

Volcanogenic sediments in the Indian Ocean

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Sediments in the marine environment are derived by (1) detrital (fluvial and aeolian), (2) biogenic (foraminifera, radiolarians/diatoms), (3) authigenic precipitation from the water column (incorporation of elements within organism and scavenging of dissolved elements by organic and inorganic particles), (4) volcanogenic (*in-situ* and transported) and (5) submarine weathering of Mid Oceanic Ridges. Among all these sources, detrital is the major contributor whereas, volcanogenic contribution is very small but significant. Volcanogenic material form the significant components in many Deep Sea Drilling Projects (DSDP) and Ocean Drilling Program (ODP). Volcanogenic sediments consist of primary components such as glass shards, pumice fragments, minerals (feldspar, pyroxene, biotite....) and lithic fragments. The secondary component is diagenetic alteration of primary components then transferred to Fe-rich smectite, palagonite and zeolites. Volcanism in different tectonic settings contributes tephra to marine environments. In the Indian Ocean volcanogenic components are derived from MOR volcanism, hot spot volcanism (ex: Reunion and Kerguelen hot spots) and subduction related volcanism in the Indonesian arc. During IIOE large number of sediment cores was retrieved in the Arabian Sea and observed ash layers at different sub surface depth but could not assign any source. In Bay of Bengal ash layers were noticed in a number of sediment cores and suggested Indonesian Arc source numerous discrete ash layers ranging from a few millimeters to 34 cm thick were observed in ODP site 758 drilled on northern Ninetyeast Ridge.

Marine ash layers provide information about cyclicity of volcanism, volcanic production rate and volume, eruption duration, geochemical character of source, temporal relation between paleoclimate and volcanic history, paleowind direction, paleo currents and sediment accumulation rates. The glass shards from the ash layer needs to be separated to study their morphology and chemical composition. Sediment containing ash layer should be sieved with 63 μm sieve which is known as coarse fraction. This coarse fraction contains glass shards, biogenic components such as foraminifera, radiolarians, diatoms, authigenic components (manganese micronodules) and detrital fragments. If glass shards are associated with foraminifera and radiolarian/diatoms then they can be removed by leaching with 0.1 N HCl and and

2M Na_2CO_3 respectively. Glass shards can be separated by heavy liquid bromoform separation. These separated glass shards should be ultra sonically cleaned before chemical analysis.

The major element composition of volcanic glass is most reliably determined by electron probe micro analyzer technique (epma), which permits distinction of minor variation in the chemistry of glass. This is grain-discrete method and the problems associated with analysis of bulk separates are avoided. Generally EPMA provides total oxides ~ 95 %. Europeans use total oxides data if it is > 95 % whereas Americans uses even if it > 90 %. This total oxide content needs to be subtracted from 100 which gives the water content and is result of hydration during sub aqueous alteration and not original volatile content of magma. Then EPMA data needs to be recalculated to 100 % which allows us to compare with the published data. Minor and trace element composition of glass offer one of the best means of discriminating between tephra layers. Bulk analytical techniques of these elements are below detection limit of microprobe. The elements such as Sc, Y, Zr, Hf and REE are small highly charged ions and are more stable under weathering conditions have potentially useful for correlation purpose. The most commonly used in determining their concentration are ICP-MS, neutron activation method and XRF.

The important control on morphology of glass shards are the properties of magma and eruptive mechanism. The shard morphology is commonly an excellent diagnostic character of particular tephra. The morphology of glass shards can be achieved with Scanning Electron Microscopy.

The stratigraphic value of ash layer is greatly enhanced if its age and paleomagnetic properties are known. The ash layers can be dated by K-Ar, fission-track, ^{40}Ar - ^{39}Ar and ionium dating techniques. However, oxygen isotope, biostratigraphy and magnetic polarity of associated components can provide age of ash layers.

In this presentation, only primary volcanic sources such as ash layers and pumice from CIOB are presented here. Though secondary volcanic products such as Fe-rich smectite, zeolites, volcanogenic hydrothermal material

(vhm) and magnetic spherules are observed in CIOB by number of authors and are not discussed here.

Glass shards are fresh, colorless, bright, and isotropic without any alteration. Majority (70 -90 %) of the shards exhibit bubble wall junction type morphology, followed by platy and blocky in southeastern Arabian Sea, Bay of Bengal and Central Indian Ocean Basin (CIOB). This morphology suggests magmatic type of eruption and precludes any in-situ origin.

Chemical analysis of glass shards contain high SiO₂ (~ 77 %) and total alkalis (~ 8 %) suggesting rhyolitic nature. These shards have moderate content of FeO (0.9 %) and CaO (0.79%) but with very low TiO₂ (0.07 %), MnO (0.06%) and MgO (0.05%) contents and compositionally identical to those of fallout deposits of the Youngest Toba Tuff (YTT) at ~74 ka from Northern Sumatra. Sometimes during microprobe analysis due to high electron beam there will be loss of alkalis as a result SiO₂ content will be increased. The rare earth elements (Σ REE) content of these glass shards have ~ 130 ppm and their chondrite-normalized pattern show light REE enrichment compared heavy REE and with a strong negative Europium anomaly. The total REE content and chondrite – normalized pattern matches very well with that of glass shards from ODP site 758 and from Northern Sumatra. This clearly suggests that ash layers present in Arabian Sea, Bay of Bengal and Central Indian Ocean Basin are of YTT of ~ 74 ka of Northern Sumatra origin. The correlation extends glass shards about 1500 km south of the previously known fallout zone into Southern Hemisphere. Recently, glass shards of YTT origin have also been reported in South China Sea which is northeast of Toba caldera and traveled about 3000 km subaerially.

The new occurrence of YTT in Central Indian Ocean Basin covers an area of ~ 3.2 x 10⁶ km². The average ash thickness in CIOB is of 10 cm. Our new ash volume estimates an additional volume of about 160 km³ to the earlier volume of 350 km³. The recent new occurrence of YTT in southeastern Arabian Sea, Murray Ridge and South China Sea, the actual volume would have been more than double compared to its original estimates of 350 km³.

Recently, in a number of long sediment cores from CIOB, there is co-occurrence of ash layers and microtektites. We selected two sediment cores: one from siliceous ooze at 3° S and other one from red lay area at 17° S. Co-occurrence of ash and microtektites occur at 165 cm and 65 cm sub surface depth of siliceous and red clay cores respectively. The epma data of microtektites and their morphology suggest that they are of Australasian microtektites of 0.8 Ma origin. The epma data of glass shards suggest that they are rhyolitic in nature and their chemical composition and morphology correlates well with

Layer D from ODP site 758 in Bay of Bengal, South China Sea and from Northern Sumatra which are known as Oldest Toba Tuff (OTT) of ~ 0.8 Ma. Chemically Layer-D/OTT and YTT are very similar but they can be differentiated by their occurrence at different depths in the sediment cores. The area covered by OTT also appears to be similar to YTT. Therefore it appears that both YTT and OTT are supereruptions.

Presence of ash layers in the bulk sediment has large implications. In CIOB sediment cores Al/Ti ratio reaches up to 48 and is nearly three times higher than Post Archean Australian Shale (16.7). This suggests that there is structurally unsupported Al or Al excess. The plot of Al vs Ti shows that best fit line intersects Al axis at 3% suggesting there is enough structurally unsupported Al. Earlier, in Pacific and Indian Ocean it was suggested that dissolved Al is scavenged by biogenic components resulting strong positive association between Al excess and biogenic opal content. Such a relation is not observed in these short sediment cores which contain ash layers. Therefore, Al excess in the cores is not due to productivity but is because of glass shards with rhyolitic composition. Similarly glass shards content increases the coarse fraction (>63 μ m) because of its higher density which should not be mistaken for productivity. On the other hand, elements like Fe, Ti, Mg, Mn, Cu and Ni are all diluted by glass shards because these elements content is lower than the associated sediment. Therefore one has to careful while interpreting bulk chemical data without looking into coarse fraction particularly Bay of Bengal, CIOB and Arabian Sea where ash layers have been reported.

Pumice is a common product of volcanic eruption, porous in nature, low density and is the only rock which can float for few months and be transported thousands of kilometers depending upon the connectedness of vesicles. Earlier studies in CIOB suggested that pumice is of *in-situ*, Krakatau 1883 and Indonesian arc volcanic sources. Recently, we have carried out major, trace and REE data of number of pumice in CIOB and suggest that they are from YTT source.

Our investigation suggests that ash layers in CIOB are of YTT and OTT origin and pumice is also from YTT. This indicates that CIOB is the sink for volcanic products in addition to in-situ origin.