

A note on Chemical Composition and Origin of Ferromanganese Oxide Coated and Uncoated Pumice samples from Central Indian Ocean Basin

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Abstract: Pumice are explosive volcanic product, occurs as uncoated or coated with ferromanganese (Fe-Mn) oxide and resides in association with ferromanganese nodules on the seabed in Central Indian Ocean Basin (CIOB). The older Fe-Mn oxide coated and younger uncoated pumice clasts were leached with 6N HCl to remove Fe-Mn oxide coatings as well as the calcium carbonate present within the vesicles. The main objective of the present study is to understand the origin of these pumice by utilizing their chemical composition. Both coated and uncoated pumice samples are rhyolite- and medium K calc-alkaline series. Major, trace, rare earth elements (Σ REE) concentration and chondrite-normalized REE patterns of both coated and uncoated pumice are nearly similar to each other suggesting a same source. Tectonomagmatic discrimination diagrams (Nb vs Y: Yb vs. Ta), triangular plot (TiO₂-Zr-Y) and High Field Strength Element ratios (La/Ta- 25; Ta/Hf- 0.2; Nb/Ta- 9; Zr/Nb- 22 and Ba/Ta-1084) indicate volcanic arc origin. These were probably sourced from the nearest Indonesian Volcanic Arc and drifted to the CIOB by currents.

Keywords: Central Indian Ocean Basin; pumice; chemical composition; Indonesian Arc Volcanism, drift.

INTRODUCTION

Pumice is a highly vesicular glassy volcanic rock produced by explosive volcanic eruptions. Its low density allows it to float on water and subsequently be transported by the currents for many months and years, over thousands of kilometers. During transportation, vesicles can be gradually filled with water and eventually sink to the seafloor on saturation (Whitham and Sparks, 1986). Pumice of the 1883-Krakatau eruption drifted across the oceans for months to few years, and reached the Indian and South Atlantic Oceans (Simkin and Fiske, 1983; Frick and Kent, 1984; Jokieli and Cox, 2003). The pumice rafts have even travelled over a distance of 20,000 km in the ocean (Richards, 1958). Pumice in the oceanic environment helps to trace surface currents (Jokieli and Fox, 2003; Bryan et al., 2004) and acts as an effective rafting agent that can help in dispersal of different types of organisms and can connect widely separated shallow marine to coastal ecosystems (de Vendie, 1982; Bryan et al., 2012).

During the exploration for- polymetallic nodule deposits in the CIOB, a large pumice field covering an area of $\sim 60,000 \text{ km}^2$ was reported by Iyer and Sudhakar, (1993). Pumice in the CIOB is found as uncoated, partially and fully coated with ferromanganese oxide and also acts as nuclei for ferromanganese nodules (Martin-Barajas and Lallier-Verges, 1993). Pumice that acts as nuclei for ferromanganese oxide growth is considered to be significantly older in age due to extremely slow Fe-Mn oxide accretion rates (Banakar, 1990). In contrast, pumice that is free from any oxide coatings is likely to be younger. Therefore, the age of pumice could range from a few million to a few thousand years.

Different sources for the pumice have been suggested in previous studies, the CIOB: *in-situ* submarine silicic volcanism (Hedervari, 1982; Iyer and Sudhakar, 1993); Indonesian Arc Volcanism (Iyer and Karisiddaiah, 1988; Martin-Barajas and Lallier-Verges, 1993), Youngest Toba Tuff eruption (Pattan et al., 2008), and 1883-Krakatau (Mudholkar and Fujii, 1995; Pattan et al., 2008). This suggests that there exists a controversy regarding the source of pumice in CIOB. A recent study was made by Kalangutkar et al., (2011) about the physical properties of pumice such as density, specific gravity, porosity, void ratio and degree of saturation. Detailed studies related to chemical composition of both coated and uncoated pumice from CIOB are rare (Pattan et al, 2008). The objective of the present study is to trace the source of Fe-Mn oxide coated and uncoated pumice samples by studying their chemical composition.

MATERIAL AND METHODS

During 4th cruise of A.A.Sidorenko 12 dredge operations were carried out in CIOB and the dredge tracks on seabed are shown in Fig.1. The water depth in the area varies from 5050 m to 5250 m. The western part of the study area is little shallower than the eastern part. We dragged the dredge for nearly 10 minutes on the seafloor and hauled up by about 150 m above the sediment-water interface and then again the dredge was lowered and dragged for another 10 minutes and it was hauled up onboard. During these dredging operations a total of ~ 7500 kg of nodules were collected. In all the dredge operations, invariably pumice clasts uncoated as well as coated with ferromanganese oxide were recovered. From these dredge hauls particularly from station No-80, four uncoated pumice and five coated with Fe-Mn oxide were utilized in this study.

The diameter (long axis) of pumice ranges from 2 cm to 6 cm, and they are mostly spherical or elliptical (Figure 2). Pumice clasts were washed with freshwater and dried in an oven at 60 °C. Small chips of the pumice were cleaned ultrasonically, dried, finely powdered and leached with 6N HCl to remove Fe-Mn oxide coatings and carbonate filled within the vesicles. The leached residue was washed several times with distilled water, dried and powdered again. The residue (0.5 gm) was mixed with Merck's Spectromelt[®] A12 flux and borate beads were prepared in a Minifuse2 induction furnace. These beads were analysed for major elements concentration by X-ray fluorescence (Axios, PANanalytical). Accuracy of the major elements was checked using the Geological Survey of Japan reference material (JR-1). Accuracy and precision of the data- is better than $\pm 4\%$. For trace and REE measurements, ~ 50 mg residue was taken in a mixture of 7:3:1 of HF, HClO₄ and HNO₃ respectively and heated on a hotplate until incipient dryness. The digest was dissolved in 10 ml of 1:1 Nitric acid and made to 100 ml final solutions with ultra-pure water. These solutions were analysed on Inductively Coupled Plasma - Mass Spectrometer (Thermo X Series 2). Accuracy of trace and REE with reference JR-1 was better than $\pm 6\%$.

RESULTS AND DISCUSSION

Major element data of both uncoated and coated- pumice clasts have been recalculated to a water free basis (anhydrous) and presented in Table 1 along with trace and REE. Total oxide content measured by X-ray fluorescence for both types of pumice varies from 93.3% to 96.8% suggesting their water content ranges from 3.2% to 6.6% with an average of 5.3%. The water content of both coated and uncoated clasts is- similar. The SiO₂ (74.82%; 73.76%) and total alkalis (6.08%; 6.32%) are significantly high in both types of pumice, and thus suggesting a rhyolitic

composition (Table 1). Iyer and Sudhakar (1993) reported the partial composition of some pumices recovered from the same basin, and suggested an *in-situ* origin for those samples. Further, their reported concentration of SiO₂ (~62%) significantly lower than that of the present suite of samples (73-74 %) , suggests a different origin. Fe-Mn oxide thickness on pumice might be a few million years old because the oxide accumulation rate in CIOB has an average of 1.9 mm/Ma (Banakar, 1990). Using this accumulation rate, pumice with Fe-Mn oxide coat of 3-4 mm appears to have an age of ~ 2-1.5 Ma. The major element oxide data of coated and uncoated pumice is nearly similar (Table 1) suggesting a long term supply of rhyolitic pumice to CIOB from the same source.

The chemical composition of the coated and uncoated pumice is nearly similar to that of YTT pumice of Youngest Toba Tuff (YTT) of ~74 ka (Pattan et al., 2008) and YTT caldera (Chesner, 1998). However, few mobile oxides such as CaO, MgO and K₂O are lower than that of - pumice from YTT caldera. There is a slight increase in Na₂O content of pumice from CIOB compared to that of YTT caldera. This might have been the result of leaching of Ca, Mg and K- due to interaction between rhyolite and seawater (Shiraki et al., 1987). The earlier studies (Pattan et al., 1999) show that YTT ash layers are equivalent to pumice of YTT origin from CIOB and contain high K₂O content compared to coated and uncoated pumice from the same basin. This could be due to burial of glass shards under the thick sediment which does not allow interaction with seawater. Pumice are mostly found at the sediment-water interface and is continuously exposed to seawater - and the apparently high water content indicate at least glass hydration has occurred.

Scatter plots of SiO₂ versus few major oxides (Al, Fe, and Ti) exhibit negative correlation, except K₂O that shows a positive association (Fig. 3). In the scatter plots when both coated and uncoated pumice chemical data was put together there exist a reasonable good single best fit line-probably suggests their supply from the similar source. The total alkali silica (TAS) - diagram for both the types of pumice suggests a rhyolitic magma source (Fig.4; Le Bas et al., 1986). A discrimination - plot of SiO₂ (wt%) vs. K₂O (wt%) (Rickwood, 1989) of rocks suggests that shoshonite, high-K calc-alkaline, calc-alkaline and low-K series occur with progressively decreasing K₂O (wt%) content. Both types of pumice clasts from CIOB occupy medium- K (calc-alkaline) series (Fig.4). Pumice of Youngest Toba Tuff (YTT) are of rhyolitic composition whereas, 1883-Krakatau are of dacite type (Chesner, 1998; Mendevillie et al., 1996; Pattan et al., 2008). Contents of Ti, Al, Fe, Mn, Mg, Ca and P oxides are nearly similar to each other in all the studied samples (Table 1). In a triangular plot of TiO₂-Zr-Y, (Fig.5) all the samples fall within the region of volcanic arc related rhyolitic tephra (Yamamoto et al., 1988). A tectonomagmatic discrimination

diagram (Nb vs. Y) is suggestive of syn-collision and volcanic arc nature (Fig. 6). Further refinement comes from the scatter plot of Ta vs. Yb which clearly suggests that these pumice are of volcanic arc origin (Fig.6). The nearest volcanic arc - such as Indonesian Arc Volcanism can be assigned as the source for these pumice.

Total rare earth elements (Σ REE) content of coated and uncoated pumice is 123 ppm and 109 ppm respectively, which are similar to fresh/uncoated pumice (121ppm) of YTT origin as reported earlier (Pattan et al., 2008). The chondrite-normalized REE patterns of all the pumice samples show- a gradual decrease in light REE, i.e. from La to Sm, with a pronounced negative Eu-anomaly and flat heavy REE patterns (Fig.7). Further, the chondrite-normalized REE patterns-occupy the area demarcated for the rhyolitic rocks from Sumatra (Ikeda et al., 1980; Masuda, 1980). This clearly suggests that pumice are of volcanic arc origin. This is contrary to the *in-situ* basinal silicic volcanism as the source of pumice (Iyer and Sudhakar, 1993). Further, the source of pumice can be confirmed by studying High Field Strength Element (HFSE) ratios. The similarity in some of the- mean HFSE ratios- (both coated and uncoated) such as Nb/Ta (9.6), La/Ta (25), Ta/Hf (0.21), Zr/Nb (23) and Ba/Ta (1007), are nearly close to the ratios of 7.3, 23, 0.35, 23 and 1084 for the pumices of arc type origin respectively (Table 2) (Kay, 2001; Kay et al., 2006; 2011). The HFSE ratios- for the pumice of intraplate volcanic source such as La/Ta (11-16), Ta/Hf (0.38 – 0.53), Zr/Nb (<15) and Ba/La (< 15) are distinctly different (Kay, 2001; Kay et al., 2006; 2011) compared to pumice of CIOB (25, 0.2, 23 and 39) respectively. Further, mean Th/U ratio of CIOB pumice is 4.9 which is within the range (<10)- reported for arc type of pumice (Kay et al.,2011). High Ba content of - uncoated (832 ppm) and coated pumice (1087 ppm) and low Nb content (10 ppm & 7.5 ppm) are also suggestive of arc type source (Kay et al., 2006). Few important scatter plots of HFSE ratios such as La/Ta vs. SiO₂, Ba/Ta vs. La/Ta and Th/Hf vs. Ta/Hf suggest that these pumice is of arc type origin (Fig. 8; Kay et al., 2006 & 2011). Therefore, CIOB pumices, whether coated or uncoated, have comparable major, minor and REE composition among themselves and are of arc type origin probably derived from Indonesian Arc Volcanic source. Further, this possibly rules out any of *in-situ* basinal silicic volcanic origin as the source of pumice. This can be further supported by the study of >20,000 seafloor photographs, covering a total area of 450 km², showing ~65% of seafloor is associated with sediment, 1% Fe-Mn crusts and basalt outcrops and remaining 34% of area is covered with nodules of varying abundance and not a single pumice dome is reported (Sharma et al., 2010). The *in-situ* silicic volcanic source for the pumice is ruled out because these pumice are of highly vesicular nature, abraded and rounded shape suggesting their long transportation (Bryan et al., 2003, 2012). Further, features such as absence of angular shape of

pumice, dense or poorly vesiculated and quench texture further support the magmatic type of source most probably Indonesian Arc Volcanism

CONCLUSION

Pumice of uncoated and coated with ferromanganese oxide from CIOB have nearly similar chemical composition suggesting same source. Both types of pumice are of volcanic arc origin probably sourced from the Indonesian Arc Volcanism and subsequently drifted to CIOB.

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Table 1. Major (wt %), trace and rare earth elements (ppm) concentration of Fe-Mn oxide coated and uncoated pumice from CIOB.

| Oxide (%) | AAS-4 80B | AAS-4 80C | AAS-4 80D | AAS-4 80E | Mean | Stdev (±) | AAS-4 80 | AAS-4 80A | AAS-4 80F | AAS-4 80G | AAS-4 80H | Mean | Stdev (±) |
|--------------------------------|-----------------|--------------|--------------|--------------|---------------|--------------|---------------|--------------|--------------|--------------|--------------|---------------|--------------|
| | ←-----→ | | | | | | ←-----→ | | | | | | |
| | Uncoated Pumice | | | | | | Coated Pumice | | | | | | |
| SiO ₂ | 74.67 | 76.47 | 73.42 | 70.47 | 73.76 | 2.52 | 77.92 | 72.78 | 74.22 | 75.86 | 73.34 | 74.82 | 2.09 |
| TiO ₂ | 0.39 | 0.19 | 0.32 | 0.54 | 0.36 | 0.15 | 0.14 | 0.56 | 0.28 | 0.36 | 0.28 | 0.32 | 0.15 |
| Al ₂ O ₃ | 15.01 | 13.31 | 15.17 | 15.19 | 14.67 | 0.91 | 12.53 | 15.12 | 14.54 | 13.77 | 15.42 | 14.28 | 1.16 |
| Fe ₂ O ₃ | 3.07 | 1.60 | 1.89 | 3.85 | 2.60 | 1.05 | 1.21 | 3.19 | 2.43 | 2.80 | 2.15 | 2.36 | 0.75 |
| MnO | 0.06 | 0.12 | 0.06 | 0.09 | 0.08 | 0.03 | 0.05 | 0.09 | 0.07 | 0.06 | 0.05 | 0.06 | 0.02 |
| MgO | 0.75 | 0.30 | 0.81 | 1.21 | 0.77 | 0.37 | 0.25 | 0.76 | 0.48 | 0.57 | 0.56 | 0.52 | 0.18 |
| CaO | 0.63 | 0.91 | 2.45 | 2.57 | 1.64 | 1.01 | 0.72 | 1.38 | 1.26 | 0.72 | 2.26 | 1.27 | 0.63 |
| Na ₂ O | 2.58 | 4.13 | 3.44 | 3.78 | 3.48 | 0.66 | 3.10 | 3.08 | 3.56 | 2.86 | 3.45 | 3.21 | 0.29 |
| K ₂ O | 2.81 | 2.94 | 2.42 | 2.24 | 2.60 | 0.33 | 4.05 | 2.99 | 3.11 | 2.94 | 2.46 | 3.11 | 0.58 |
| P ₂ O ₅ | 0.03 | 0.04 | 0.03 | 0.04 | 0.04 | 0.01 | 0.03 | 0.07 | 0.05 | 0.05 | 0.03 | 0.05 | 0.02 |
| Li.ppm | 41.75 | 17.06 | 22.32 | 18.65 | 24.95 | 11.42 | 35.67 | 26.44 | 34.20 | 33.43 | 23.48 | 30.64 | 5.35 |
| Be | 1.75 | 1.53 | 1.74 | 1.37 | 1.60 | 0.18 | 1.73 | 1.79 | 1.97 | 1.70 | 1.59 | 1.76 | 0.14 |
| Sc | 12.37 | 2.86 | 7.09 | 13.95 | 9.07 | 5.07 | 4.14 | 11.68 | 6.42 | 9.23 | 4.55 | 7.20 | 3.21 |
| V | 55.16 | 7.65 | 32.81 | 79.34 | 43.74 | 30.66 | 13.38 | 58.68 | 25.93 | 52.32 | 41.46 | 38.35 | 18.68 |
| Cr | 30.47 | 2.15 | 2.47 | 8.35 | 10.86 | 13.38 | 5.18 | 20.92 | 10.30 | 24.59 | 7.22 | 13.64 | 8.61 |
| Co | 4.10 | 1.85 | 4.71 | 8.89 | 4.89 | 2.94 | 1.59 | 4.18 | 3.04 | 4.17 | 4.26 | 3.45 | 1.15 |
| Ni | 4.58 | 3.53 | 1.51 | 1.77 | 2.85 | 1.46 | 1.68 | 5.12 | 2.24 | 6.61 | 2.20 | 3.57 | 2.17 |
| Cu | 19.70 | 3.80 | 5.55 | 4.11 | 8.29 | 7.64 | 2.93 | 6.11 | 5.26 | 17.11 | 3.09 | 6.90 | 5.87 |
| Zn | 44.69 | 40.43 | 36.47 | 47.03 | 42.16 | 4.67 | 41.93 | 45.71 | 39.44 | 157.60 | 38.01 | 64.54 | 52.11 |
| Ga | 25.21 | 31.05 | 29.48 | 35.43 | 30.29 | 4.22 | 40.16 | 40.08 | 35.90 | 25.15 | 25.82 | 33.42 | 7.45 |
| Ge | 3.40 | 2.58 | 2.39 | 3.31 | 2.92 | 0.51 | 2.35 | 3.52 | 2.83 | 3.05 | 2.31 | 2.81 | 0.51 |
| As | 71.00 | 89.00 | 75.00 | 82.00 | 79.00 | 7.93 | 116 | 161 | 131 | 132 | 32 | 114.00 | 48.83 |
| Y | 20.63 | 20.80 | 13.46 | 33.68 | 22.14 | 8.42 | 17.67 | 31.60 | 19.63 | 20.37 | 10.61 | 19.98 | 7.56 |
| Zr | 214.00 | 161.00 | 106.00 | 271.00 | 188.00 | 71.00 | 90.00 | 349.00 | 215.00 | 295.00 | 95.00 | 209.00 | 116 |
| Nb | 10.18 | 6.70 | 6.04 | 6.96 | 7.47 | 1.85 | 9.08 | 12.11 | 9.50 | 14.06 | 5.66 | 10.08 | 3.20 |
| Mo | 1.77 | 2.00 | 1.40 | 2.11 | 1.82 | 0.31 | 2.30 | 12.44 | 2.19 | 11.39 | 2.14 | 6.09 | 5.33 |
| Ag | 0.38 | 0.33 | 0.14 | 0.59 | 0.36 | 0.18 | 0.16 | 0.61 | 0.42 | 0.70 | 0.15 | 0.41 | 0.25 |
| Cd | 0.06 | 0.05 | 0.03 | 0.08 | 0.06 | 0.02 | 0.02 | 0.11 | 0.06 | 0.16 | 0.02 | 0.07 | 0.06 |
| Sn | 1.75 | 0.47 | 0.86 | 1.09 | 1.04 | 0.54 | 1.81 | 2.48 | 1.64 | 2.20 | 1.57 | 1.94 | 0.39 |
| Sb | 0.58 | 0.08 | 0.53 | 0.29 | 0.37 | 0.23 | 0.58 | 2.05 | 0.62 | 2.53 | 0.57 | 1.27 | 0.95 |
| Cs | 6.44 | 2.40 | 5.26 | 2.99 | 4.27 | 1.90 | 8.93 | 6.75 | 7.49 | 5.99 | 5.46 | 6.92 | 1.36 |
| Ba | 526 | 914 | 821 | 1066 | 832 | 227 | 1531 | 1414 | 1162 | 622 | 707 | 1087 | 409 |
| La | 24.07 | 25.92 | 20.44 | 20.32 | 22.69 | 2.77 | 26.24 | 27.75 | 28.16 | 23.78 | 19.76 | 25.14 | 3.46 |
| Ce | 52.71 | 47.31 | 38.35 | 47.28 | 46.41 | 5.95 | 62.46 | 68.00 | 65.62 | 50.15 | 44.04 | 58.05 | 10.42 |
| Pr | 4.92 | 5.14 | 3.81 | 4.96 | 4.71 | 0.61 | 5.16 | 6.39 | 5.63 | 4.93 | 3.49 | 5.12 | 1.07 |
| Nd | 18.70 | 19.58 | 13.99 | 20.60 | 18.22 | 2.92 | 18.33 | 26.20 | 21.17 | 18.97 | 12.48 | 19.43 | 4.96 |

| | | | | | | | | | | | | | |
|-----------|-------|-------|-------|------|--------------|------|-------|-------|-------|-------|-------|--------------|------|
| Sm | 3.76 | 3.73 | 2.64 | 4.08 | 3.55 | 0.63 | 3.44 | 5.75 | 3.97 | 3.85 | 2.21 | 3.84 | 1.27 |
| Eu | 0.67 | 0.67 | 0.62 | 1.05 | 0.75 | 0.20 | 0.78 | 1.41 | 0.94 | 0.85 | 0.78 | 0.95 | 0.26 |
| Gd | 3.01 | 2.99 | 2.18 | 4.08 | 3.07 | 0.78 | 2.78 | 4.67 | 3.10 | 3.14 | 1.81 | 3.10 | 1.03 |
| Tb | 0.53 | 0.51 | 0.36 | 0.79 | 0.55 | 0.18 | 0.46 | 0.85 | 0.52 | 0.54 | 0.29 | 0.53 | 0.20 |
| Dy | 2.89 | 2.75 | 1.88 | 4.49 | 3.00 | 1.09 | 2.45 | 4.62 | 2.75 | 2.97 | 1.48 | 2.85 | 1.14 |
| Ho | 0.56 | 0.54 | 0.36 | 0.90 | 0.59 | 0.23 | 0.46 | 0.89 | 0.53 | 0.57 | 0.29 | 0.55 | 0.22 |
| Er | 1.83 | 1.80 | 1.17 | 2.94 | 1.94 | 0.74 | 1.51 | 2.85 | 1.72 | 1.87 | 0.93 | 1.78 | 0.70 |
| Tm | 0.32 | 0.33 | 0.20 | 0.53 | 0.35 | 0.14 | 0.27 | 0.49 | 0.30 | 0.33 | 0.17 | 0.31 | 0.12 |
| Yb | 2.18 | 2.31 | 1.41 | 3.56 | 2.37 | 0.89 | 1.90 | 3.28 | 2.08 | 2.23 | 1.19 | 2.14 | 0.75 |
| Lu | 0.34 | 0.37 | 0.22 | 0.56 | 0.37 | 0.14 | 0.30 | 0.51 | 0.33 | 0.35 | 0.19 | 0.34 | 0.12 |
| Hf | 4.66 | 3.84 | 2.71 | 5.84 | 4.26 | 1.32 | 4.79 | 7.57 | 5.13 | 6.05 | 2.53 | 4.81 | 2.15 |
| Ta | 1.28 | 0.64 | 0.83 | 0.63 | 0.85 | 0.30 | 1.37 | 0.94 | 1.28 | 1.10 | 0.55 | 1.05 | 0.32 |
| Bi | 0.18 | 0.09 | 0.09 | 0.12 | 0.10 | 0.04 | 0.33 | 0.15 | 0.25 | 0.40 | 0.24 | 0.27 | 0.10 |
| Th | 12.21 | 10.97 | 11.47 | 9.24 | 10.97 | 1.26 | 20.26 | 15.96 | 16.98 | 12.61 | 11.81 | 15.52 | 3.43 |
| U | 2.68 | 2.27 | 2.19 | 1.95 | 2.27 | 0.30 | 4.05 | 3.12 | 3.43 | 2.80 | 2.22 | 3.12 | 0.68 |

Table 2. Comparison of some of important High Field Strength Element (HFSE) ratios of uncoated and coated pumice along with their average values from CIOB and that of pumice of Arc type and intra-plate origin (Kay, 2001; Kay et al., 2006, 2011).

| HFSE ratio | Uncoated | Coated | Avg-CIOB | Arc type * | Intra-plate * |
|-------------------|-----------------|---------------|-----------------|-------------------|----------------------|
| La/Ta | 26.6 | 23.9 | 25.2 | 22.8 | 11-16 |
| Ta/Hf | 0.20 | 0.22 | 0.21 | 0.35 | 0.38 – 0.52 |
| Ba/Th | 76 | 70 | 73 | 147 | DNA |
| Zr/Nb | 25.2 | 20.7 | 23 | 23 | <15 |
| Ba/Ta | 979 | 1035 | 1007 | 1084 | DNA |
| Ba/La | 37 | 41 | 39 | 28-46 | <15 |
| Nb/Ta | 8.8 | 9.6 | 9.6 | 7.3 | DNA |
| Th/U | 4.8 | 4.97 | 4.9 | <10 | DNA |

* Kay, 2001; *Kay et al., 2006, 2011. NDA- data not available.

Caption for the figures

- Fig. 1. Location map showing study area with detailed bathymetry along with dredge tracks from where both coated with ferromanganese oxide and uncoated pumice recovered from CIOB.
- Fig. 2. Photographs of coated with ferromanganese oxide and uncoated pumice recovered by dredge.
- Fig. 3. Scatter plots of SiO_2 (wt%) vs. Fe_2O_2 (wt%), TiO_2 (wt%) and K_2O (wt%) for both types of pumice.
- Fig. 4. Total Alkali Silica (TAS) diagram (Le Bas et al., 1986) for coated and uncoated pumice suggesting rhyolitic nature (top) and scatter plot of SiO_2 (wt%) vs. K_2O (wt%) suggesting pumice are of medium K series (Ringwood 1989), (bottom) .
- Fig.5. Ternary diagram(TiO_2 -Zr-Y) showing both coated and uncoated pumice lying in the hatched area. The hatched area is for rhyolite tephra (Yamamoto et al., 1986).
- Fig.6. Tectonomagmatic discrimination diagrams (Nb vs.Y: Ta vs. Yb) of pumice suggesting volcanic arc origin.
- Fig.7. Chondrite-normalized (mean) REE pattern of both coated and uncoated pumice. Shaded area is for volcanic rocks of Sumatra (Ikeda et al., 1989; Masuda, 1980).
- Fig.8. Few important scatter plots of High Field Strength Elements (HFSE) ratios of uncoated and coated pumice from CIOB.

Fig. 1

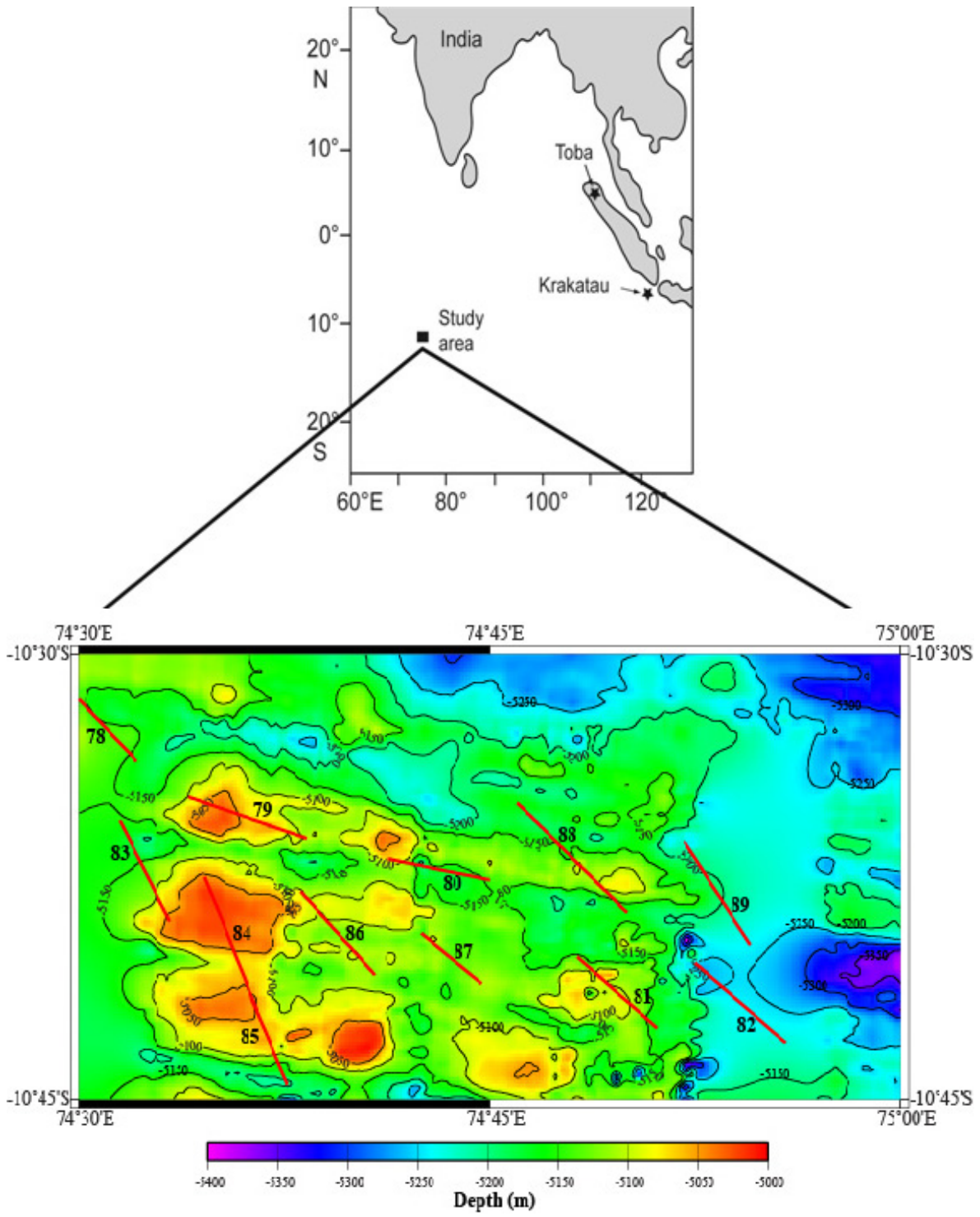


Fig.2

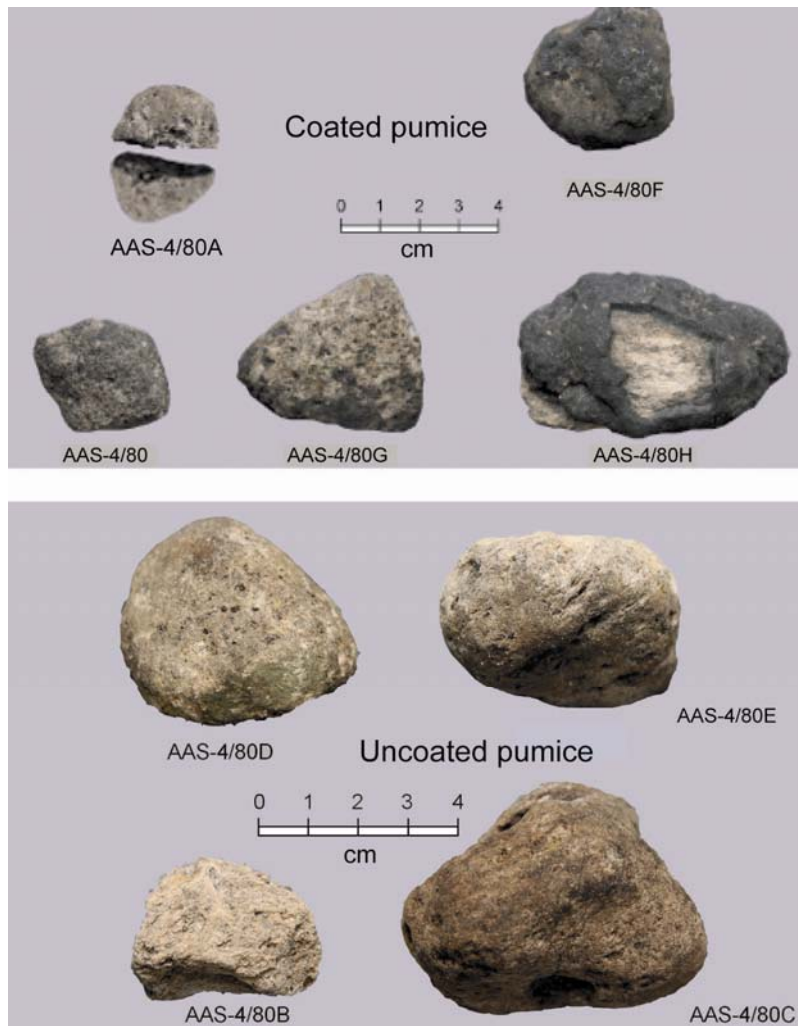


Fig. 3

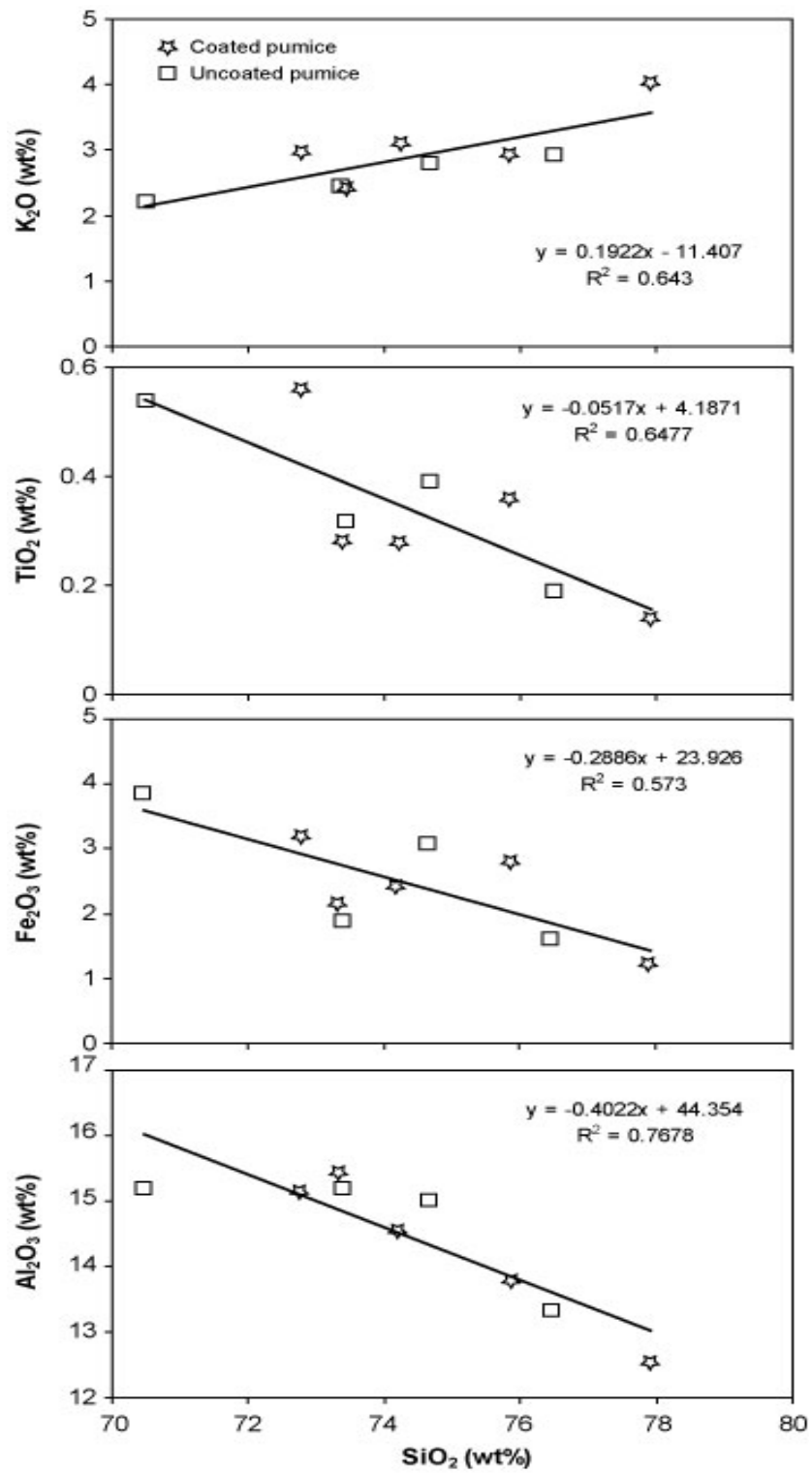


Fig.4

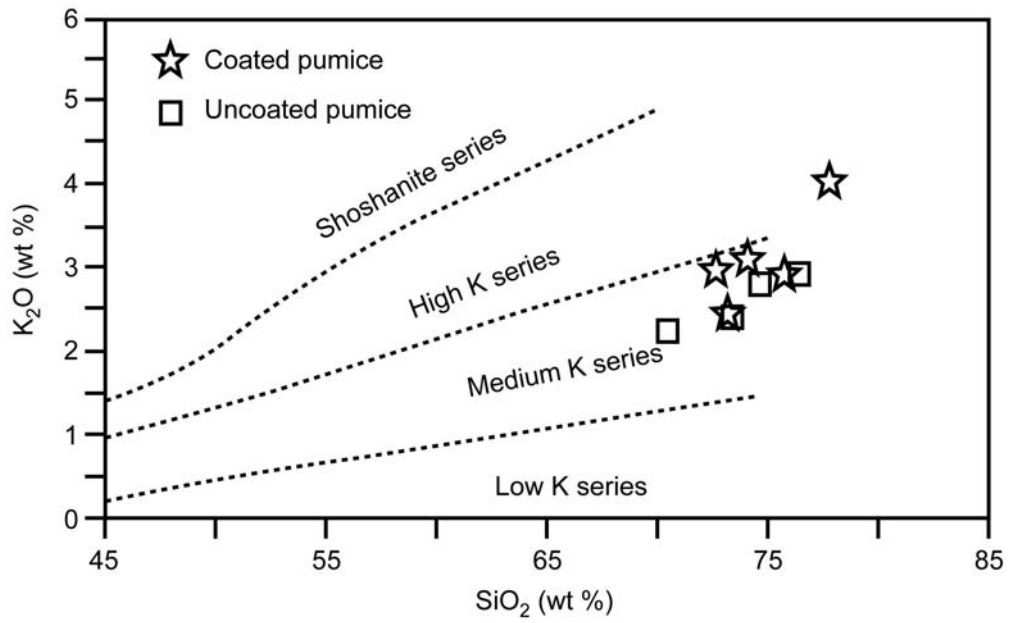
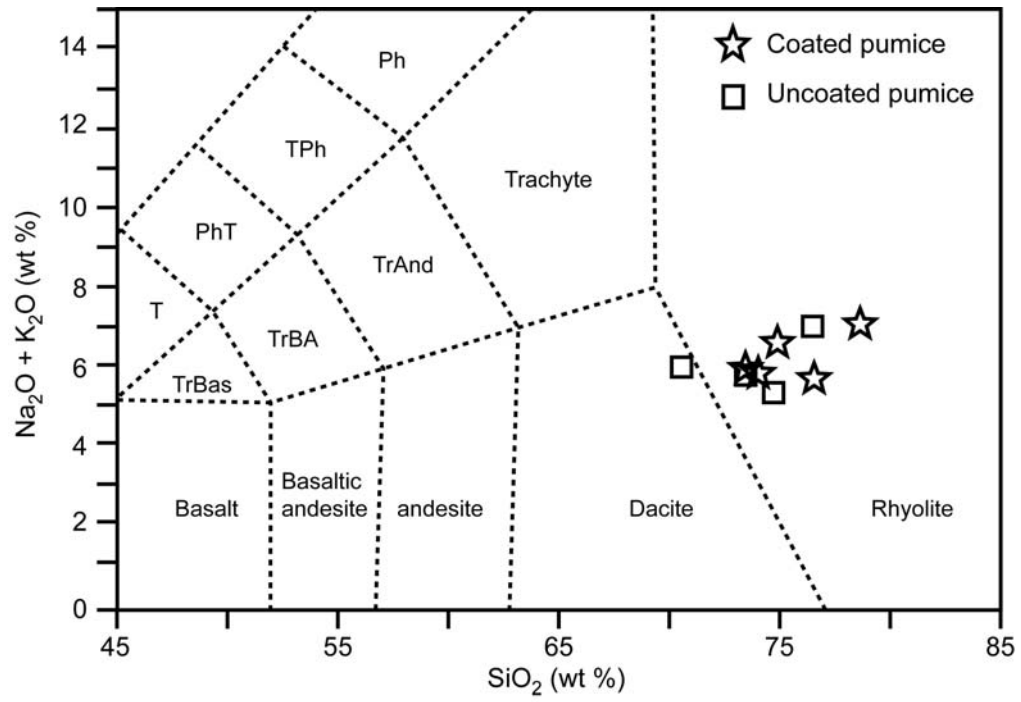


Fig. 5

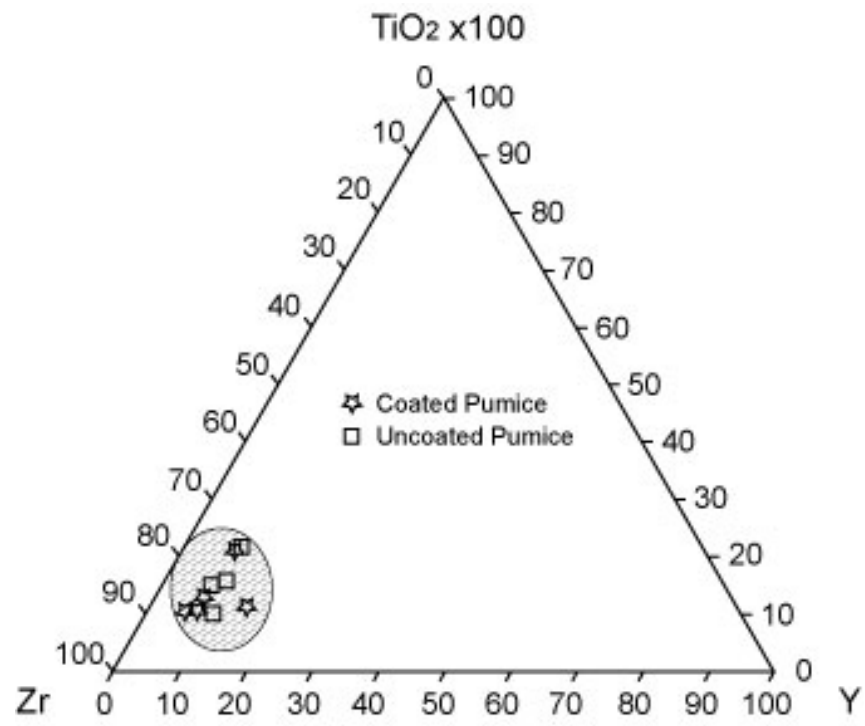


Fig.6

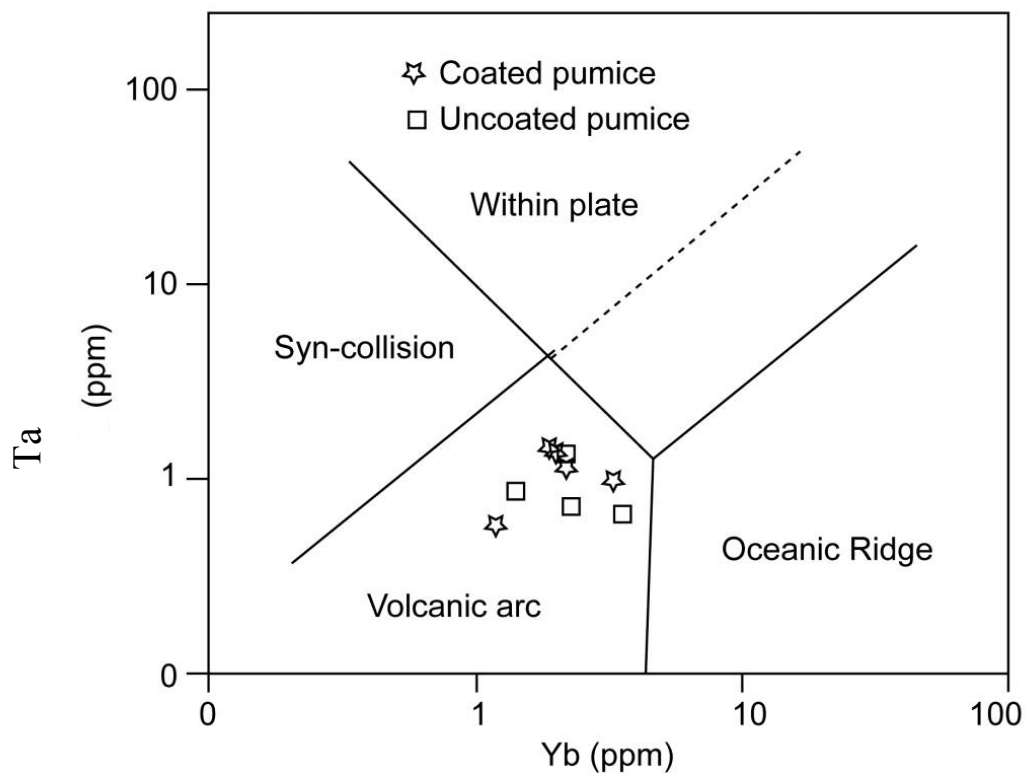
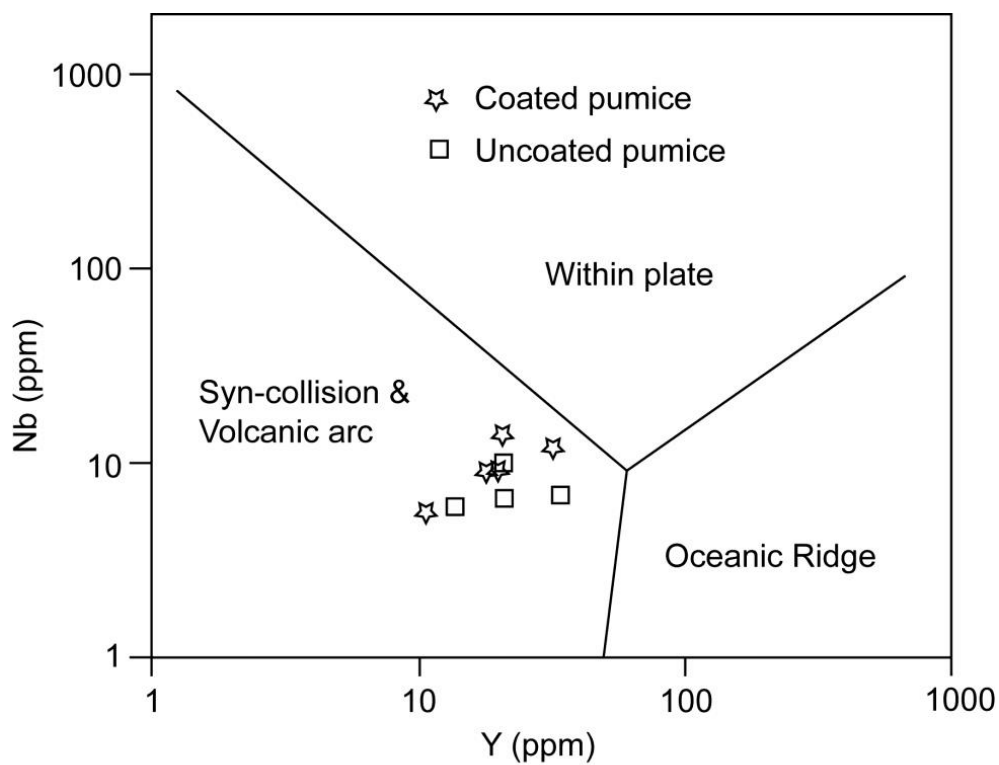


Fig. 7

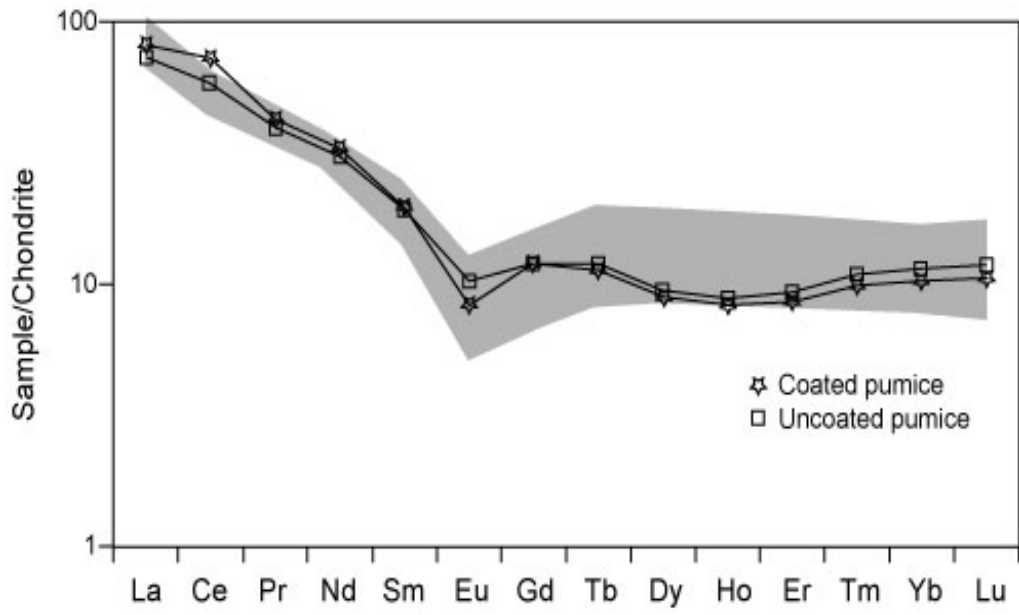


Fig.8

