cauvery Basin, India: A Sequence Stratigraphic Approach, 8th Biennial international conference and exposition on petroleum geophysics.

Rathore, S. S., Singh, M. P., Vijan, A. R., Bansal, M., Prabhu, B. N. and Misra, K. N., 2003, Standardization of Ar-Ar dating facility at KDMIPE, ONGC, Dehradun, Silver Jubilee ISMAS Symp., NIO, Goa, ESP-19, pp. 598-604.

Rathore, S. S., Rajeev Kumar, Uniyal, G. C and Bansal, M., 2013, Establishment of Samarium-Neodymium (Sm-Nd) dating technique at KDMIPE, ONGC, Dehradun, Proceed; 12th ISMAS Triennial Inter. Conf. on Mass Spectrometry, Goa, pp. 183-189.

Renne, P. R., Swisher, C. S., Deino, A. L., Karner, D. B., Owens, T. L. and DePaolo, D. J., 1998, Intercalibration of standards, absolute ages and uncertainties in $^{40}Ar/^{39}Ar$ dating, Chem. Geol., vol. 145, pp. 117-152.

Steiger, R. H. and Jager, E., 1977, Subcomission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology, Earth Planet. Sci. Lett., vol. 36, pp. 359-362.

Storey, M., Mahoney, J. J., Saunders, A. D., Duncan, R. A., Kelley, S. P. and Coffin, M. F., 1995 Timing of Hot Spot- Related Volcanism and the Breakup of Madagascar and India, Science, vol. 267, pp. 852-855.

Torsvik, T. H., Tucker, R. D., Ashwal, L. D., Carter, L. M., Jamtveit, B., Vidyadharan, K. T. and Venkataramana, P., 2000, Late Cretaceous India Madagascar fit and timing of break-up related magmatism, Terra Nova, vol. 12 (5), pp. 220–224.

Uppal, S., Chakrabarty, S., Nanda, J., Verma, S., Shukla, M., Raza, S. and Mondal, A., 2017, Sediment Dispersal Pattern and High Resolution Biostratigraphy Enabling Process Response Depositional Model of East Coast Basins of India, Unpub. ONGC Report.