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Ash layer at ~ 8 Ma in ODP Site 758 from the Bay of Bengal: evidence from Sr, Nd isotopic compositions and rare earth elements

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Strontium and neodymium isotopic compositions are widely used to delineate the provenance of sedimentary formations. These isotopes have characteristic signatures for crust and mantle material and therefore can distinguish between volcanic and other rock types. We report here $^{87}Sr/^{86}Sr$, $\varepsilon_{Nd}(0)$ and rare earth elements (REE) of clastic sediments from ODP Site 758 in the Bay of Bengal. The age model for this site is based on biostratigraphy, which shows good agreement with the Sr-isotope derived ages. Most of the samples have $^{87}Sr/^{86}Sr$ of ~ 0.712 and $\varepsilon_{Nd}(0)$ of ~ – 12, except one sample (at ~ 8.2 Ma) that exhibits distinctly low radiogenic Sr and high radiogenic Nd ($^{87}Sr/^{86}Sr = 0.708$ and $\varepsilon_{Nd}(0) = -1.1$). REE pattern of this sample looks similar to that reported for volcanic ash from Toba, Sumatra. We suggest this sample to be a tephra layer, which originated from the Indonesian Volcanic Arc and got inter-stratified with the sediments. Our results clearly show that Sr and Nd isotopes can identify thin ash layers that otherwise may not easily be recognized.

AS a result of weathering and denudation on land, large amount of sediments are brought to the Bay of Bengal via major rivers from different regions, namely Himalaya-Tibet, the Indian subcontinent and western Burma. Inter-stratified with these sediments, several tephra layers are reported from North Indian Ocean[1–5]. Geochemical, including isotopic studies of ocean sediments through time are expected to reveal the provenance and erosional history of the source region(s). Sr and Nd isotopic compositions of clastic sediments are useful tracers to delineate provenance of ocean sediments. These isotopic fingerprints also contain effects of tectonic and climatic processes that prevailed in the source region.

Several attempts have been made to study the sediments from the Bay of Bengal for provenance, uplift in Himalaya-Tibet, erosional history and tephrochronology[1,5–8]. Based on Sr, Nd isotopic and clay mineralogical studies on terrigenous sediments at ODP Leg 116 in the distal Bengal Fan, the provenance is suggested to be High Himalayan Crystalline[6]. Ninkovitch[1] has described several tephra layers in deep-sea sediments of northeastern Indian Ocean, ranging in age from late Miocene to Recent. Geochemical studies of fragments of altered ash layer and

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pumice associated with Mn nodules in the Central Indian Basin have indicated that the volcaniclastic material originated from Toba eruptions in northern Sumatra[3]. Many ash layers from Plio-Pleistocene time have been reported[5] from ODP Site 758. An attempt is made here to understand the nature of the source area of the clastic sediments at ODP Site 758 using Sr, Nd isotopic ratios and rare earth elements (REE).

Sediment samples of late Miocene period were obtained from ODP Site 758, located in the northeast Indian Ocean (lat. 5°23′N, long. 90°21′E; water-depth 2925 m; Figure 1). The sediments, all beige in colour, are mainly composed of pelagic biogenic carbonates, fine-grained terrigenous material and volcanic ash[9,10]. The modern aeolian contribution at this site is reported to be negligible, as shown by the low concentration of soil (mineral) aerosol particles in the marine atmosphere[9,10]. However, as no information is available on this aspect for late Miocene, we assume it to be negligible. The age model presented here is based on nannofossil events[11] which shows good agreement with the Sr-isotopically derived ages using high-resolution $^{87}Sr/^{86}Sr$ values of planktonic foraminifera[12] from the same site and Sr isotope look-up table[13]. For example, the biostratigraphic age of the proposed ash layer sample (8.24 Ma) is close to the Sr isotopically-derived age[13] (8.15 Ma).

Sr and Nd isotopic measurements were carried out on the carbonate-free fraction by leaching with 1M HCl. Isotopic analyses were carried out on VG 354E Thermal Ionization Mass Spectrometer in the dynamic triple collector mode. The $^{87}Sr/^{86}Sr$ values were corrected for fractionation with $^{86}Sr/^{88}Sr = 0.1194$; SRM-987 = 0.710210 ± 24 (2σ, $n = 15$). $^{143}Nd/^{144}Nd$ were corrected for fractionation with $^{146}Nd/^{144}Nd = 0.7219$ and normalized to La Jolla Nd = 0.511850 ± 10 (2σ, $n = 12$). The ε_{Nd} (0) was determined using the following equation;

$$\varepsilon_{Nd}(0) = (^{143}Nd/^{144}Nd_{sm}/^{143}Nd/^{144}Nd_{chur} - 1)10^4;$$

where

$$^{143}Nd/^{144}Nd_{chur} = 0.512638.$$

Blank contribution in the Sr and Nd isotopic measurements was negligible, being estimated to be < 250 and < 25 pg respectively. REE analysis was carried out on ICP–MS using standard procedure[14].

The $^{87}Sr/^{86}Sr$ values range between 0.708 and 0.713 and ε_{Nd} (0) from – 1.23 to – 13.7 for the period from ~ 8 to 8.8 Ma (Figure 2). The lowest $^{87}Sr/^{86}Sr$ value (0.708) with highest ε_{Nd} (0) (– 1.23) for the sample at 8.2 Ma, is distinctly different from the results of other sediment samples. Terrigenous material at this site can have influence from the Ganges–Brahmaptra (G–B), Arakan ranges and Irrawaddy sediments. G–B sediments are reported[6,15] to have an average $^{87}Sr/^{86}Sr$ value of ~ 0.75 and ε_{Nd} (0) ~ – 15, Arakan coast sediments ~ 0.716 and ~ – 7 and Irrawaddy sediments ~ 0.713 and ~ – 10.7 (ref. 16). The isotopic compositions of the sample at 8.2 Ma imply that its source is different. Low $^{87}Sr/^{86}Sr$ and high ε_{Nd} (0) are

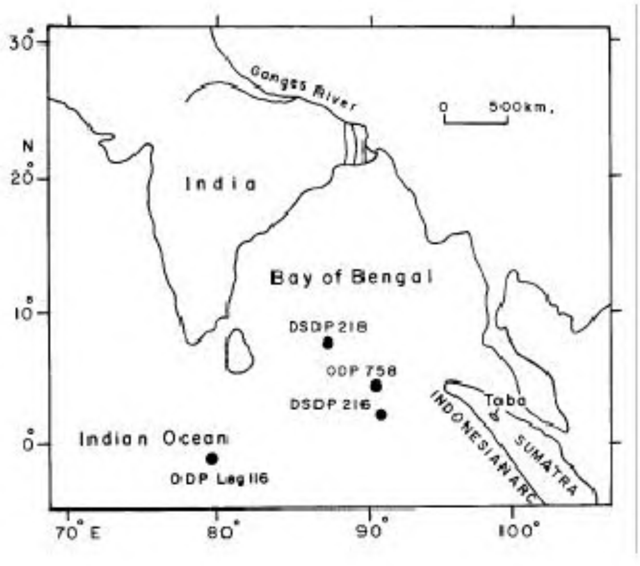

Figure 1. Location map of ODP Site 758 in the Bengal basin, modified after Rose and Chesner[4]. DSDP sites 216, 218 and ODP Leg 116 are also shown.

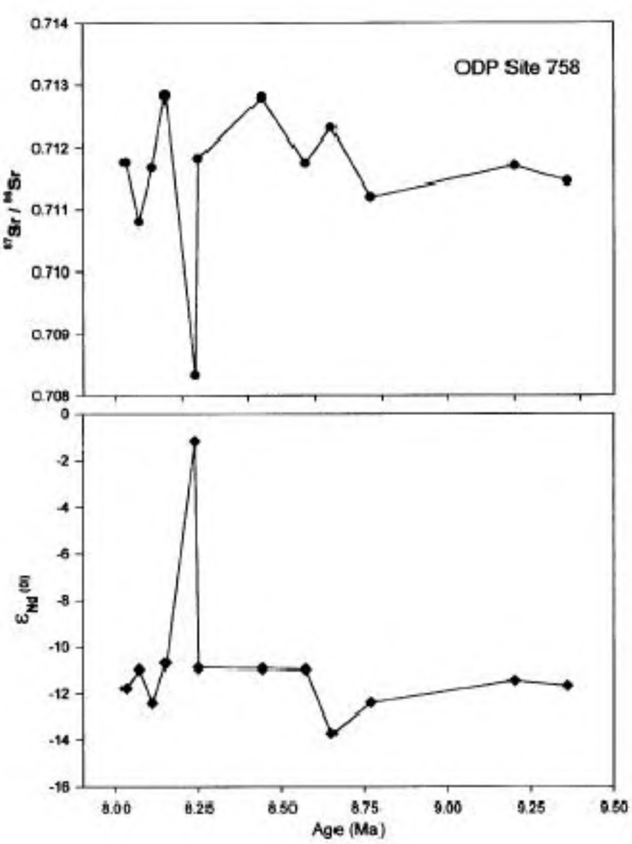

Figure 2. $^{87}Sr/^{86}Sr$ and ε_{Nd} (0) vs biostratigraphic age (Ma).

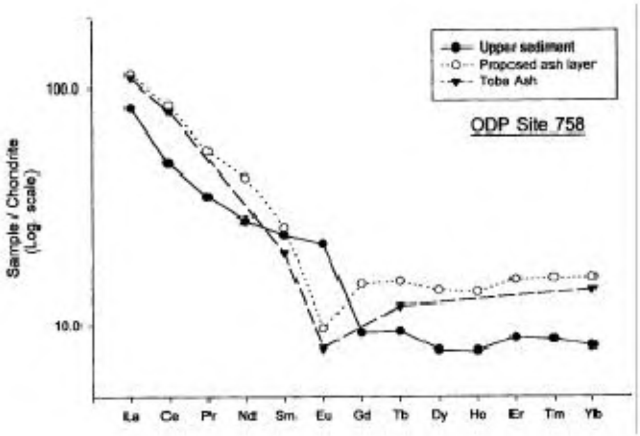

Figure 3. Chondrite normalized REE pattern of sample at 8.2 Ma along with those of overlying sediment and Toba ash[4] given for comparison.

characteristic of volcanic material. We suggest that this sample is of volcanic origin (ash layer) and may be correlated to explosive volcanism in the Indonesian Arc for which $^{87}Sr/^{86}Sr$ ranging from 0.704 to 0.709 and ε_{Nd} (0) between 3 and – 4 are reported[17].

Tephra layers in marine sediments are formed as a result of highly explosive eruptions. Such eruptions can inject ash into the stratosphere, where it can travel for thousands of kilometres before being deposited. The ash is deposited upon the ocean surface and then settles through the water column[5]. ODP Site 758 is only about 1000 km from Toba, Sumatra. Volcanic ash from Toba has been reported[18] from regions as far as 3000 km. Dehn *et al.*[5] have developed a tephrochronology for the past 5 Ma for Site 758 using stratigraphy, age and chemical composition of major ash layers and have inferred the source region to be northern Sumatra.

Chondrite-normalized REE pattern of the sample at 8.2 Ma along with that of overlying sediment shows steep LREE, flat HREE and negative Eu anomaly, which is distinctly different from that of terrigenous sediment (Figure 3). The similarity in REE plots indicates a strong correlation with the Toba ash[4]. It is also similar to the REE pattern reported for Sumatra rhyolite rocks[3]. High ΣLREE and negative Eu anomaly observed in this sample indicate a highly fractionated magma[3].

This study demonstrates that Sr and Nd isotopic compositions can delineate thin ash layers in ocean sediments which are not recognizable from physical appearance. Variable involvement of sialic crust with the ascending magma may modify $^{87}Sr/^{86}Sr$, but ε_{Nd} (0) is a more reliable tracer for source identification.

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