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Strontium-Neodymium (Sr-Nd) isotopic and chemical fingerprinting of basalts encountered in deep water wells of NELP block KG-DWN-2002/1, Krishna Godavari Basin: Implications to Kerguelen Plume Linkage

S. S. Rathore, Piyush Gupta, G. C. Uniyal and K. K. Das

Geochronology Laboratory, Geology Group, KDM Institute of Petroleum Exploration

Oil and Natural Gas Corporation Ltd., Dehradun, India

Presenting author, E-mail: rathore_ss1@ongc.co.in

Abstract

This paper presents Sr-Nd isotopic along with petrographic and chemical studies carried out on basalts encountered in deep water wells F-AA, NAD-EB and G-18-A drilled in the Kakinada Graben of the Krishna-Godavari basin in the Eastern Offshore of India. These studies are aimed to understand the type and origin of basalts and also to decipher the tectonic settings under which they were emplaced and possible correlation with equivalent volcanism onland and offshore of India as well as linkage with Kerguelen plume volcanism.

The Sr-Nd isotopic compositions of studied basalt samples show isotopic signatures typical of Rajmahal Group-II Continental Flood Basalts and are related to the initial phase of the Kerguelen plume activity marked by huge outpouring of lava in the Eastern/Northeastern region of Indian Peninsula roughly during 119 Ma to 100 Ma ago. The studies indicate wide variations in Sr isotopic compositions due to varied amount of crustal contaminations. The discrimination plots of trace elements suggest Within-Plate Basalt (***WPB***) category of the studied basalt samples, similar to the onland Rajmahal and Sylhet Traps. Further, these basalts exhibit isotopic signatures similar to that of Central and South Kerguelen Plateaus and Elan Bank in the Kerguelen Archipelago which suggests the role of Kerguelen Plume/Hotspot system in the eruption of the basalts encountered in the Krishna-Godavari basin.

Introduction

The eastern continental margin of India represents a fully evolved passive divergent margin associated with a triple junction. The Indian plate, which formed a part of Gondwanaland till Early Mesozoic, initially fragmented around 200 Ma ago and the first contact between Indian and Eurasian plates took place around 56 Ma ago (1). During northward movement of the Indian plate towards the Eurasian plate in Cretaceous time, there was a change in the configuration of the east coast of India, from initial E-W direction to NE-SW, involving a 20° anticlockwise rotation (2). This resulted in an easterly tilt giving rise to a south easterly drainage pattern along the east coast forming five major sedimentary basins, viz. 1) Cauvery 2) Palar-Pennar 3) Krishna Godavari 4) Mahanadi and 5) West Bengal.

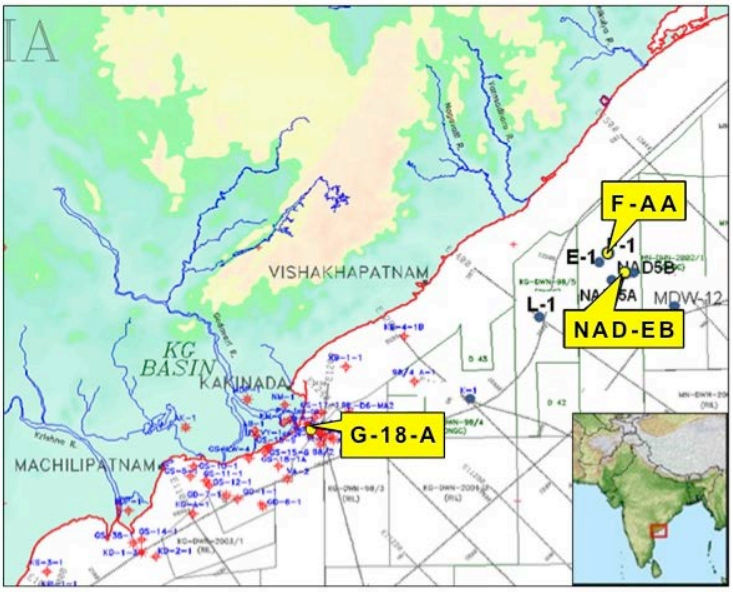
The Krishna-Godavari (KG) basin, a proven petroliferous basin with more than 2.3% of organic matter in some of the source rocks, extends over an area of 15,000 sq. km onland and about 39,000 sq. km offshore up to 2000 m isobath and covers mostly the coastal tract of Andhra Pradesh from Vishakhapatnam in the north to Ongole in the south. Significant contributions towards understanding the geological evolution of the KG Basin have been made by several authors (3, 4 and 5). The basin originated in Jurassic times due to extension tectonics and has evolved in two phases – rift phase and drift phase. The rift processes resulted in north east trending horsts and grabens. Based upon the juxtaposed horst-graben relationship sixteen tectonic blocks have been recognized in the basin from north to south (6) and the basin has been divided into three sub basins (grabens) as Krishna, West Godavari and East Godavari differentiated by two prominent subsurface ridges called Baptala and Tanuku horsts, respectively (4).

In the plate tectonics model, triple junction of divergent plates and island split-off like Madagascar from Africa, are important for hydrocarbon exploration. These places are the ideal sites for better protection and moderate to high maturation of organic matter (7). In the East Coast of India, the ‘Godavari bend’ between Godavari and Krishna rivers (Machilipatnam Bay) coincides with the triple junction of diverging Indian, Australian and Antarctican plates. Similarly, the separation of Sri Lanka from the Indian Peninsula leaves behind the promising ‘Gulf of Mannar’ for hydrocarbon exploration (8).

Present study deals with Strontium-Neodymium isotopic and chemical fingerprinting of the basaltic rocks encountered in three deep water wells F-AA, NAD-EB and G-18-A in the KG Basin. The main objective of this study is to characterize the basalts encountered in these offshore wells through multi-isotopic (Sr-Nd) studies and certain immobile trace elements and to decipher their mode of origin, tectonic setting, possible correlation with equivalent volcanism onland and offshore and linkage with Kergueleon plume.

Sample Details

The basalt cutting samples from three deep water wells F-AA, NAD-EB and G-18-A have been taken up for multi-isotopic and trace elemental analysis. The petrographic studies of selected samples have also been carried out to characterize the basalts. Location of the studied wells is shown in Fig. 1(a). The wells F-AA and NAD-EB fall in the deep water NELP block KG-DWN-2002/1 and were drilled to a depth of 4802 m and 5690 m at a water depth of 2442 m with trap thickness of 517 m and 282 m, respectively. The well G-18-A was drilled to a target depth of 5400 m in Godavari PML of KG Offshore with 336+ m of Rajmahal Volcanics (?).



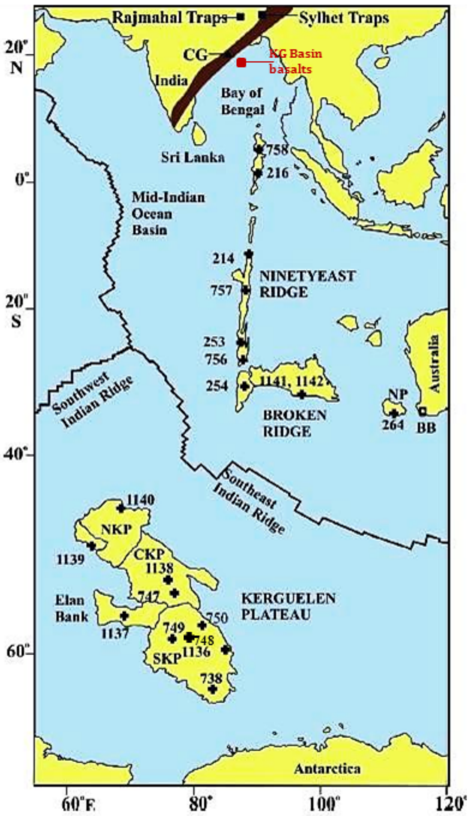


Fig.1: (a) Location map of Krishna-Godavari Basin of India showing location of the studied wells, (b) Map of part of the Indian Ocean and surrounding continents present day with physiographic features, after Ingle et al. (2002) and Frey et al. (2000), showing locations of the Sylhet and Rajmahal Traps.

Experimental Techniques

For trace elemental analysis, the samples were digested using mixture of acids in steel digestion bombs. About 25 mg of the sample powder was weighed in a Teflon beaker and ultrapure acids (3 mL HNO_3 and 2mL HF) were added and placed in a steel Parr bomb vessel. The bomb was kept at 200°C for about 24 hours in an oven. The digested sample was dried and the residue was dissolved in 3mL 6N HCl and dried. The final solution was prepared in 100mL 10% HNO_3 and was filtered to remove any undissolved particles. The trace elemental analysis was carried out on ICP-AES.

For Rb, Sr, Sm, and Nd isotopic analyses, about 100 mg powder sample was dissolved 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. After complete dissolution, the acids were evaporated and the residue was re-dissolved in 3mL 6N HCl and dried. The final solutions were prepared in 2mL 2N HCl and were centrifuged before loading onto the chromatographic columns for elemental separation. The Rb, Sr, Sm and Nd elements were separated using ion exchange chromatography as per the in-house established procedure (9).

For isotopic analysis, Rb and Sr were loaded onto degassed single Ta filaments while Sm and Nd were loaded onto degassed double Re filaments. The Rb, Sr, Sm and Nd isotopic ratios were measured using multi-collector TRITON-TIMS. The measured data for Sr and Nd isotopes 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 < 25 ng for Sr and Nd and <10 ng for Rb and Sm. During the course of this study, 13 analyses of Sr reference material SRM- 987 yielded an average value of $^{87}Sr/^{86}Sr = 0.710257 \pm 7$; for Nd reference materials, 6 analyses of JNdi-1 yielded an average value of $^{143}Nd/^{144}Nd = 0.512107 \pm 2$ and 4 analyses of La Jolla yielded an average value of $^{143}Nd/^{144}Nd = 0.511846 \pm 2$. The results for the Sr and Nd standards were well within their reported values.

Results and Discussion

The Ti, Zr, Y, and Nb contents of basalts vary systematically with tectonic setting of eruption (10). Most basalts erupted in within-plate settings can be identified by their high Ti/Y and Zr/Y ratios (11). Similarly, Most basalts erupted in island arc settings can be distinguished from mid oceanic ridge basalts (MORB) by their lower absolute abundance of Ti, Zr or Nb at any given Cr concentration (12). Also, most alkali basalts can be distinguished from tholeiitic basalts by their lower Ti/Nb, Zr/Nb or Y/Nb ratios (11).

When Zr/Y verses Zr content of the studied basalt samples are plotted on the diagram of Pearce and Norry (10), most data points lie in the region of high Zr/Y content, some being even towards higher ratios region (Fig. 2a). These basalt samples have also been compared with published data of Storey et al. (13) from Kerguelen Plateau and Rajmahal Traps (Fig. 2a). This indicates that the basalts from KG Basin show close affinity to Within-Plate Basalt (***WPB***) and also to the South Kerguelen Plateau lavas and Rajmahal Traps. The Ti/100–Zr–3xY triangular plot of Pearce and Cann (11) for samples under study (Fig. 2b) also strongly suggests that these basalts were emplaced under Within-Plate tectonic conditions, being either continental or oceanic plates, typically related to Kerguelen plume related magmatism.

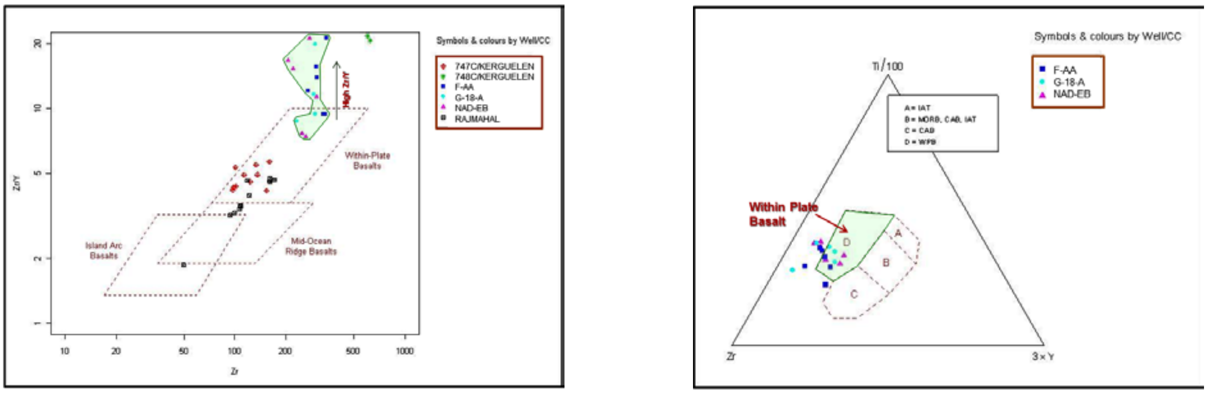


Fig. 2: (a) Zr/Y vs. Zr diagram, after Pearce and Norry (10), of basalt samples under study. The data points of basalt samples from South and Central Kerguelen Plateau (ODP Legs 747C and 748C) and main sequence Rajhamal Traps, after Storey et al., (13), are also shown for comparison, (b) Ti/100–Zr–3xY triangular plot, after Pearce and Cann (11), for basalt samples under study

The Sr and Nd isotopic data of the studied samples are plotted in Fig. 3. Their initial ε_{Nd} vs. $^{87}Sr/^{86}Sr_{(I)}$ ratios calculated at 117 Ma are shown in Fig. 3 and compared with relevant Kerguelen-plume related basalts in the Southern Indian Ocean as well as with the Rajmahal basalts in the Onshore Indian

Subcontinent. The data fields for Indian MORB, and possible crustal and lithospheric contaminants from Eastern Ghat Belt, including the Chilka Granulite are also shown here. A general correspondence of the KG Basin basalts with all the ODP site lavas (numbered fields) in the Southern and Central Kerguelen Plateau, Bunbury and Rajmahal Group I and II basalt data is noteworthy.

The initial ε_{Nd} values for three KG Basin basalts range from –1.5 to –8.7 (Fig. 3). The $\varepsilon_{Nd(I)}$ values for NAD-EB basalts range from –1.5 to –2.6 (Fig. 3) with an average value of –1.9, whereas basalts from well F-AA show more negative $\varepsilon_{Nd(I)}$, ranging between –3.5 to –7.0 (Average value of –5.0), with an exception of sample 1479 which has $\varepsilon_{Nd(I)}$= –1.4 (Fig. 3) . Basalts from well G-18-A show further negative $\varepsilon_{Nd(I)}$ values ranging from –3.8 to –8.7 (Fig. 3), with an average value of –4.9. The initial $^{87}Sr/^{86}Sr$ values of NAD-EB basalts range from 0.705367 to 0.707467, with a low average value of 0.705944 (Fig. 3a). The F-AA basalts show more radiogenic values ranging from 0.705842 to 0.709511 (average = 0.707380) with the exception of sample 1479 having a relatively low ratio of 0.705314 (Fig. 3a). Basalts from well G-18-A show further scattered values of initial $^{87}Sr/^{86}Sr$ which are in the range 0.706465 to 0.710984 (Fig. 3a), with an average of 0.707717.

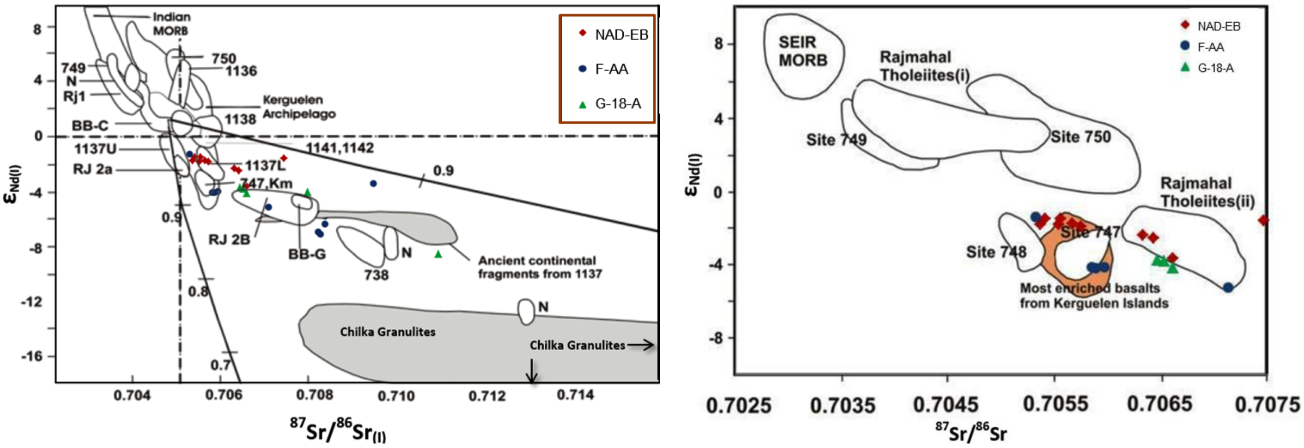


Fig. 3: (a) Initial ε_{Nd} vs. $^{87}sr/^{86}sr$ at 117 Ma for the basalts encountered in wells NAD-EB, F-AA and G-18-A are shown and compared with data from the Rajmahal Traps, Bunbury basalts, Kerguelen Plateau basalts, and Eastern Ghat Belt (EGB) granulites (14). The field of Indian MORB includes the Southeast Indian Ridge (15), (b) Initial ε_{Nd} vs. $^{87}sr/^{86}sr$ at 117 Ma for the studied basalts are shown and compared with that of Kerguelen Plateau and Rajmahal basalts (13). Also shown the field of most enriched basalts from Kerguelen Island (16) on which most of basalt samples from present study lie, along with Rajmahal Group II Tholeiites.

According to the $^{40}Ar/^{39}Ar$ chronology established by Kent et al. (17), the magmatism related to Kerguelen Plume activity took place in three discrete stages. Initial phase included the emplacement of Bunbury basalts, which were erupted in two phases, first one at ~130 Ma and second at ~123 Ma. These were the oldest lavas linked to the Kerguelen hotspot and are exposed at Bunbury, Western Australia. This phase was also marked by large outpouring of lava in the Eastern India including Rajmahal Traps, Bengal basin and Sylhet province of northeastern India, along with the formation of large igneous provinces (LIPs) e.g. South and Central Kerguelen Plateaus and Elan Bank in the South eastern Indian Ocean. The $^{40}Ar/^{39}Ar$ age given by Baksi (18) is ~117 Ma for the Rajmahal Traps whereas the ages of formation of South and Central Kerguelen Plateaus have been established as ~119-108 Ma and ~100 Ma (17), respectively. In the second phase of Kerguelen magmatism, the construction of Broken Ridge (~95 Ma), Ninetyeast Ridge (~82-38 Ma) and Northern Kerguelen Plateau (~34 Ma) took place. In the third phase the remaining plateaus in the archipelago were formed from ~29 Ma to present (17).

Raju et al. (20) have done extensive work related to the stratigraphic information on Cretaceous volcanism in the deep water KG Basin for the wells under study. The study confirms existence of the Pre-Deccan Volcanism in this basin. These authors have suggested Valanginian/Hauterivian to Early Albian (140-100 Ma) age for the volcanics encountered in well F-AA and Aptian age (125-112 Ma) for the volcanics in the well G-18-A. Further, these authors have suggested relatively younger Coniacian age (~87 Ma) which marks the upper age limit to the volcanics encountered in the well NAD-EB. This range of age is highly suggestive of these basalts to be the age equivalents of the Kerguelen hotspot activity which also emplaced Rajmahal Traps to the East of KG Basin on the onland Eastern India.

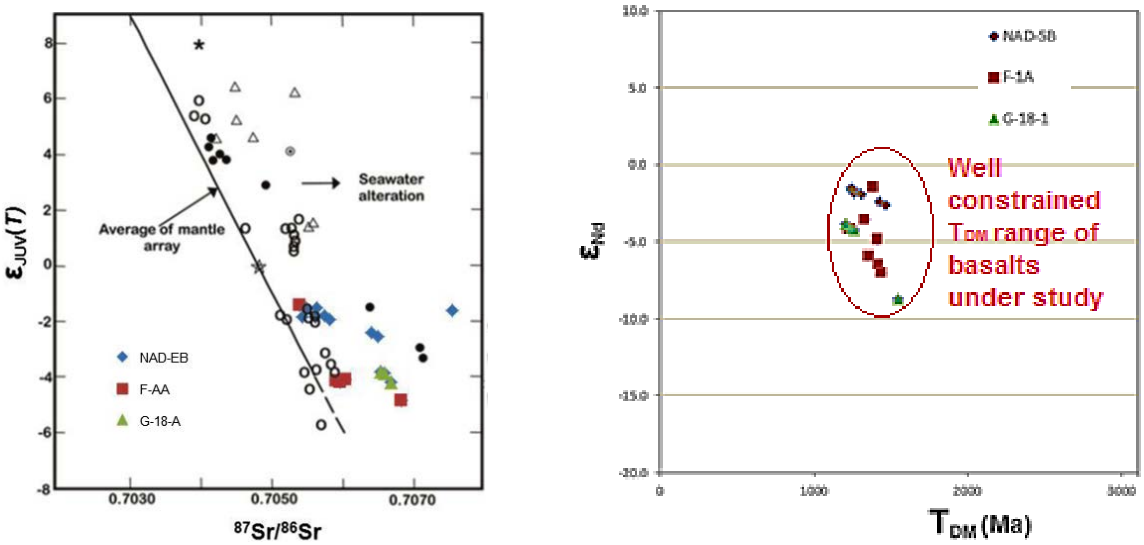


Fig. 4: (a) Initlal ε_{Nd} vs. Sr isotopic ratios of KG Basin basalts compared to that of the Rajmahal Traps and Ninetyeast Ridge samples. Also plotted are the average line of the trend defined by mantle-derived rocks, the presumed bulk Earth value (BE), and the position of the least contaminated Deccan samples from Mahabaleshwar (★). ●, Main sequence Rajmahal lavas; Δ, Ninetyeast Ridge samples; Ọ, Kerguelen igneous rocks (21), (b) ε_{Nd} vs, T_{DM} plot for samples under study. The Basalts of KG basin are well constrained within a narrow T_{DM} range.

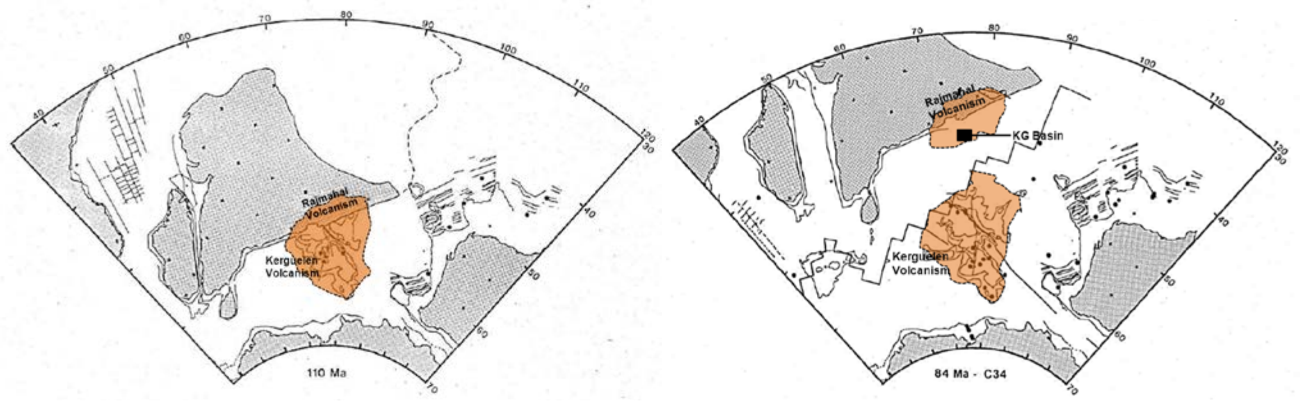


Fig. 5: Mode of emplacement of KG Basalts with respect to Kerguelen Plume activity and northward drift of Indian subcontinent (19).

The Sr-Nd isotopic composition of the studied samples from deep water wells NAD-EB, F-AA and G-18-A and their interpretation clearly suggests that most of the data points lie within the initial isotopic ratio of Rajmahal Group II basalts, Central Kerguelen Plateau basalts and Elan Bank lavas encountered in the ODP sites (Fig. 3). The study further suggests that the emplacement of KG Basin basalts appears to have been caused by a relative primitive Kerguelen plume source that also caused the emplacements of Rajmahal Traps, and Central Kerguelen Plateau and Elan Bank basalts.

On comparing the initial ε_{Nd} vs. $^{87}Sr/^{86}Sr$ isotopic ratios of the KG Basin basalts with that of Rajmahal Traps and Ninetyeast samples along with the average line of trend defined by mantle derived rocks (Fig. 4a), the presumed bulk Earth value (BE), and the position of the least contaminated Deccan samples from Mahabaleshwar (21), it is seen that all KG Basin basalt sample points are plotted right to the mantle array and the field of Kerguelen rocks (Fig. 4a) with $^{87}Sr/^{86}Sr$ ratio towards seawater (Present day sea water value is 0.7092). This clearly suggests that these KG Basin lava flows appear to have been erupted either subaerially or in very shallow water, as explained by the varying degrees of alteration of isotopic ratios by the exposure to sea water (Fig. 4a).

Model ages (T_{DM}) of the samples under study indicate the time when the parent magma of these samples first got separated from the mantle. In the ε_{Nd} vs. T_{DM} plot (Fig. 4b) of the studied basalts it is indicated that these rocks are well constrained within a narrow range showing least model age separation, clearly suggesting the incidence of a single petrogenetic episode. This further strengthens the inference that the basalt rocks under study have been erupted from Kerguelen hotspot activity during a single volcanic episode.

Conclusions

The chemical studies on basalts from deep water wells of KG Basin strongly indicate their affinity to Within Plate Basalt (WPB) category. The Sr-Nd isotopic signatures suggest these basaltic rocks to be related to Rajmahal Group II basalts. The isotopic studies further suggest that these basalts are related to the initial phase of the Kerguelen plume activity marked by huge outpouring of lava in the Eastern/ Northeastern region of Indian Peninsula as well as the emplacement of South and Central Kerguelen Plateau and Elan Bank in the Kerguelen Archipelago roughly during 119 Ma to 100 Ma. The relatively higher initial Sr isotopic ratios as well as scatter in the Sr isotopic ratios of the studied samples suggest varied degree of alteration due to interaction with the sea water. The Nd model ages (T_{DM}) of the studied samples are constrained within a narrow range suggesting cogenetic nature and hence a common plume source for the basalts.

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