

Morphology and chemical composition of ash layer of about 8 Ma old from ODP-758 site, Bay of Bengal

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Glass shards from an ash layer of about 8 Ma old extracted from a core drilled at an ODP-758 site in the Bay of Bengal (BOB) were studied for morphology and chemical composition in order to trace their possible source. Glass shards are of bubble wall, platy and pumice shard type indicating magmatic type of eruption. Electron probe micro analysis (EPMA) of glass shards suggests rhyolite composition and high K cal-alkaline series. FeO (1.23%) and TiO₂ (0.1%) contents of these glass shards are distinctly higher compared to the earlier known Youngest (~74 ka), Middle (~0.54 Ma) and Oldest (~0.84 Ma) Toba Tuffs. Tectonomagmatic, triangular (Ti-Zr-Y) plot and chondrite-normalized REE pattern, are all indicative of volcanic arc source most probably from the nearby Indonesian arc volcanism.

[Keywords: Ash layer, 8 Ma, Bay of Bengal, ODP-758, rhyolitic, magmatic, volcanic arc, Indonesian arc volcanism]

Introduction

During the explosive volcanic eruption, mainly gases in the magma expand and escape violently into the atmosphere where it solidifies into fragments of volcanic rocks and glass. The glass shards from the ash in the marine environment could be either transported from the land by the action of wind and by runoff water or local submarine *in situ* volcanic source. There are four known volcanic eruptions from Toba caldera at 0.074 Ma, 0.54 Ma, 0.84 Ma and 1.2 Ma which are known as Youngest Toba Tuff (YTT), Middle Toba Tuff (MTT), Oldest Toba Tuff (OTT) and Haranggoal Dacite Tuff (HDT) respectively¹. Ash layers of YTT origin have been traced in BOB²⁻⁴ Arabian Sea⁵⁻⁷ and Central Indian Ocean Basin (CIOB)⁸. Ash layers of MTT and OTT origin are reported in BOB (ODP-758) but OTT occurred in association with Australasian microtektites of ~0.77 Ma old in CIOB⁹⁻¹¹. These volcanic eruptions from Toba

caldera have affected climatic cooling, prolonged deforestation, tropical ecosystem and human population in the Indian sub continent¹². Earlier, Dehn et al⁴, reported 31 ash layers of varying thickness at ODP-758 site in the BOB and oldest being at 5 Ma. Based on the results of Sr and Nd isotopes of sediments from ODP-758, it was suggested that there is occurrence of ash layer of about 8 Ma old¹³. This ash layer has not been studied in detail. Therefore, in the present study, glass shards from this ash layer of about 8 Ma old from ODP-758 site in the BOB is studied for its morphology and chemical composition in order to trace their source.

Materials and Methods

An ash layer of about 8 Ma old occurs in the ODP-758 site in the BOB (latitude 5°23'N, longitude 90°21' E) at a water depth of 2925m (Fig. 1).

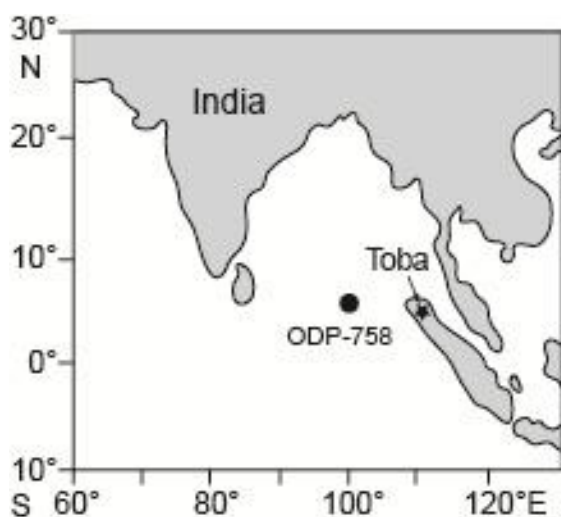


Fig.1-Map showing location of ODP-758 site in the Bay of Bengal.

Bulk sediment from the ash layer has been treated with 0.1 N HCl to remove the calcium carbonate. Then from the residue glass shards were picked up under binocular microscope and cleaned ultrasonically. These glass shards were studied for morphology using Scanning Electron Microscope (JEOL JSM-5800L). Few glass shards were mounted on a resin, polished, carbon coated and analysed for major elements with Electron Probe Micro Analyser (EPMA, CAMECA SX-5). The operating conditions of Scanning Electron Microscope and Electron Probe Micro Analyser are provided in the recent report¹⁴. Glass shards were finely powdered in a agate mortar. About 0.25 g of the finely powdered glass shard sample was weighed in a PTFE beaker and added 10 ml of acid mixture of HF+HClO₄+HNO₃ in the ratio of 7:3:1 and heated on a hot plate till it becomes like a paste. Again 10 ml of same acid mixture was added and heated till it becomes like a paste. To this 4ml of 1:1 HNO₃ and 0.1 ml of Rhodium (internal standard) were added and heated for 5 minutes. Then filtered and made to 50 ml solutions with ultra pure water. Similarly, acid blank and standard reference material (JR-1) were also prepared. Solutions of glass shards, blank and JR-1 were analysed for number of trace and rare earth elements on Inductively Coupled Plasma-Mass Spectrometer (Thermo X Series 2). Accuracy of the data based on standard reference material was $\pm 7\%$.

Results

The major elements oxide data of 15 individual glass shards along with the mean values and standard deviation from ODP-758 site are presented in Table 1. The EPMA data are normalized to 100% to make water free basis. Trace and rare earth element (REE) data of glass shards are presented in Table 2. Glass shards have higher contents of SiO₂ (78.7%) and total alkalis (6.7%). FeO (1.23%) and TiO₂ (0.1%) contents in glass shards are also high while, MnO (0.05%) and MgO (0.07%) contents are low. Among the trace metals Ba, Zr and Sr contents are high while, the total REE content is 147 ppm.

Discussion

Morphology of glass shards

Glass shards under binocular microscope are white in colour indicating silicic nature¹⁵. These shards are fresh without any alteration. This could be due to their burial within the sedimentary column without exposing to seawater. Morphology of a glass is the diagnostic feature in identifying source of volcanic material. Glass shards exhibit mostly bubble wall junction type, followed by platy and pumice shards (Plate 1a, b, c). Some glass shards have micro-pits indicating aerodynamic effect during their transport in the atmosphere. The bubble wall type morphology of glass shards is an indicative of magmatic type of eruption. This is similar to the earlier observation made on the glass shards recorded from BOB, Arabian Sea and CIOB^{3,5,6,8,11}. The bubble wall junction morphology of these shards form at lower viscosity of rhyolitic magma of $< 850^{\circ}\text{C}$ ¹⁶.

Glass shard Chemistry

Major element oxide data obtained by EPMA on 15 individual glass shards are very identical suggesting they are from one single volcanic event. Glass shards have high contents of SiO₂ (~78%) and total alkalis (5-6%) suggesting rhyolite composition¹⁷(Fig.2a) and are of high K calc-alkaline series (Fig.2b). SiO₂ and Al₂O₃ contents of these glass shards are nearly similar to that of YTT (0.074 Ma), MTT (0.54 Ma) and OTT (0.84 Ma) reported in the BOB, Arabian Sea, Indian Sub-continent, CIOB and South China Sea^{5,8,11,18-20}.

Table 1. Electron probe micro analysis (EPMA) of individual glass shards (n=15) from ODP-758, in the Bay of Bengal. All values are in wt %. Analysis is normalized to an anhydrous basis. Fe reported as FeO. H₂O – water by difference calculated from original analytical total.

Sr.No	SiO ₂	Al ₂ O ₃	TiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	H ₂ O
1	78.62	12.40	0.08	1.09	0.02	0.09	0.52	2.41	4.51	0.23	7.40
2	79.14	11.96	0.06	1.09	0.08	0.05	0.50	2.59	4.36	0.27	7.52
3	79.33	12.17	0.09	1.13	0.05	0.05	0.48	2.61	3.87	0.23	6.95
4	78.71	12.67	0.06	1.29	0.06	0.07	0.56	2.55	3.76	0.23	6.36
5	79.15	12.58	0.12	1.36	0.05	0.06	0.56	2.18	3.74	0.22	7.45
6	78.36	12.41	0.11	1.29	0.02	0.06	0.50	2.72	4.28	0.23	6.82
7	78.55	12.29	0.09	1.20	0.01	0.08	0.45	2.46	4.62	0.24	7.16
8	77.76	12.54	0.11	1.50	0.10	0.07	0.57	2.65	4.46	0.23	8.00
9	78.37	12.49	0.11	1.29	0.08	0.10	0.57	2.62	4.09	0.27	7.33
10	79.22	12.17	0.09	1.08	0.03	0.05	0.48	2.27	4.38	0.24	6.63
11	78.93	12.34	0.10	1.21	0.07	0.09	0.45	2.39	4.20	0.22	6.39
12	78.35	12.52	0.12	1.26	0.05	0.05	0.55	2.92	3.95	0.21	5.34
13	78.59	12.47	0.11	1.19	0.09	0.09	0.53	2.85	3.85	0.26	6.34
14	78.75	12.33	0.06	1.16	0.04	0.04	0.51	2.32	4.51	0.27	7.51
15	78.18	12.76	0.12	1.36	0.04	0.08	0.54	2.64	4.00	0.23	7.48
Mean	78.67	12.40	0.09	1.23	0.05	0.07	0.52	2.54	4.17	0.24	6.98
Stdev	±0.43	±0.21	±0.02	±0.12	±0.03	±0.02	±0.04	±0.21	±0.30	±0.02	±0.68

Table.2. Trace and rare earth element concentration (ppm) of glass shards analysed on ICP-MS from ODP-758 in the Bay of Bengal.

Elements	Conc. (ppm)
Li	13.56
Be	1.58
Sc	4.32
Ta	1.10
V	18.79
Cr	13.27
Ni	4.46
Cu	19.08
Zn	71.41
Ga	16.55
Rb	205
Sr	87.28
Y	29.26
Zr	119
Nb	8.45
Mo	2.38
Sb	0.81
Cs	12.55
Ba	527
La	33.81
Ce	55.99
Pr	6.82
Nd	28.78
Sm	5.32
Eu	0.72
Gd	4.22
Tb	0.73
Dy	3.89
Ho	0.74
Er	2.43
Tm	0.45

Yb	3.01
Lu	0.48
Hf	3.94
Pb	12.94
Bi	0.46
Th	21.05
U	5.82

Among the major elements, FeO (1.23%) in these glass shards is distinctly higher compared to that of YTT (0.87%, n=236)¹⁹, MTT (0.9%, n=20)⁴ and OTT (0.86%, n=69)^{11,21}. Similarly, TiO₂ content of glass shards is also high (0.1%) compared to that of YTT, MTT and OTT (~0.06%). Therefore, Fe and Ti contents will help in identifying the source of ash layers.

Total rare earth elements (Σ REE) content of glass shards is 147 ppm (Table 2) and is nearly in the similar range to that in YTT, MTT and OTT¹⁹. However, it is difficult to distinguish among the different tephra layers based on major element oxides. The chondrite-normalized REE pattern (Fig.3) shows enrichment of light REE, with a pronounced negative Eu-anomaly and heavy REE remains constant and almost flat type and is within the range reported for rhyolite rocks from Sumatra/Indonesia²²⁻²³. The triangular plot of Ti-Zr-Y (Fig. 4) shows that glass shards fall within the compositional field of “arc related rhyolite”.

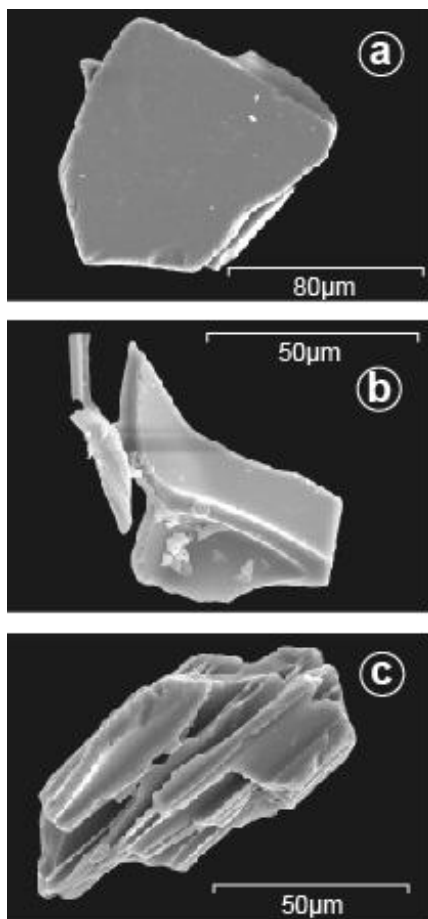


Plate 1-Scanning electron microphotographs of glass shards from ODP-758, (a) platy (b), bubble wall (c) pumice shards.

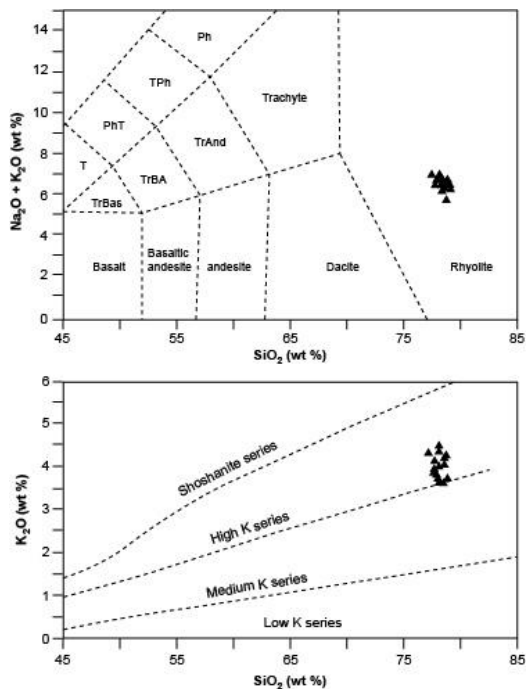


Fig. 2-Scatter plots of SiO₂ vs. Na₂O + K₂O (top) and SiO₂ vs. K₂O (bottom) for the glass shards recovered from the ash layer in the ODP site 758 from BOB.

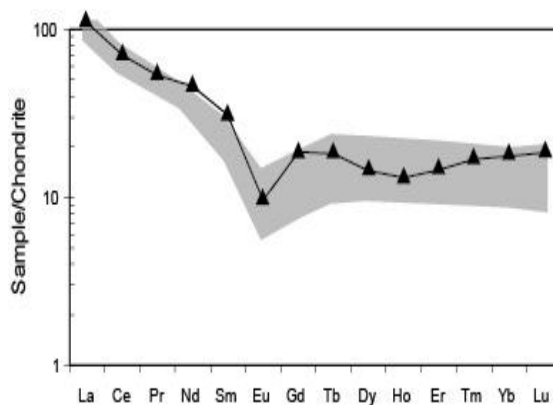


Fig. 3-Chondrite-normalized REE pattern of glass shards. Hatched area is for the rocks from Sumatra as reported earlier (Masuda, 1980; Ikeda et al., 1980).

The tectonomagmatic discrimination diagram of Y vs. Nb (Fig. 5a) suggests that glass shards fall in the area of Syn-collision and volcanic arc type²⁵.

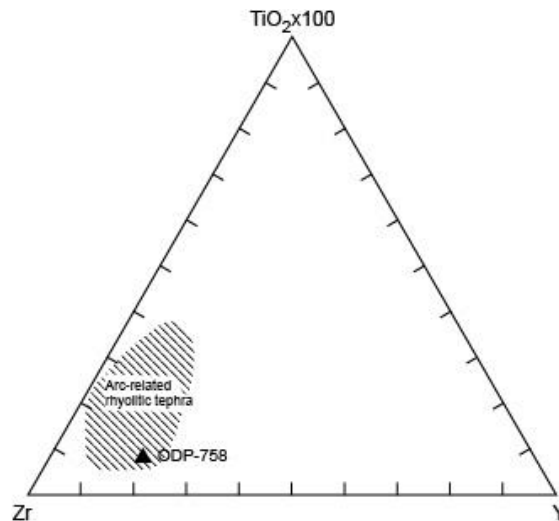


Fig. 4-Triangular plot (Ti-Zr-Y) in which glass shard data falls in the hatched area. Hatched area is for arc related tephra (Yamamoto et al., 1986).

Further, to differentiate within syn-collision and volcanic arc, the Ta-Yb discrimination plot suggest that it is of volcanic arc origin (Fig. 5b). The nearest volcanic arc is Indonesian arc volcanism and that could be the source for these glass shards. Number of trace elements such as Be, Sc, V, Ni, Zn, Ga, Y, Zr, Nb, Mo, Sb, Cs, Hf, Pb, Th and U content of glass shards were reported in Table 2 and among them Ba is high while Nb is low suggesting arc type origin²⁶. Further, trace metals like Zr and Sr contents are also high in these glass shards (Table 2).

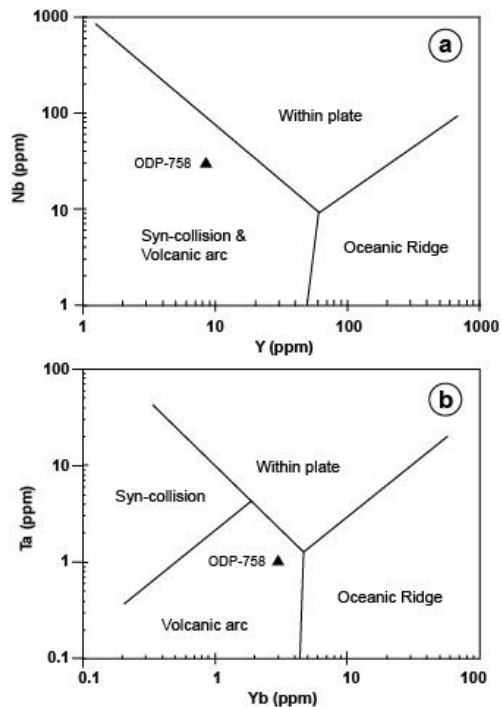


Fig. 5-Tectonomagmatic plots for glass shards (after Winchester and Floyd, 1977). (a). Scatter plot of Nb (ppm) Vs Y (ppm) and (b) Scatter plot of Ta (ppm) Vs Yb (ppm).

Conclusion

The glass shards from the ash layer of about 8Ma old horizon of a core from ODP-758 site in BOB is of magmatic type and volcanic arc origin most probably supplied from the nearest Indonesian Arc volcanism.

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References

1. Chesner, C. A., The Toba tuffs and caldera complex, Sumatra, Indonesia: Insights into magma bodies and eruptions. *Thesis. Michigan Technology University*, (1988) 428 pp.
2. Ninkovich, D., Shackleton, N.J., Abdel-Menem, S.A., Obradovich, J.D. and Izett, G., K-Ar age of the late Pleistocene eruption of Toba, north

Sumatra. *Nature.*, 276 (1979) 574-577.

3. Rose, W.L., Chesner, C. A., Dispersal of ash in the great Toba eruption. *Geology.*, 15(1987) 913-917.
4. Dehn, J., Farrell, J. W., Schmincke, H. U., Neogene Tephrochronology from Site 758 on northern Ninet-yeast Ridge: Indonesian Arc Volcanism of the past 5 Ma. *Proceedings of the Ocean Drilling Program, Scientific results*, 121(1991) 273-295.
5. Pattan, J. N., Shane, P., Pearce, N. J. G., Banakar, V. K., Parthiban, G., An occurrence of ~74 ka Youngest Toba Tephra from the Western Continental Margin of India. *Current Science*, 80(2001) 1322-1326.
6. Nambiar, A. R., Sukumaran, P. V., Characterisation of Late Pleistocene Tephra in deep sediments of Arabian Sea. *Journal of Geological Society of India*, 59 (2002) 79-88.
7. Schulz, H., Kay-Christian Emeis., Ereenkeuser, H., Vo Rad U., Rolf C., The Toba volcanic event and interstadial/stadial climates at the marine isotope stage 5 to 4 transition in the Northern Indian Ocean. *Quaternary Research*, 57(2002) 22-32.
8. Pattan, J. N., Shane, P. and Banakar, V. K., New occurrence of Youngest Toba Tuff in abyssal sediments of the Central Indian Basin. *Marine Geology*, 155(1999) 243-248.
9. Glass, B.P., Koeberl, C., Australasian microtektites and associated impact ejecta in the South China Sea and the middle Pleistocene super eruption of Toba. *Meteoritics and Planetary Science*, 41(2006) 305-326.
10. Prasad, M.S., Mahale, V.P., Kodagali, V.N., New sites of Australasian microtektites in the Central Indian Ocean: Implications for the location and size of source crater. *Journal Geophysical Research*, 102,(2007)E06007, doi.10.1029/2006JE 002857.
11. Pattan, J. N., Prasad, M. S., Babu, E. V. S. S. K., Correlation of the oldest Toba Tuff to sediments in the central Indian Ocean Basin. *Journal of Earth System Science*, 199(2010) 531-539.
12. Williams, M.A.J., Ambrose, S.H., van der Kaars, S., Ruehleemann, C., Chattopadhyaya, U., Pal, J. and Chauhan, P., Environmental impact of the 73 ka Toba super eruption in South Asia. *Paleogeography, Paleoclimatology, Paleoecology*, 284(2009) 295-314.
13. Padmakumari, V. M., Ahmed, S. M., Ash layer at ~8 Ma in ODP Site 758 from the Bay of Bengal: evidence from Sr, Nd isotopic compositions and rare earth elements. *Current Science*, 86(2004) 1323-1325.
14. Jumaila Ummu, C.P., Ash layer of ~8.2 Ma in ODP-758 from Bay of Bengal and its correlation with Fe-Mn oxide coated pumice from the Central Indian Ocean Basin. Project report, NIO, Goa, (2013) pp. 1-59, Unpublished.
15. Horn, D.R., Delach, M.N., Horn, B.M., Distribution of volcanic ash layers and turbidites in the North Pacific. *Geological Society of American Bulletin*, 81 (1969) 1715-1724
16. Izeet, G.A., Volcanic ash beds: recorders of Upper Cenozoic silicic pyroclastic volcanism in

- the western United States. *Journal Geophysical Research*, 86 (1981) 10200-10222.
17. Le Bas, M.J, Matre, R W., Streckheisen, A., Zanettin, B., A chemical classification of volcanic rocks based on the Total Alkaline-Silica diagrams. *Journal of Petrology*, 27 (1986) 745-750.
 18. Shane, P., Westgate, J., Williams, M., Korisettar, R., New geochemical evidence for the Youngest Toba Tuff in India. *Quaternary Research*, 44(1995) 200-204.
 19. Westgate, J.A., Shane, P.A.R., Pearce, N. J.G., Perkins, W.T., Korishettear, R., Chesner, C.A., Williams, M.A., Acharyya, S.K., All Toba tephra occurrences across peninsular India belong to the 75,000 yr B.P. eruption. *Quaternary Research*, 50 (1988) 107-112
 20. Song, S-R., Chen, C-H, Lee, M-Y., Yangm, T.F., Iizuka, Y., Wei, K-Y., Newly discovered eastern dispersal of the youngest Toba Tuff. *Marine Geology*, 167(2000) 303-312
 21. Lee, M-Y., Chen, C-H., Wei, K-Y., Lizuka, Y., Carey, S., First Toba super eruption revival. *Geology*, 32(2004) 61-64.
 22. Ikeda, T., Nishimura, S., Yokoyama, T., Hehuwat, T., Trace element variations in volcanic rocks in the Sunda Arc regions, Indonesia. In: S. Nishimura (Editor), *Phy. Geol. Indonesian Island Arcs, Kyoto University*, (1980) 97-108.
 23. Masuda, A., Trace element abundances in the igimbrites from Sumatra and Sulawesi islands, Indonesia. In: S. Nishimura (Editor), *Phy. Geol. Indonesian Island Arcs, Kyoto University*, (1980) 144-147.
 24. Yamamoto, K., Sugisaki, R., Arai, F., Chemical aspects of alteration of acidic tuffs and their application to siliceous deposits. *Chemical Geology*, 55(1986) 61-76.
 25. Winchester, J.A., Floyd, P.A., Geochemical discrimination of different magma series and their differntation products using immobile elements. *Chemical Geology*, 20 (1977) 325-343.
 26. Kay, S.M., Coira, B., Worner, G., Kay, R.W., Singer, B.S., Geochemical, isotopic and single crystal $^{40}\text{Ar}/^{39}\text{Ar}$ age constraints on the evolution of the Cerro Galan ignimbrites. *Bulletin of Volcanology*, 3 (2011) 1487-1511.