

Tephra from Quaternary sediments of western slope of Lakshadweep Ridge, Arabian Sea

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Extensive occurrence of fallout tephra in the Quaternary sediments of Arabian Sea is observed in the gravity cores collected from western slope of Lakshadweep Ridge between water depths of 2505 and 3481 m. The Western Lakshadweep Tephra (WLT) layer is associated with olive grey to dark grey, pelagic to hemi-pelagic clay and bioclasts, and occurs between depths of 95 and 156 cm below seafloor. The tephra layers are admixed with clayey sediments and are relatively hard, compact and partly dehydrated with lesser amount of biogenic material.

The glass shards associated with the sediments are fresh, colourless and transparent with abundant pale-brown pyroclastic aggregates. The glass shards are mainly bubble wall type, with some having forms like cusped, curved platy, multi-junctional and pipe vesicles. The high silica, alumina and K₂O and low FeO and MgO indicate rhyolitic composition of glass shards. In the Or–Ab–An plot the samples fall in the rhyolite field. Major element chemistry and morphology of WLT suggest Youngest Toba Ash as their source. This tephra-bearing zone may be used as a marker horizon for stratigraphic correlation and calculating the rate of sedimentation.

Keywords: Arabian sea, chemistry, shard morphology, Tephra.

VOLCANIC ash is an extraordinarily complex material, which typically consists of a mixture of crystals of several minerals, shards and frothy network of silicic glass, lithic fragments and wide variety of non-silicate particles derived from eruptive volatiles¹. Large volume of ash vents into the atmosphere when the rising magma mixes with water at or near the surface to produce ash deposits in sporadic and energetic steam blasts².

The intensity of explosion varies depending upon the magma composition and volatile content. During an explosive eruption, the larger particles thrown into the atmosphere settle in the immediate vicinity of the vent. But the very fine-grained ash particles (<2 mm) with residence times of 10⁴ days in the atmosphere get transported to thousands of kilometres away from the source before deposition. During atmospheric transportation, the ash particles get differentiated based on their size. Preservation

of this volcanic ash on land is generally rare owing to anthropogenic activities. On the other hand, in the open sea where the rate of sedimentation is very low, the ash particles settle through the water column and get preserved as thin layers within pelagic sediments.

While delineating the boundary of Toba tuff distribution in the western Bay of Bengal, Ninkovich *et al.*³, Rose and Chesner⁴ have extended the western limit of the fallout zone up to northeastern part of the Indian Ocean south of Indian Peninsula. Korisettar *et al.*⁵ have reported the occurrence of tephra bed in the Quaternary sediments of Maharashtra, Peninsular India. Acharyya *et al.*⁶ have correlated the ash layer marker in the Late Pleistocene sediments within the Indian subcontinent with those of Toba tephra layers reported in the deep sea cores of Indian Ocean and Bay of Bengal. The rare earth element (REE) signature of fallout tephra in the Quaternary sediments of the Arabian Sea was compared by Nambiar *et al.*⁷ with that of Toba tephra. Bühring *et al.*⁸ studied the dispersal of ashes from Sumatra in both western and eastern directions and suggested that the Toba eruption probably happened during the Southeast Asian summer monsoon season and the volume of erupted magma was larger than previously interpreted. Pattan *et al.*⁹ studied the tephra layer from the western continental margin of India and concluded that the glass shards have high SiO₂ (77%) and total alkalis (8.5%), indicating rhyolitic composition. Based on the major, trace and REE composition of these glass shards, it was suggested⁹ that the tephra layer from the western continental margin of India is indistinguishable from that of Youngest Toba ash of ~74 ka from the Northern Sumatra. Pattan *et al.*¹⁰ studied the major, trace and REE composition and morphology of the shards of Central Indian Ocean Basin and observed that Youngest Toba Tuff (YTT) of ~74 ka of Northern Sumatra as the source for the ash. The source, transport and deposition of distal ash-fall layers in the Arabian Sea, from violent ultra-Plinian eruptions of the Indonesian volcanic archipelago, were discussed by Von Rad Ulrich *et al.*¹¹. This study suggests the use of YT ash (70 ± 4 ka BP) found in the Arabian Sea and Bay of Bengal sediments, in the palaeo-climatic correlation.

The area is blanketed by pelagic to hemi-pelagic silty clay sediments with abundant foraminiferal and radiolarian tests of recent origin. The sediment column in general consists of yellowish brown to brown (10YR 5/3-6/3), laminated clay at the top (40–70 cm) followed by olive grey to dark grey (5Y6/2-4/1) laminated compact clay. The tephra layers are admixed with silty clay and biogenic debris and are relatively hard, compact and partly dehydrated with lesser amount of biogenic material. The tephra layers are picked up at depths ranging from 95 to 156 cm below the seafloor with a peak of abundance in between and the thickness of the overlying sediments decreases further towards the abyssal plain. The tephra zones are identified by the presence of glass shards and

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pyroclastic non-crystalline aggregates. The glass shards become dominant in the peak zones (Figures 1 and 2).

Seven gravity cores (Gc-1, 2, 3, 4, 5, 6 and 7) collected from the western slope of Lakshadweep Ridge during the cruise of the Geological Survey of India Research Vessel *Samudra Manthan*, at water depths ranging from 2505 to 3481 m were studied to identify the tephra zone (Figure 3). About 15–20 g of sub-samples were taken along the entire length of the core for preliminary scanning and identification of the tephra layers.

The samples after dispersion with ammonia solution were sieved using 270 ASTM mesh (0.053 mm size) to separate the coarse fraction. The coarse fraction was then treated with dilute HCl to remove shell carbonates and

washed repeatedly. The dried samples were studied under binocular microscope. After identifying the tephra zones in the cores, the process was repeated with more quantity of tephra-bearing samples. The coarse fractions containing glass shards and other non-carbonate debris were further purified using Isodynamic separator at 1 Amp with 25° forward slope and 15° tilt. The tailings were enriched with glass shards, however the pale brown non-carbonate lapilli sized aggregates associated with glass shards could not be eliminated completely. Although a few glass shards are sporadically present at some other levels in the core, the enriched zones only are recognized as significant tephra layer. Cores Gc-1 and 4 do not contain any prominent tephra layer. The separated shards are analysed by AAS (Varian SpectrAA-30) at the Chemical Laboratory of GSI, Mangalore. Morphological characters of glass shards were studied with the help of SEM photographs taken at Palaeontological Division, Southern Region, GSI, Hyderabad.

The glass shards separated are fresh, isotropic, colourless and transparent with lots of pale brown lapilli sized non-carbonate aggregates. The glass shards are very fine grained, elongated, and size varies from 50 to 118 μm (Figure 4). The non-carbonate biogenic components include radiolarian tests and sponge spicules. Mineral fragments associated with tephra are chiefly fresh angular transparent quartz grains, and sporadic crystals of microcline, plagioclase, biotite, hornblende, rutile and some opaques. Presence of a zircon grain is observed in one sample.

The glass shards are mainly of bubble wall type with subordinate amount of forms like cusate, curved platy, platy, triradiate, multijunctional and pipe vesicles. Long

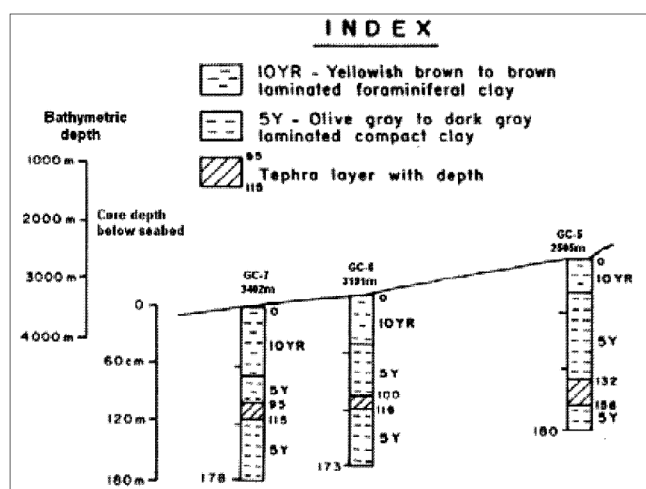


Figure 1. Core lithlog and distribution of tephra along transect 13°10'N latitude.

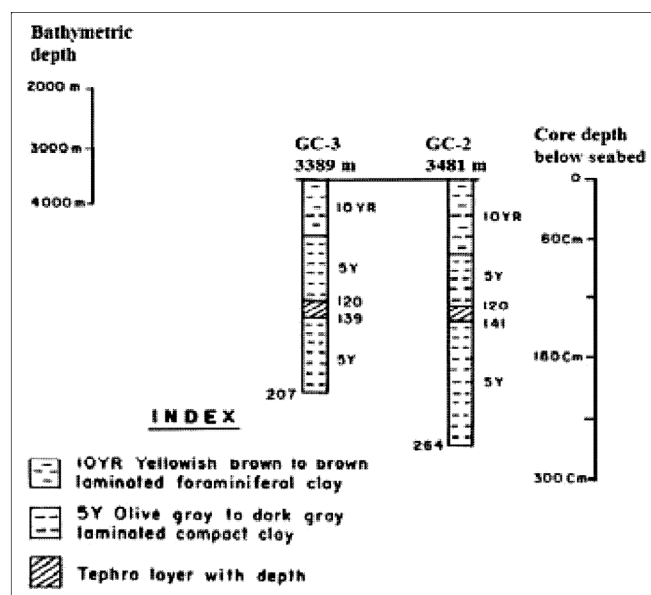


Figure 2. Core lithlog and distribution of tephra along transect 75°15'E longitude.

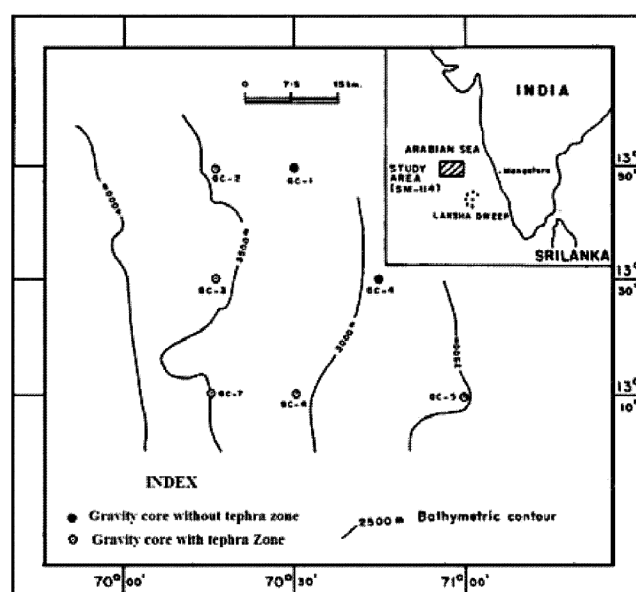


Figure 3. Sample location map.

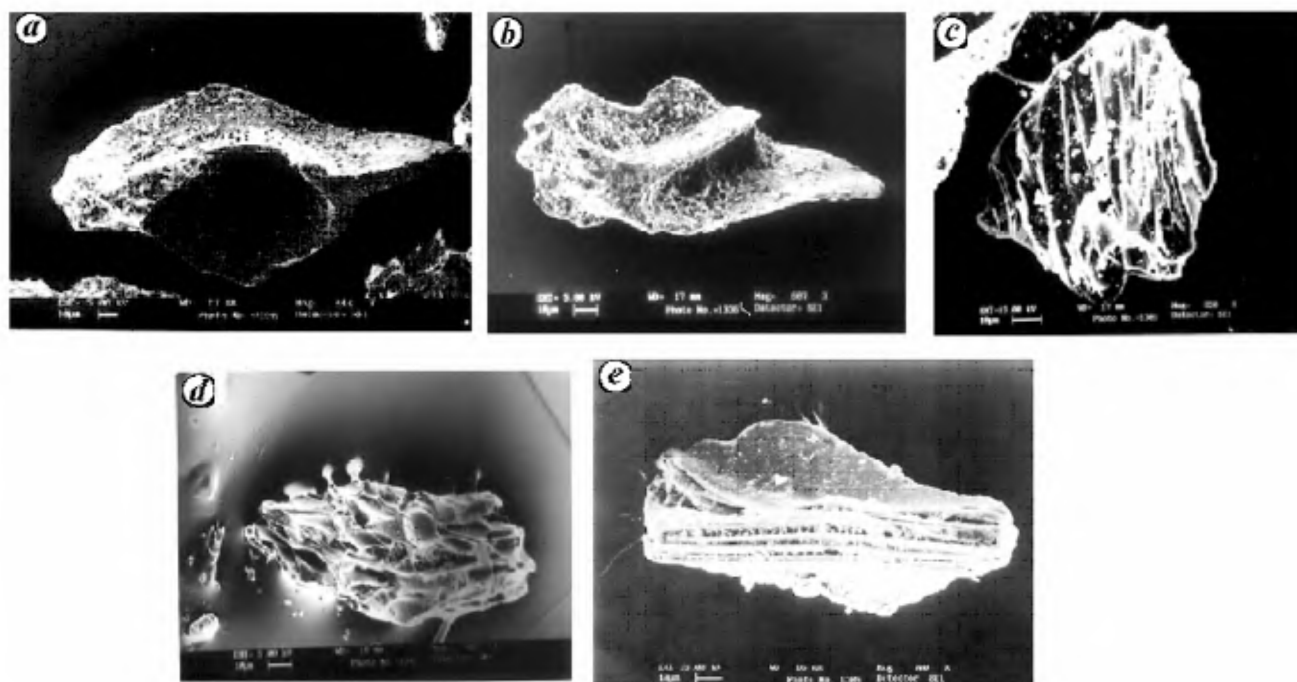


Figure 4. *a*, Broken bubble wall showing the size of a vesicle remnant; *b*, Coalescence of bubbles results in multi-junctional forms; *c*, Sub-parallel pipe vesicles; *d*, Discontinuous parallel pipe vesicles; *e*, Curved platy shard with sub-parallel pipe vesicles.

and sub-parallel pipe vesicles are noticed in many shards. The shards have walls of moderate thickness (5–7 μm) with sharp edges. The sharp edges are indicative of scant reworking. Figure 4 shows the SEM photographs of forms like triradiate and pipe vesicles. The low radii of curvature of the shard fragments are indicative of the smaller size of the bubbles. Figure 4*a* shows the actual dimension of a partially broken vesicle remnant. Coalescence of two or more bubbles has resulted in multijunctional bubble morphology (Figure 4*b*). The parallel to sub-parallel arrangement of pipe vesicles is clearly brought out in Figure 4*c* and *d* and may be indicative of highly viscous parent magma. Figure 4*e* shows the magnified SEM photograph of parallel pipe vesicles. The fineness and prominent curved platy nature of glass shards and ratio of abundance of glass shards against the pyroclastic aggregates point out that the tephra are possibly products of later phases of eruption.

Chemical composition of the glass shards is given in Table 1. The high silica, alumina and K_2O contents along with low Fe_2O_3 and MgO show their compositional proximity to rhyolite and rhyodacite and also the acidic nature of the parent volcanism. The tephra has 35.92–36.15% normative quartz, 22.16–22.46% orthoclase, 23.19–23.95% albite, 4.96–5.21% anorthite and 3.26–4.68% hypersthene (Table 2). In Or–Ab–An plot, the samples fall in the rhyolite field (Figure 5). The plot for GC-3 falls in the rhyolite field whereas GC-5 and M2 fall almost along the boundary between the rhyolite and rhyodacite field. M1 and M3 fall nearer to the line sepa-

rating alkali rhyolite and rhyodacite. The shift towards rhyodacite field for GC-3, 5 and M2 may be due to the changes in chemical composition brought about by marginal post-depositional alteration.

For understanding the post-depositional changes if any in the chemical composition of the glass shards due to the interaction with seawater, their Alteration Index (AI) was calculated using the formula suggested by Vivallo¹².

$$\text{AI} = \frac{\text{K}_2\text{O} + \text{MgO}}{\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{MgO} + \text{CaO}} \times 100.$$

An AI of 50 indicates lack of any alteration. Hence unaltered composition of the parent rock is arrived by drawing a parallel to the y -axis starting from the x -axis at AI 50 and taking the value of intersection with the regression line for individual elements.

The AI of all the four samples fall within a range of 50–53 indicating only a marginal change in the chemical composition. The computed original composition of the tephra glass using AI vs major element plot is given in Table 1. The comparison of the calculated original composition of the glass shards with that of the WLT indicates the enrichment in FeO and MgO and the depletion in SiO_2 , CaO , K_2O , Na_2O and MnO in the latter. The content of Al_2O_3 almost remained unchanged. The calculated composition of the tephra glass almost corresponds to that of M1 with an AI of 50. The changes in the chemical composition of the shards can be attributed to the post-

depositional alteration due to the interaction with seawater.

The active volcanic regions nearest to the present area are the Indonesian Arc and Red Sea, of which Red Sea volcanism is dominantly basaltic in composition. The

Table 1. Major oxides percentage in Western Lakshadweep Tephra

Oxides	GC-3	GC-5	M1*	M2*	M3*
SiO ₂	70.70	71.04	71.80	72.20	71.87
TiO ₂	0.15	0.15	0.14	0.11	0.13
Al ₂ O ₃	13.00	13.20	13.10	12.90	13.10
FeO	1.39	1.93	0.85	0.90	0.80
Fe ₂ O ₃	0.16	0.22	0.15	0.15	0.15
MnO	0.05	0.04	0.07	0.06	0.07
MgO	0.40	0.60	0.25	0.35	0.22
CaO	1.00	1.05	1.65	2.20	1.80
Na ₂ O	2.83	2.74	3.70	2.80	3.56
K ₂ O	3.80	3.75	5.10	5.10	5.20

M1* Glass shard fraction, from the top of the 90°E Ridge.

M2* TOBA (Si Gura, Id 680); welded tuff sample.

M3* Unaltered composition of the parent magma calculated using Alteration index.

Table 2. CIPW weight norm

Mineral	GC-3	GC-5	M1	M2	M3
Quartz	35.92	36.15	27.20	31.26	27.41
Orthoclase	22.46	22.16	30.14	30.14	30.73
Albite	23.95	23.19	31.31	23.69	30.12
Anorthite	4.96	5.21	4.08	7.57	4.41
Corundum	2.41	2.72	—	—	—
Diopside	—	—	3.21	2.65	3.55
Hypersthene	3.26	4.68	0.33	0.99	—
Magnetite	0.23	0.32	0.22	0.22	0.22
Ilmenite	0.28	0.28	0.27	0.21	0.25
Apatite	—	—	0.12	—	—
Wollastonite	—	—	—	—	0.14

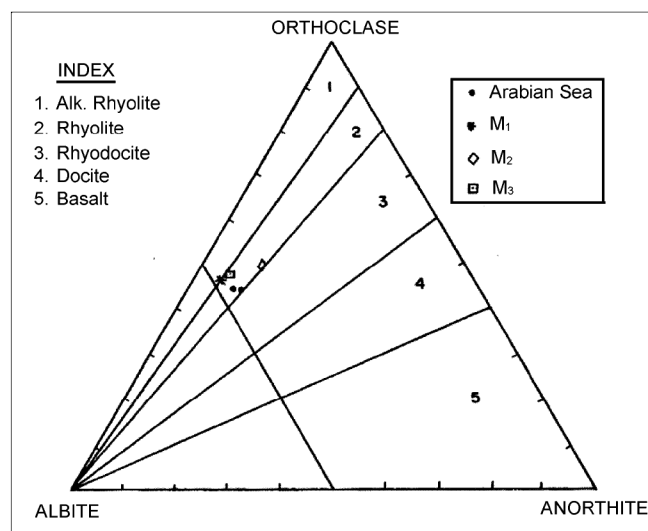


Figure 5. Or-Al-An plot.

mid-ocean ridge associated volcanism is also not silicic and explosive. Known for subduction-related silicic volcanic activity throughout the Tertiary and Quaternary, the Indonesian Arc is the most likely source for WLT. The Toba caldera in North Sumatra located in Indonesian Arc was the site of earth's largest and the most widespread explosive eruption, the YTT, which occurred around 75 ka (ref. 4). As already stated, distribution of YT ash is tracked up to south of Indian peninsula in the Indian Ocean in deep sea cores³ and in Quaternary river valley sediments in Peninsular India also⁶. Isothermal fission track dating has fixed the distal YTT at $68,000 \pm 7000$ YBP¹³ and dating of tephra samples from the western Peninsular India has also indicated an age of 75,000 YBP. It was decided by the eminent volcanologists that all reported Toba tephra occurrences in India are related with YTT volcanism¹⁴.

The chronological status of WLT is tentatively arrived with the help of data on average rate of sedimentation determined by Kalluraya¹⁵ and Sarkar¹⁶ in the western slope of the Lakshadweep domain. The sedimentation rate of 2.25–2.3 cm/ka is calculated using C¹⁴ and δO^{18} from the cores collected from water depths of 2077 and 2523 m respectively^{15,16}. Since the core no. Gc-5 is located in the identical physiographic set up, it is taken for comparative study. An age of 68,000–69,000 YBP for the tephra layer present in this core between 132 and 156 cm below seafloor is determined based on the above sedimentation rate, which is comparable with that of YTT. It is pertinent to mention here that since the rate of sedimentation decreases westwards (Figure 1), the above rate of sedimentation cannot be applied for determining the chronological status of WLT recovered from deeper areas.

On the basis of compositional identity, Pattan *et al.*¹⁷ have suggested that the volcanic glass and pumice found in siliceous abyssal sediments of the Central Indian Basin are fallout deposits of the YTT erupted at 74 ka from northern Sumatra. Occurrence of Youngest Toba Tephra of about 74,000 YBP is also reported from the Western Continental Margin of India⁹.

Geo-chemical signature of major elements, morphology of glass shards and chronological status based on rate of sedimentation indicate that WLT is a product of YT volcanism. Considering the extensive occurrence of WLT, it can be used as a marker horizon for stratigraphic correlation and for determining the rate of sediment accumulation.

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ACKNOWLEDGEMENTS. We thank Shri V. K. K. Kalluraya, Dy. Director General, Geological Survey of India, WCO-1, Marine Wing, Mangalore for encouragement, logistic support and permission to publish this paper. We also thank Palaeontology Division Southern Region, GSI, Hyderabad for providing SEM photographs of the glass shards and Chemical Laboratory, Mangalore for AAS analysis. We thank the participants of cruise SM-114 for their co-operation.

Received 24 October 2008; revised accepted 4 September 2009

MEETINGS/SYMPOSIA/SEMINARS

International Conference on Recent Trends in Graph Theory and Combinatorics (ICRTGC-2010)

Date: 12–15 August 2010

Place: Cochin, India

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