ASH LAYERS FROM SOUTH ANDAMAN SEA: PROBABLY SOURCED FROM TOBA CALDERA

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ABSTRACT: Deep Sea sediment core PC-1 from the South Andaman Sea (7˚19.85' N; 94˚ 39.26' E; in East Andaman Basin) below the water depth of 3144 m contain discrete ash layers at various depths. According to morphological study, these ash layers contain glass shards of different varieties *i.e.* Type-I, Type-II, Type-III, Type-IV and Type-V and it is comparable to glass shards of Toba volcanic reported from other parts of the world. This observation is also supported on the basis of relative biostratigraphic datum observed in the core PC-1. The Layer-A (56 cm thick) at 210 cm bsf is just above the biostratigraphic datum of *ca.* 0.12 Ma, correspond to Youngest Toba Tuff (YTT), followed by Layer-C belongs to Middle Toba Tuff (MTT) and Layer-D inferred as Oldest Toba Tuff (OTT). This interpretation is further supported by the geochemical data obtained from the EDX analysis, which suggest high silica and alkali contents of rhyolitic composition. Hence, geochemical composition, morphology and biostratigraphic data of these discrete tephra layers show identical characteristics to the products of Toba eruptions, including YTT, MTT and OTT.

Keywords: Glass shards, Andaman Sea, Toba ash, YTT, MTT and OTT

INTRODUCTION

The Toba caldera on the Sumatra Island is the largest known explosive volcanism on earth during the Quaternary period, at least in the last 100,000 years (Smith and Bailey, 1968; Rose and Chesner, 1987; Zielinski et al., 1996; Oppenheimer, 2002). Over the past 1.2 Ma, there have been four ash flow tuff eruptions noticed from the caldera complex (Chesner and Rose, 1991; Chesner et al., 1991). The youngest Toba tuff (YTT) was erupted at 74 ka (Ninkovich *et al.,* 1978; Chesner et al., 1991) and has a minimum volume of 2800 km^3 (Rose and Chesner, 1987). The other Toba eruptive products are the Middle Toba Tuff (MTT) erupted at *ca.* 0.50 Ma ($^{40}Ar/^{39}Ar$), Chesner et al., 1991) and the Oldest Toba Tuff (OTT) eruption was at *ca.* 0.84 Ma ($^{40}Ar/^{39}Ar$, Diehl *et al.,* 1987). The total erupted rock volume of YTT was approximately 3 orders of magnitude greater than Mount St. Helens' 1980 eruption (Robock et al., 2009).

The Toba ash layer and dispersed glass shards from the Toba caldera eruption in northern Sumatra have been reported from Malaysia, the northern and central Indian Ocean, Arabian Sea and South China Sea (Figure 1; Ninkovich et al., 1978; Dehn et al., 1991; Schulz et al., 1998; Pattan et al., 1999; Bühring and Sarthein, 2000, Pattan et al., 2002; Liu et al., 2006; Pattan et al., 2010). Apart from Sumatra Island and the northern Indian Ocean, Toba tephra has been found in Quaternary sediments throughout the eastern and central part of Indian peninsula, particularly in lower Narmada basin and central Narmada valley (William and Royce, 1982; William and Clarke, 1984; Rose and Chesner, 1987; Basu et al., 1989; Biswas et al., 1989; Acharyya and Basu, 1993; and Rachna, 2008). Toba eruptive products have also been reported from other parts of India, including along the Kukadi River at Bori, Maharashtra (Korisettar et al., 1989), Mahanadi and Brahmani River basins (Devdas and Meshram, 1991) Goguparhu, Kareni and Guruwara (Acharyya and Basu, 1993), Vansadhara and Nagavali River basins (Devdas and Meshram, 1991), and Sagileru River basin, Andhra Pradesh (Acharyya and Basu, 1993).

Moreover, other researchers also reported detailed analysis from site-758 core and identified the presence of multiple ash layers at various depths represented as layer A, C, D and E (Dehn et al., 1991, Pattan et al., 2010; Pearce et al., 2014). These different eruptive episodes of Toba correspond to layer A as YTT (1.5 m to 1.84 m), layer C corresponds to MTT (7.12 m to 7.35 m), layer D to E corresponds to OTT (10.8 m to 10.93 m; 11.62 m to 11.67 m) respectively. Similarly, we documented the presence of several ash layers in the South Andaman Sea (7˚19.85' N; 94˚ 39.26' E; in East Andaman Basin; at a water depth of 3144 m) during onboard R. V. Samudra Ratnakar expedition cruise of Geological Survey of India. In 28.95 m length of Piston Core (PC-1), distinct ash layers were discovered at depths of 2.10 m to 2.66 m**,** 13.50 m to 14.50 m and 18 m to 24 m below sea floor (bsf). Geochemical,

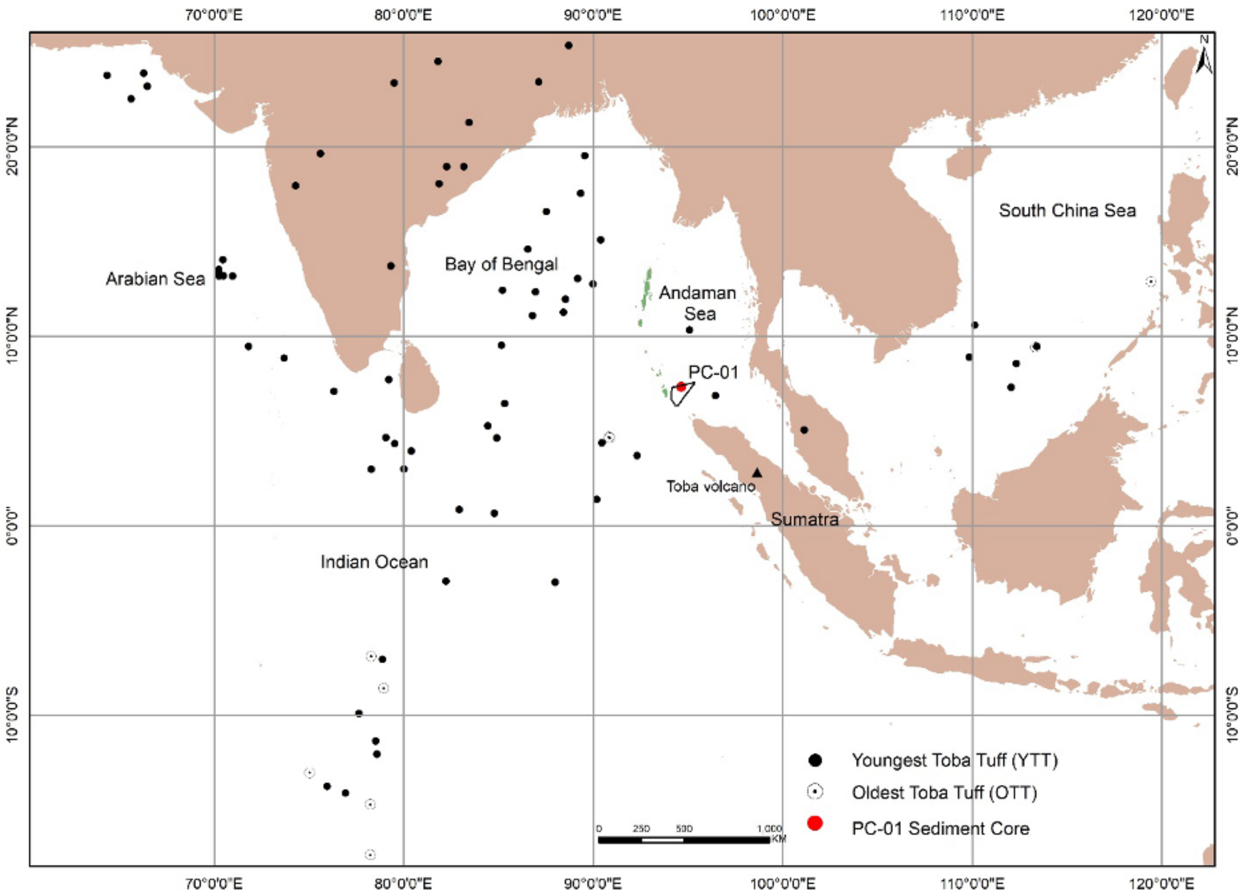

Figure 1. Toba Tuff distribution map around northern part of Indian Ocean, Bay of Bengal, Indian Subcontinent, South China Sea and Andaman Sea along with core location (modified after Liu et al., 2006).

morphological and stratigraphical, analyses were performed in this study to better understand the relationship between these ash layers and Toba Volcanics.

Geological setting of study area

Study area is located at East Andaman basin in a complex back-arc extensional setting, along highly oblique convergent margin of overriding Eurasian Plate and subducting Indo-Australian Plate (Figure 2; McCaffrey, 1991; Curray, 2005; and Cochran, 2010). Initially, a proto-Andaman Sea is thought to have existed as an extensional basin in place of the present Mergui-North Sumatra that shifted westward probably as a consequence of the Early Miocene intercontinental under thrusting to a location between the Alcock and Sewell seamount complexes (Curray, 2005). The north-south ridge system opened the eastern Andaman Sea by drifting from the main land of Malay Peninsula during early Tertiary (Curray, 2005). Later, the extension of the Andaman Sea kept on changing which was initially almost E-W and WNW-ESE during Late Palaeogene and highly oblique extension (NNW-SSE) during Neogene (Morley, 2017). The plate edge assumed to be the Sagaing Fault (SF) that was directly associated with the former West Andaman Fault (WAF) in the Early Oligocene (Curray, 2005). The present plate edge is the Sagaing Fault in Myanmar, which passes through the system of short spreading axes and transform faults to the longer spreading axis, then southward on the WAF, Seulimeum fault system (SEU) and Sumatran fault system (SFS) (Figure 2).

The WAF and SFS separate the geomorphic configuration of back-arc region of the East Andaman Basin and North Sumatra basin from the fore-arc basin. However, the western boundary of the sample area is adjacent to the SEU, in the southern part having mixed response of strike-slip as well as normal-fault (Curray, 2005; Figure 3). The WAF on the other hand, runs roughly N-S direction as a prominent tectonic and physiographic feature extends for more than 1000 km, in the western part of the Andaman Sea and eventually merging with SFS around Great Nicobar and finally abutting to the Sunda Subduction Zone (Curray, 2005; Figure 2). An active SEU traced along the submarine volcanic arc and extends up to the West Sewell Ridge (WSR), and converges with the SFS at 5˚N. A series of submarine volcanoes with well-developed craters aligned parallel to the Subduction zone exist along the SEU fault system (Tripathi et al., 2018; Figure 3).

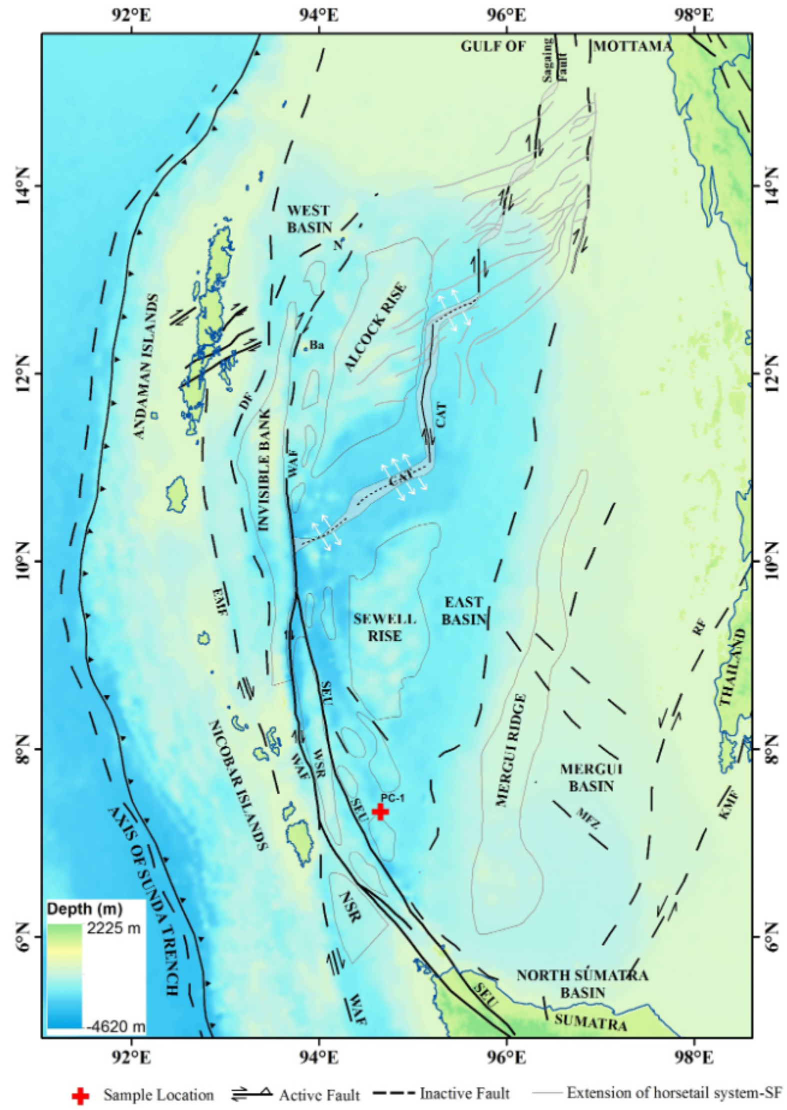

Figure 2. Map depicts disposition of major lineaments in the Andaman Sea. Abbreviations for this figure: Ba= Barren Island, N = Narcondam Island, DF = Diligent Fault, EMF= Eastern Margin Fault, NSR = North Sumatra Ridge, SEU = Seulimeum fault, WAF= West Andaman Fault, CAT= Central Andaman Trough, White arrow shows extension regime within the CAT spreading axis (after Curray, 2005 and Diehl et al., 2013).

METHODOLOGY

The study is primarily focused on the ash layers discovered at a depth of 2.10 m to 2.66 m bsf, with sediments showing variation from the silty clay to clayey silt (Figure 4). The colour of the ash layer is pale grey. It is also noticed that the glass shards abundant in range between 2.10 m to 2.36 m and down to 2.36 m, pumice is gradually increasing and glass shards are significantly reducing (Figure 4). Apart from 2.10 m ash layer, many other discrete glass shards layers were observed at various depths with the main zones at 13.50 m to 14.50 m and 18 m to 24 m. Entire sediment core was sampled at 2 cm interval for coarse fraction study. To eliminate organic components, subsampled ash layers were treated with 6% hydrogen peroxide. To remove the carbonate material, mild hydrochloric acid was added later. The ash layers were then wet sieved through > 63 µm mesh and oven dried for further study. The glass shards were handpicked under a binocular microscope and separated samples were then subjected to a detailed morphological study under Scanning Electron Microscopy (SEM). To determine the origin of the ash layers, the major element composition was determined by using the technique developed by Westgate and Gorton (1981), utilising an Energy Dispersive X-ray Spectroscope (EDX). SEM-BSE-EDX analysis on representative glass shards separated from PC-1 sediment core was performed using ZEISS EVO 40 of Carl Zeiss AG that installed at NCEGR, GSI, Kolkata. The separated and handpicked glass/pumice shards were mounted on the carbon tapped stubs that had been carbon coated and scanned under electron microscope to study the morphological aspects and achieve high resolution images. All the elements were analysed using normalized standards of MAC (25mm × 5mm Brass). To determine the elemental composition of shards components, X-ray

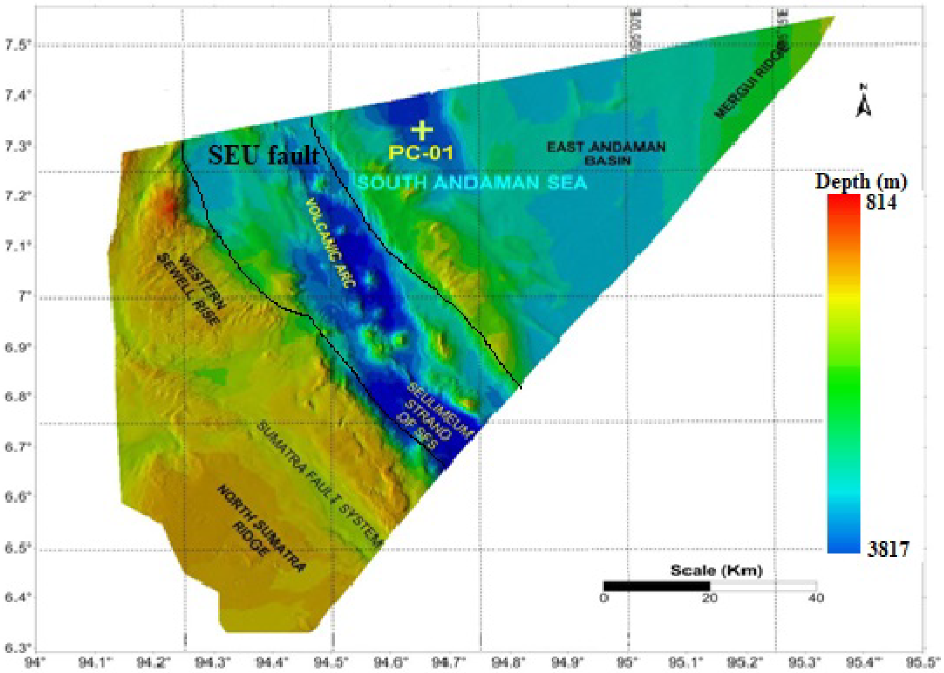

Figure 3. Swath bathymetric map depicting major morpho-tectonic features of South Andaman sea.

spectroscopy (EDX) analysis was done. As operational parameters, an accelerating voltage of 10 - 20 kV and an electron beam current of 12 nA focused to 1 µm spot size were used for the analyses. Along with sedimentological studies, micropalaeontological studies were also carried out to determine the relative age of the sediments and their depositional environment.

RESULTS AND DISCUSSION

The microscopic study of the coarse fraction indicates the presence of radiolarians, biotite, rock fragments and glass-pumice shards of varying abundance. The glass shards are fresh, unaltered, colourless and blocky in nature, whereas pumice shards are white to colourless and extremely vesiculated in nature. The average size of the glass shards ranges between 10 and 300 µm. Glass shards with blocky fractures are completely absent at the top of representative sample and scarce at the bottom indicating a prominent source. A detailed study has been carried out below to establish the possible link with Toba volcanic to pinpoint the possible source.

Morphology

In SEM study, various types of glass shards were noticed as mentioned in Figure 5. Shards are colorless, fresh, unaltered, and isotropic in nature with typical bubble wall junction morphology. Shards are mainly > 63 microns size and can be classified into five types (Figure 5). Type-I, glass shards are flat/oval in shape and are formed by disintegration of large flattened bubbles (Pattan

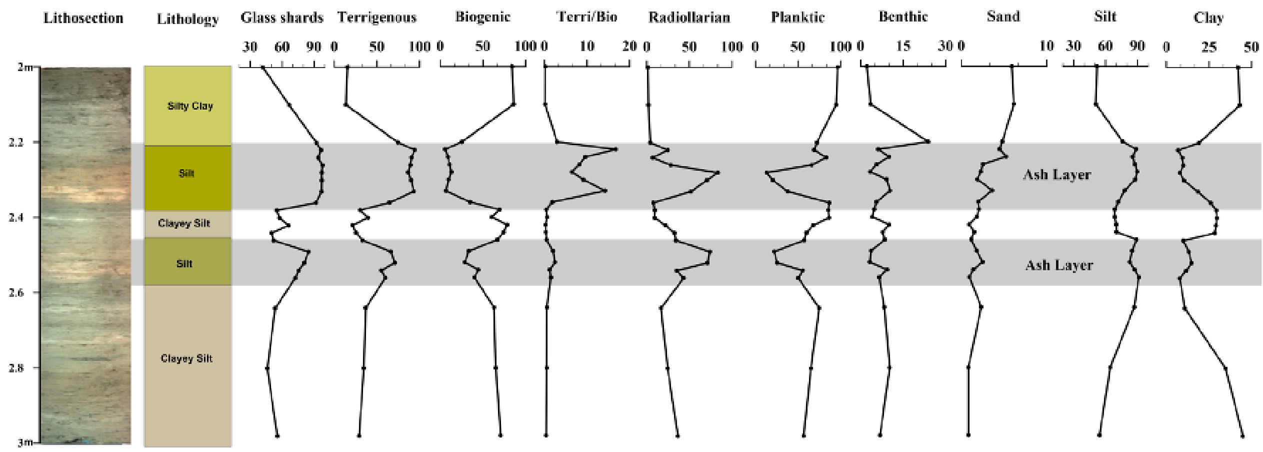

Figure 4. Coarse fraction data representing biogenic, terrigenous and glass shards data between 2 to 3 m of the studied core PC-1, depicts two prominent peaks of ash layer corresponding to YTT.

et al., 2002; Rose and Chenser, 1987). Type-II is distinguished by two to three bubble wall junctions, whereas Type-III are characterized by more than three or multiple bubble wall junctions. Type-IV forms the pumice shards with elongated vesicles, which are comparatively bigger in size and Type-V shards have fluid/gas inclusions. The glass shards consist of wall of tiny shattered bubbles or junction of bubbles formed by the vesiculation of silicic magma. Furthermore, Izett et al. (1981) proposed that pumice shards, bubble walls and shard wall junctions formed from high viscosity rhyolitic magma. A similar observation is seen in the analysed glass shards. The bubble wall nature and the characteristics of the glass shards indicate a subaerial volcanic source, which is almost similar to Toba ashes reported from Central Indian Ocean Basin (Dehn et al., 1991), Indian Subcontinent, Bay of Bengal (Rose and Chesner, 1987), South China Sea (Bühring and Sarnthein, 2000 and Liu et al., 2006).

Geochemical study

Major elemental compositions identified by X-ray spectroscopy (EDX) of the selected samples of glass shards is given in Table 1. The glass shards are high in silica and alkali contents; the SiO_2 content ranges from 77 to 82 wt %, and the alkali content ranges from 5 to 6 wt % that display a very little variation both within and between samples (Table 2). The EDX results of glass shards samples were plotted to TAS classification diagram of Le Maitre et al. (1989), and samples suggest rhyolitic composition (Figure 6). Major elemental composition gives high silica along with other associated elements Al_2O_3 (~10.5-12.5wt%) and FeO (~0.50-2.5 wt%). Silica versus K_2O plots demonstrate that the shards are falling in high K-field (Figure 7). Overall, geochemical contents of PC-1 glass shards showing its affinity with ash layers reported from CIOB (Pattan et al., 1999), Bay of Bengal (Gasparotto et al., 2000; Dehn et al., 1991), Indian Subcontinent (Shane et al.,1995), Northern Sumatra (Chesner, 1988) and South China Sea (Bühring et al., 2000; Song et al., 2000; Liang et al., 2001). Further, bivariant plots of SiO_2 vs Al_2O_3 and SiO_2 vs Na_2O shows comparable YTT characteristics. The comparative analysis of the glass shards suggest that the shards were probably derived from the Toba eruptions.

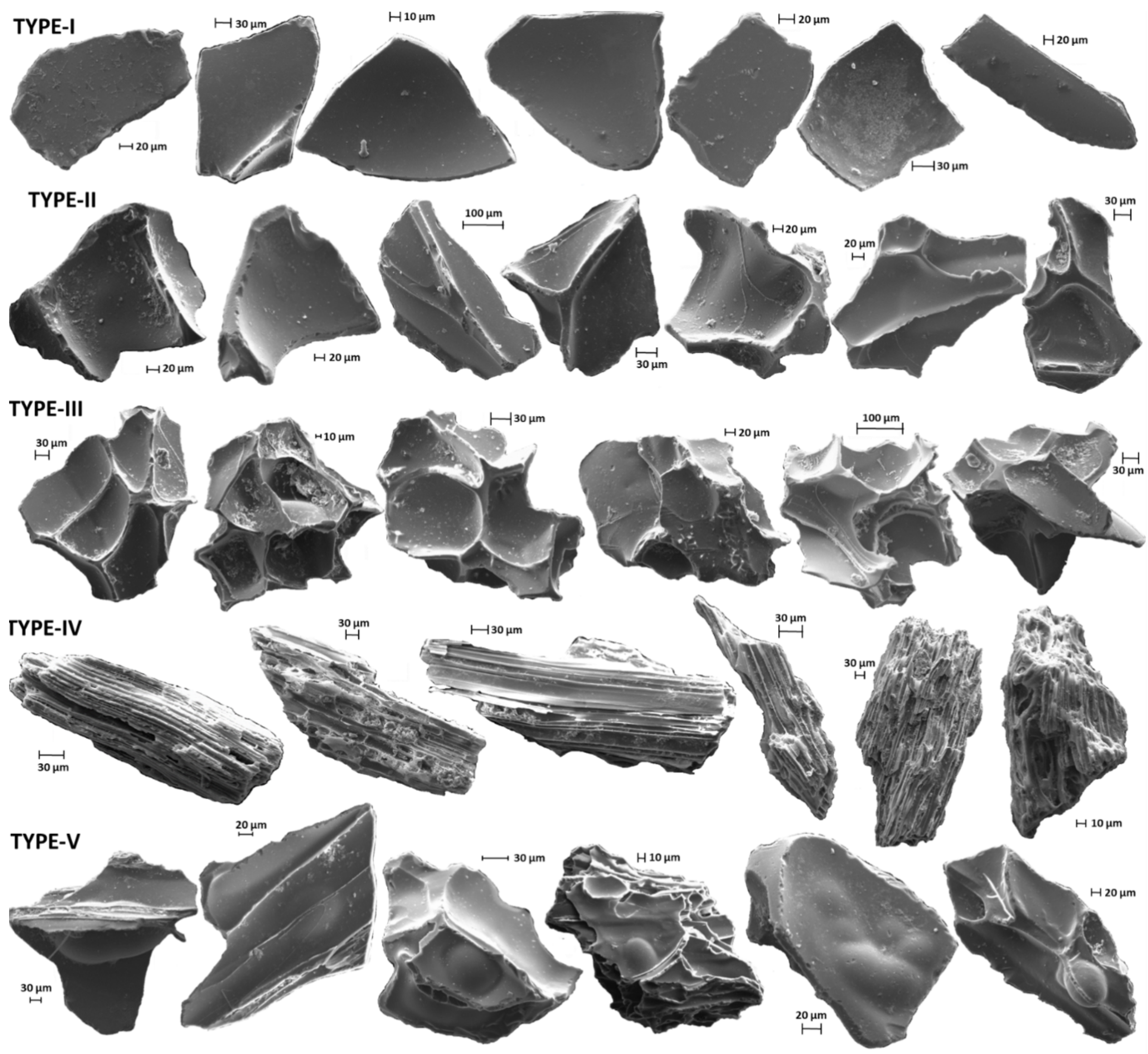

Figure 5. Types of glass shards based on the bubble wall junction morphology from Core PC-1 (Type-I: flat / oval shaped, Type-II: two- three bubble wall junctions, Type-III: more than three or multiple bubble wall junctions, Type-IV: pumice shards with elongated vesicles and Type-V: shards with fluid/gas inclusions).

Table 1: Major elemental composition (wt%) of the glass shards examined using energy dispersion spectrum (EDX) for 7 subsamples from the core PC-1.

Sl no.	*Sample no*	*Si*	*O*	*Al*	*Ca*	*Fe*	*K*	*Zn*	*Na*	*Cl*
1	PC-1/105	41.97	43.69	6.75	0.85	1.11	5.63	-	-	-
2	PC-1/110	42.01	42.81	6.78	0.2	2.09	5.89	0.22	-	0
3	PC-1/111	40.59	39.55	6.27	2.49	1.11	5.71	0.51	0.77	3.02
4	PC-1/112	35.33	54.37	5.89	0.28	0.16	3.83	0.13	-	-
5	PC-1/115	36.55	52.49	6.19	0.22	0.41	4.14	-	-	-
6	PC-1/116	34.98	53.71	6.14	0.57	0.4	3.93	-	0.53	-
7	PC-1/117	43.26	42.36	6.75	0.81	0.96	5.84	-	-	-

Table 2. Comparison of EDX results of major elemental composition of selected glass shards from sediment core PC-1 with major oxide compositions data taken from various selected literatures.

Sl no	*Location*	*Sample number*	*SiO_2*	*Al_2O_3*	*CaO*	*FeO*	*K_2O*	*Na_2O*
1	South Andaman Sea (PC-1)	*PC-1/105*	*80.21*	*11.39*	*1.06*	*1.28*	*6.06*	*0.00*
2	South Andaman Sea (PC-1)	*PC-1/110*	*79.72*	*11.36*	*0.25*	*2.37*	*6.29*	*0.00*
3	South Andaman Sea (PC-1)	*PC-1/111*	*77.87*	*10.63*	*3.12*	*1.28*	*6.17*	*0.93*
4	South Andaman Sea (PC-1)	*PC-1/112*	*82.22*	*12.11*	*0.42*	*0.23*	*5.02*	*0.00*
5	South Andaman Sea (PC-1)	*PC-1/115*	*81.69*	*12.22*	*0.32*	*0.55*	*5.21*	*0.00*
6	South Andaman Sea (PC-1)	*PC-1/116*	*80.32*	*12.45*	*0.84*	*0.55*	*5.08*	*0.76*
7	South Andaman Sea (PC-1)	*PC-1/117*	*80.69*	*11.12*	*0.99*	*1.08*	*6.13*	*0.00*
8	*Northern Bay of Bengal*	*Gasparotto et al., 2000*	*77.08*	*12.87*	*0.75*	*0.84*	*5.26*	*3.13*
9	*Southern Bay of Bengal*	*Dehn et al., 1991*	*77.54*	*12.53*	*0.8*	*0.83*	*5.15*	*3.02*
10	*CIOB*	*Pattan et al., 1999*	*76.81*	*12.8*	*0.8*	*0.96*	*5.06*	*3.4*
11	*Indian Subcontinent*	*Shane et al., 1995*	*77.15*	*12.67*	*0.78*	*0.86*	*5.08*	*3.26*
12	*South China Sea*	*Lui et al., 2006*	*76.78*	*13.09*	*0.8*	*0.97*	*4.26*	*2.75*

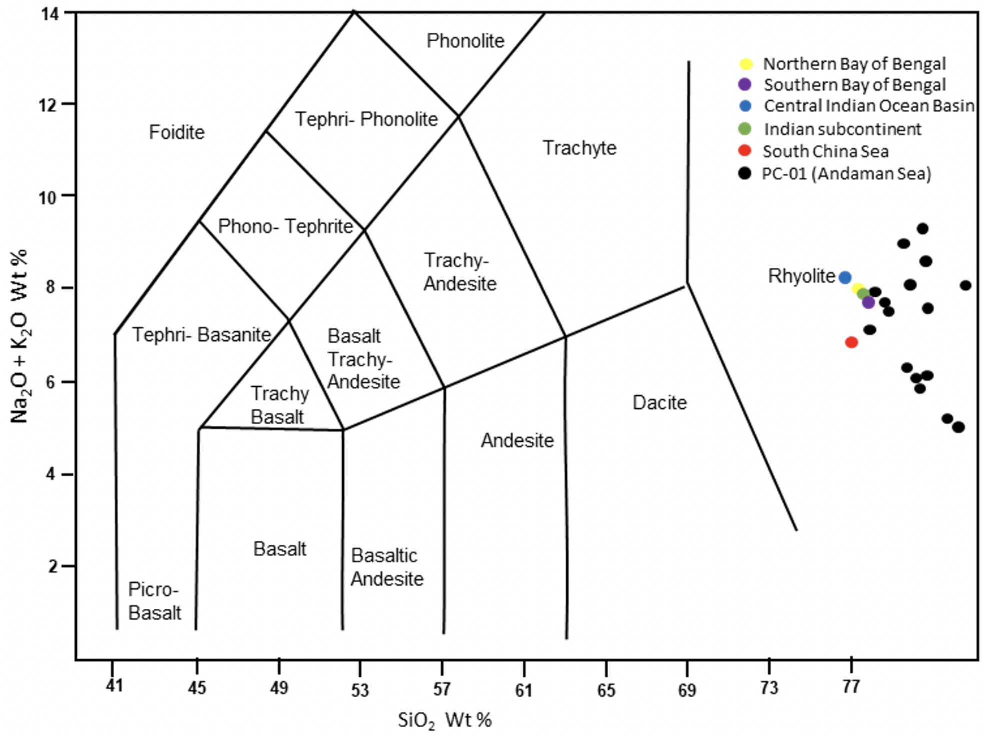

Figure 6. Total alkali silica diagram (TAS) used for volcanic rock nomenclature (Le Bas et al., 1986).

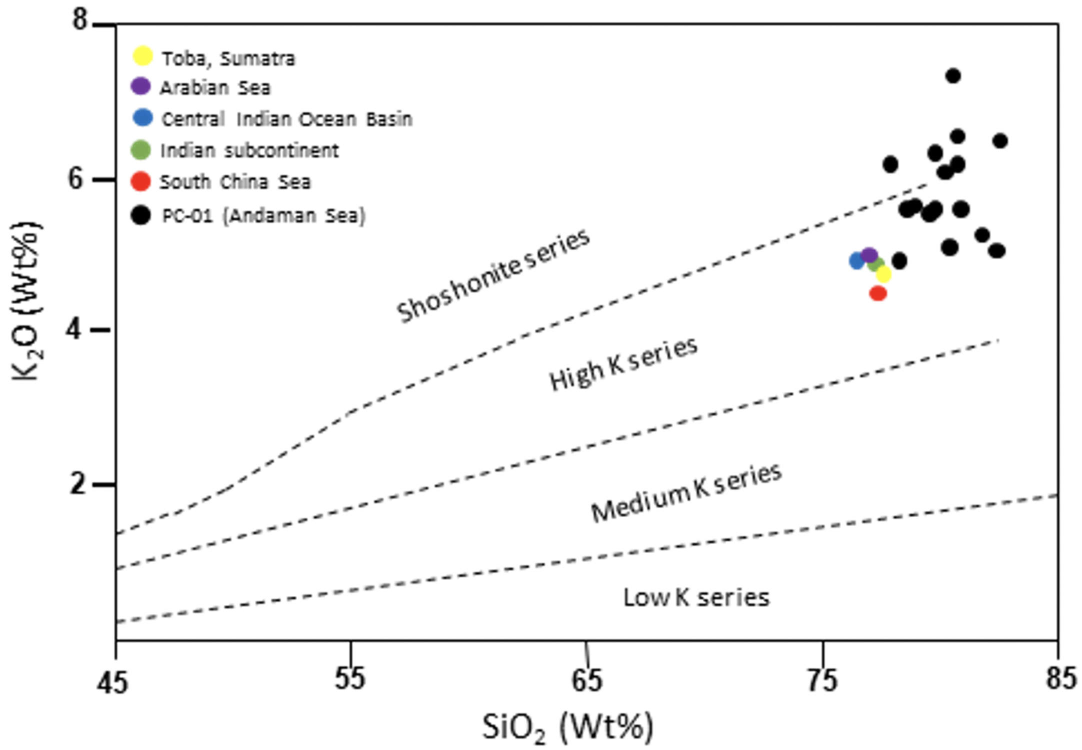

Figure 7. Bivariant diagram showing SiO_2 vs K_2O in which majority of the data fall in the High-K Series (add reference of data)

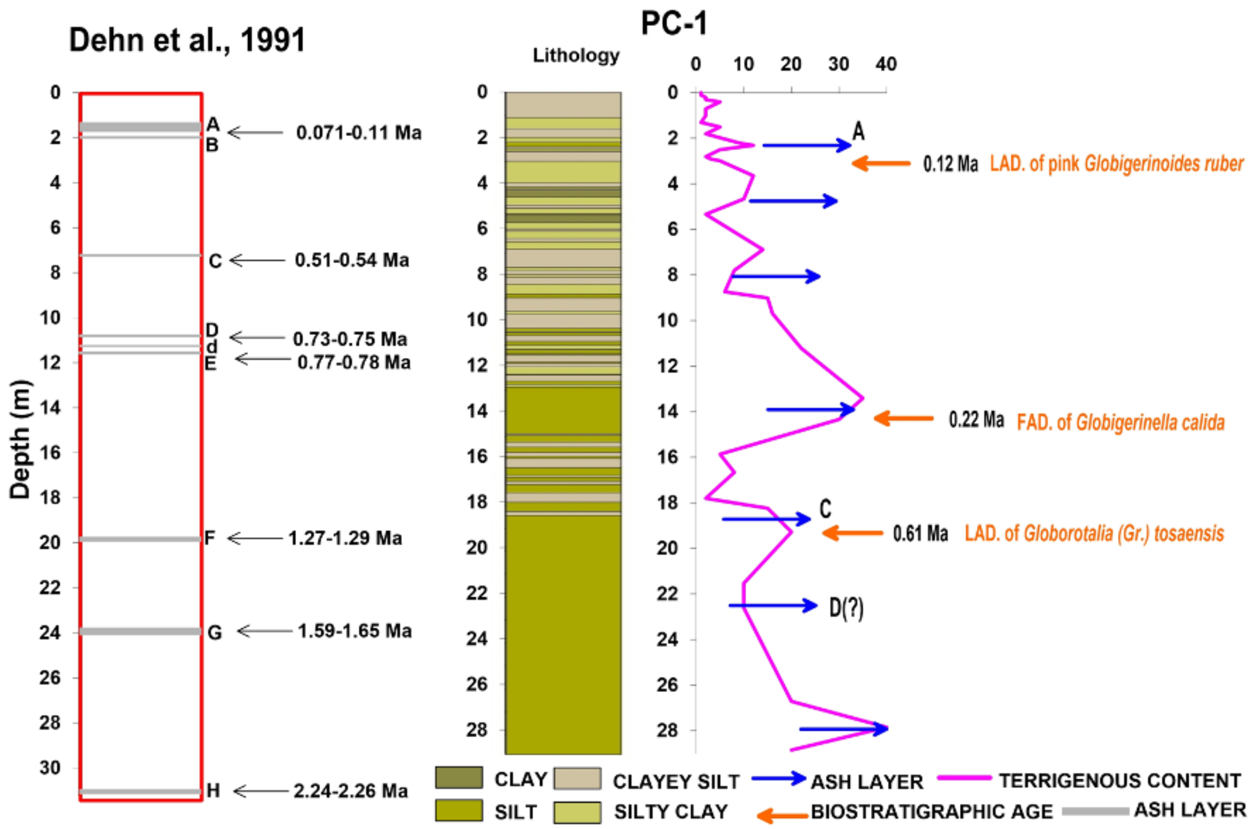

Figure 8. Comparative study plots of ash layers from ODP Site 758 (Dehn et al., 1991) and PC-1 core from South Andaman Sea. Ash layers of PC-1 are marked with the help of relative biostratigraphic datum and also with various ash layer A, B, C and H reported by Dehn et al., 1991 for site 758.

Age Control

In core PC-1, the age control is based on the biostratigraphic study, which are on the basis of first appearance (FAD) and last appearance (LAD) of planktonic foraminifera species namely *Globorotalia (Gr.) tosaensis, Globigerinella Calida* and pink *Globigerinoides ruber.* Based on biostratigraphic datums from tropical oceans (Wade et al., 2011), three datums were identified within the sediment core of PC-1 that correspond to 0.61 Ma (LAD of *Globorotalia (Gr.) tosaensis*) at 18.3 m bsf, 0.22 Ma (FAD of *Globigerinella calida*) at 14.3 m bsf, and 0.12 Ma (LAD of pink *Globigerinoides ruber*) at 3.4 m bsf respectively. Thus, the presence of glass shards at 2.10 m to 2.66 m can be inferred as younger than the 0.12 Ma (Figure 7). This implies that the inferred ash layer may be part of YTT, whereas no such thick unit was observed above 2.10 m, except the presence of thin occurrence of dark brownish green tinted basaltic glass shards at 30 cm bsf. In addition, other thin layer observed below the depth interval between 13.50 m to 14.50 m and 18 m to 24 m, which are potentially correlated to MTT and OTT units (Figure 8). Similar observations were also noticed in the study of Nishimura et al. (1977) and Diehl et al. (1987) suggested eruptions of the Toba caldera at 0.84 Ma and 1.20 Ma respectively. Furthermore, Chesner (1988) also documented several eruptions of the Toba caldera at 0.075, 0.450, 0.840 and 1.2 Ma, which described these layers as the Youngest Toba Tuff (YTT), the Middle Toba Tuff (MTT), the oldest Toba tuff (OTT), and the Haranggoal Dacite Tuff (HDT) respectively. These tephra layers can also be correlated to the sediment core of Site 758 as: YTT to layer A, MTT to layer C, OTT to layer E, and HDT to layer F. Based on previous observations and the present findings, it is possible to correlate that the observed ash layers preserved in the sediment core of PC-1 may be the part of eruptive product of the Toba caldera, such as YTT, MTT and OTT.

CONCLUSIONS

The sediment core PC-1 collected from the South Andaman Sea below the water depth of 3144 m preserved discrete ash layers at various depths, ranging from 2.10 m - 2.66 m, 13.50 m - 14.50 m and 18 m - 24 m. Morphological study of layer-A (56 cm thick) at 2.10 m to 2.66 m represent shards of different varieties with similar glass shards of YTT, as reported from other part of the world. This observation is further corroborated by the biostratigraphic datum, which shows that the layer-A is just above the 0.12 Ma biostratigraphic datum horizons. As a result, the glass shards between 2.10 m to 2.66 m implies YTT and younger than 0.12 Ma. The geochemical composition data obtained from the SEM-EDX analysis suggested high silica and alkali contents indicating rhyolitic composition that display compositional similarity with Toba eruptive products. Further comparative study with IODP core will help to determine the several other eruptive histories, marked as MTT and OTT. Therefore, based on the geochemical composition, morphology and biostratigraphic data, discrete ash layers of PC-1 have similar affinities and possible link to the Toba caldera.

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