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## Mineral Identification of Sedimentary Deposits of the 2004 Tsunami on the Aceh Besar Coast, Indonesia

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# Mineral Identification of Sedimentary Deposits of the 2004 Tsunami on the Aceh Besar Coast, Indonesia

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**Abstract.** Understanding tsunami deposit is quite important in order to understand the history of the tsunami and its process deeply. Nonetheless, most tsunami deposit studies only discussed the sediment grain characteristics, not the mineral contents in the deposits. Meanwhile, understanding the minerals in tsunami deposits is essential in order to understand the sediment composition deeply. Thus, we have utilized X-Ray Fluorescence and X-Ray Diffraction to study the sedimentary deposits of the 26 December 2004 Indian Ocean tsunami on the Aceh Besar coast, Indonesia. Our results showed that the sedimentary deposits of tsunami 2004 on the Aceh Besar coast contain 55% of  $\text{SiO}_2$ , 19% of  $\text{Fe}_2\text{O}_3$ , 12% of  $\text{Al}_2\text{O}_3$ , 9% of  $\text{CaO}$ , 3% of  $\text{K}_2\text{O}$ , and 2% of  $\text{TiO}_2$ . The deposits are found to be crystalline with the average crystallite size of 678 Å. There is no heavy mineral found in the tsunami deposit from Aceh Besar coast. Our results revealed that the composition of mineral contained in the sedimentary deposits of tsunami 2004 on the Aceh Besar coast is the same as those from the volcanic ash.

## 1. Introduction

The mega-earthquake occurred on the 26<sup>th</sup> of December 2004 was located at 3.3° N and 99.95° E near Banda Aceh city in Indonesia. The focal depth of this earthquake was about 10 km which the seismic moment magnitude was up to 9.1 to 9.3 [1]. According to the previous study, this earthquake initiated slowly at first with a small slip for several seconds. After that, the rupture was expanded with fast speed which extended up to more than 1200 kilometers. The fault slip was up to about 15 meters along the plate boundary offshore of the Sumatra and Nicobar islands [2]. This mega-earthquake had triggered the giant tsunami that caused more than 250 thousand deaths. This disaster has a major impact on the geomorphology and sedimentology of the coast of Sumatra [3, 4].

Identifying tsunami deposit is very important in order to understand the history of tsunamis deeply. The paleoseismic events have been recognized based on their tsunami deposits [5, 6]. A recent study using radiocarbon analyses found an extraordinary 7,400-year stratigraphic sequence of prehistoric tsunami deposits from a coastal cave in Aceh, Indonesia [7]. According to this study, there were at least 11 prehistoric tsunamis struck the Aceh coast between 7,400 and 2,900 years ago and the tsunami occurred about every 450 years [7]. Most tsunami deposit studies only discussed the sediment grain characteristics, not the mineral contents in the deposits [5-8]. Moore et al. studied sedimentary deposits of the 26 December 2004 tsunami on the northwest coast of Aceh, Indonesia [8]. They found some tsunami sediments near Lhoknga beach in Aceh Besar district in Indonesia where the grain size fines both inland and upwards in the sand [8]. Nonetheless, detail information of minerals contained in the tsunami deposit on the Aceh coast is still unknown. On the other hand, tsunami sediments could



contain hazard materials such as heavy minerals (As, Pb, Hg, etc.). Thus, it is important to study the minerals contained in the tsunami deposit. The purpose of the study is to identify the minerals contained in the sedimentary deposits of the 26 December 2004 Indian Ocean tsunami on the Aceh Besar coast, Indonesia. Detail results are reported in this paper.

## 2. Methods

The sedimentary deposits of the 2004 tsunami were obtained from the Lambada Lhok Village (marked by X), Aceh Besar district, Indonesia as shown in figure 1. This village was swept by the 26 December 2004 Indian Ocean tsunami. The location of the sample obtained was about 100 meter from the beach. Four samples of sedimentary deposits were collected that were at 0 – 2 cm depth (sample 01), 10 – 12 cm depth (sample 02), 20 – 22 cm depth (sample 03), and 30 – 32 cm depth (sample 04). X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) have been utilized to identify the mineral content in the all samples of sedimentary deposits.



**Figure 1.** The location of the study area marked by X  
(Source: Map data @2018 Google).

## 3. Results and Discussion

The sediment types of all samples were classified as sandy. Our results of XRF measurement were shown in table 1.

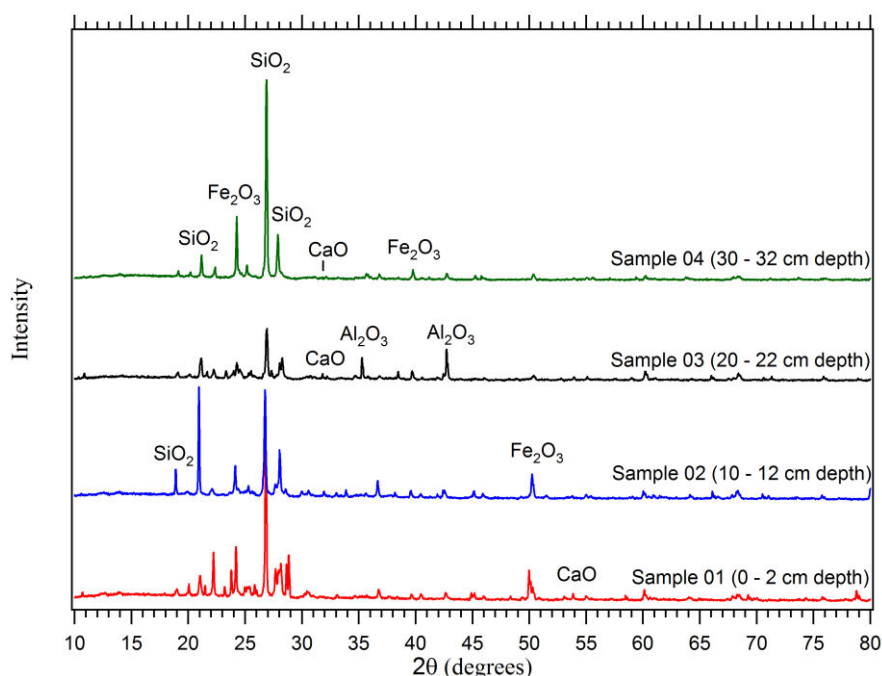
**Table 1.** XRF data from the sedimentary deposits of tsunami 2004 on the Aceh Besar coast.

Kind of Mineral	Sample 01 (0 – 2 cm)	Sample 02 (10 -12 cm)	Sample 03 (20 -22 cm)	Sample 04 (30 -32 cm)
SiO <sub>2</sub> (%)	56.9	57.9	51.4	53.6
Fe <sub>2</sub> O <sub>3</sub> (%)	17.2	17.0	20.4	20.5
Al <sub>2</sub> O <sub>3</sub> (%)	11.0	12.0	12.0	12.0

CaO (%)	8.5	7.9	9.5	8.3
K <sub>2</sub> O (%)	3.0	3.0	2.3	2.5
TiO <sub>2</sub> (%)	1.6	1.5	2.2	1.9
SrO (%)	0.4	0.3	0.4	0.4
MnO (%)	0.3	0.2	0.3	0.3
Eu <sub>2</sub> O <sub>3</sub> (%)	0.2	0.2	0.3	0.3

The sedimentary deposit at the ground surface (0 – 2 cm depth) contains 56.9% of SiO<sub>2</sub>. The silicon oxide is also found in sedimentary deposits from the 10 – 12 cm depth (57.9% of SiO<sub>2</sub>), 20 – 22 cm depth (51.4% of SiO<sub>2</sub>), and 30 – 32 cm depth (53.6% of SiO<sub>2</sub>). The percentage of silicon oxide contained in each sample is about the same with the average of 55%. The sedimentary deposit also contains Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO, K<sub>2</sub>O, TiO<sub>2</sub>. The percentage of Fe<sub>2</sub>O<sub>3</sub> from each sample is about the same. Its average is 19% of Fe<sub>2</sub>O<sub>3</sub>. It is similar to the compositions of other phases (Al<sub>2</sub>O<sub>3</sub>, CaO, K<sub>2</sub>O, TiO<sub>2</sub>). The average percentages of Al<sub>2</sub>O<sub>3</sub>, CaO, K<sub>2</sub>O, TiO<sub>2</sub> from sedimentary deposits are 12%, 9%, 3%, 2%, respectively. Besides the phases mentioned above, there are some other phases contained in the sedimentary deposits (SrO, MnO, Eu<sub>2</sub>O<sub>3</sub>) but the percentages of those phases are very small.

Our result of XRD measurement for all samples is shown in figure 2. Our XRD data were compared to JCPDS data (Joint Committee on Powder Diffraction Standards) to determine kind of minerals (phases) contained in the sedimentary deposits of tsunami 2004 on the Aceh Besar coast.



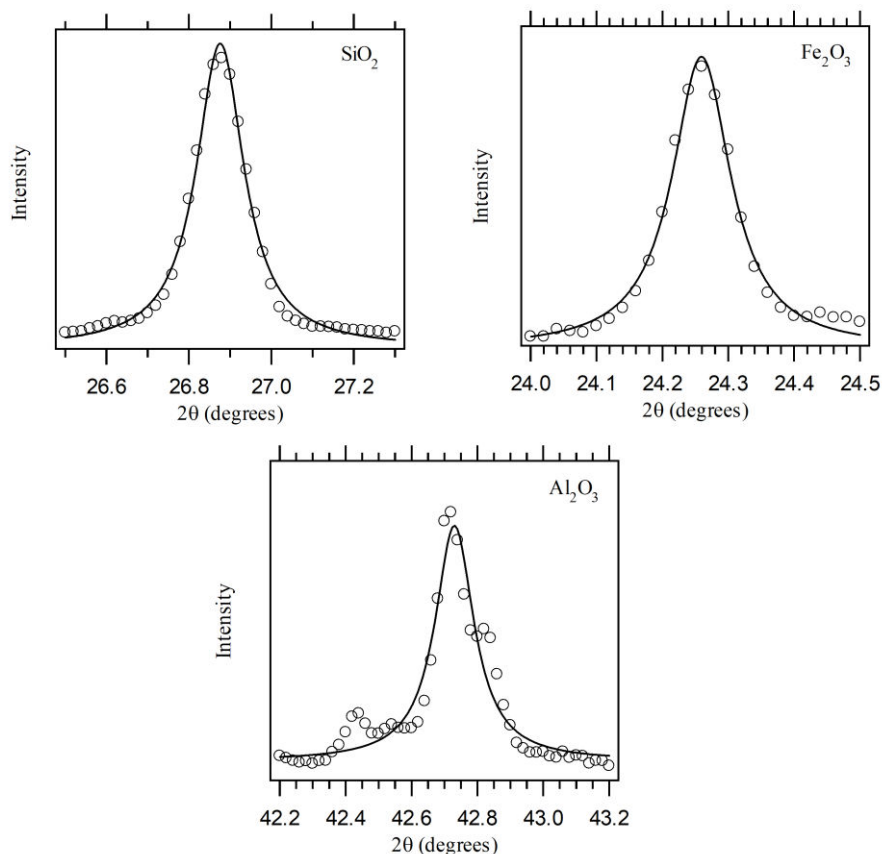
**Figure 2.** XRD data from the sedimentary deposits of tsunami 2004 on the Aceh Besar coast.

Our XRD data analysis revealed that the sedimentary deposits of tsunami 2004 on the Aceh Besar coast contain  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{CaO}$ . The  $\text{SiO}_2$  peak at the Bragg angle ( $2\theta$ ) of 26.88 degrees is the highest peak. This indicates that the  $\text{SiO}_2$  has the largest percentage contained in the sedimentary deposits of tsunami 2004. The other sharp peaks were observed at the Bragg angle ( $2\theta$ ) of 24.26 degrees ( $\text{Fe}_2\text{O}_3$ ) and 42.73 degrees ( $\text{Al}_2\text{O}_3$ ). The  $\text{K}_2\text{O}$  and  $\text{TiO}_2$  phases were not observed by XRD because the percentage of these phases are quite small. In general, our XRD data are in good agreement with our XRF data. The crystallite size of the sedimentary deposits of the tsunami was determined by using the following equation [9]:

$$D = \frac{k \cdot \lambda}{\beta \cdot \cos(\theta)} \quad (1)$$

Where  $D$  = the crystallite size;  $k = 0.95$  (constant);  $\lambda = 0.15406$  nm (the wavelength of x-ray used in the experiment);  $\beta$  = the full width at half maximum (FWHM in radian);  $\theta$  = the Bragg angle (degrees).

The FWHM for each peak was determined by fitting a Lorentzian function to the experimental XRD data as shown in figure 3.



**Figure 3.** The comparison of the XRD data (circles) from the sedimentary deposits of tsunami 2004 on the Aceh Besar coast and calculated best fit (solid lines).

By using the equation (1) above, we found that the crystallite size of  $\text{SiO}_2$  is 61.29 nm (612.9 Å). The crystallite size of  $\text{Fe}_2\text{O}_3$  was found to be 79.37 nm (793.7 Å) which is a little bit larger than that of  $\text{SiO}_2$ . The crystallite size of  $\text{Al}_2\text{O}_3$  was found to be 62.74 nm (627.4 Å) which is almost the same as

the crystallite size of  $\text{SiO}_2$ . The average of crystallite size of the sedimentary deposits of tsunami 2004 on the Aceh Besar coast is 67.80 nm (678 Å). The summary of the crystallite size of all phases is listed in table 2.

**Table 2.** The crystallite size of the sedimentary deposits of tsunami 2004 on the Aceh Besar coast.

No	Phase	2 $\theta$ (deg)	FWHM (deg)	D (nm)
1	$\text{SiO}_2$	26.88	0.14	61.29
2	$\text{Fe}_2\text{O}_3$	24.26	0.11	79.37
3	$\text{Al}_2\text{O}_3$	42.73	0.14	62.74
Average crystallite size				67.80

Based on our results above, the percentage of mineral contained in each sample is about the same which means that the thickness of sedimentary deposits of tsunami 2004 on the Aceh Besar coast is about 30 cm. The sedimentary deposits of tsunami 2004 on the Aceh Besar coast mainly contain 55% of  $\text{SiO}_2$ , 19% of  $\text{Fe}_2\text{O}_3$ , 12% of  $\text{Al}_2\text{O}_3$ , 9% of  $\text{CaO}$ , 3% of  $\text{K}_2\text{O}$ , and 2% of  $\text{TiO}_2$ . There is no heavy mineral found in sedimentary deposits of tsunami 2004 on the Aceh Besar coast. Veerasingam et al. found that the tsunami deposits from Indian Ocean tsunami 2004 at the southeast coast of India contain about 50% of  $\text{SiO}_2$ , 12% of  $\text{CaO}$ , and 1% of  $\text{TiO}_2$  [10] which are in good agreement with our study. However, the composition of mineral from sedimentary deposits of tsunami 2004 on the Aceh Besar coast is different than those from tsunami deposits in Sendai Japan [11] as shown in tabel 3. The tsunami deposits in Sendai Japan contains 79% of  $\text{SiO}_2$  while it is only 55% of  $\text{SiO}_2$  in the sedimentary deposits of tsunami 2004 on the Aceh Besar coast. The compositions of  $\text{Fe}_2\text{O}_3$  and  $\text{CaO}$  are also quite different. This suggests that the source type of sedimentary deposits of the 26 December 2004 Indian Ocean tsunami is different than those of tsunami in Sendai Japan.

**Table 3.** The comparison of mineral contained in the sedimentary deposits of tsunami 2004 on the Aceh Besar coast and tsunami deposit from Sendai Japan.

Kind of Mineral	This Study	Tsunami deposit in Sendai Japan [11]	Volcanic ash from Mount of Merapi [12]
$\text{SiO}_2$ (%)	55	79.39	52.52
$\text{Fe}_2\text{O}_3$ (%)	19	0.63	9.17
$\text{Al}_2\text{O}_3$ (%)	12	13.61	18.69
$\text{CaO}$ (%)	9	1.40	8.96
$\text{K}_2\text{O}$ (%)	3	2.15	2.10
$\text{TiO}_2$ (%)	2	1.5	1.45

Wahyuni et al. found that the volcanic ash from Merapi Mountain in Yogyakarta contains 52.52% of SiO<sub>2</sub>, 18.69% of Al<sub>2</sub>O<sub>3</sub>, 9.17% of Fe<sub>2</sub>O<sub>3</sub>, and 8.96% of CaO [12]. The comparison between this study and the mineral contained in the volcanic ash from Merapi Mountain in Yogyakarta is shown in table 3. It is very surprising that the composition of mineral contained in sedimentary deposits of tsunami 2004 on the Aceh Besar coast is about the same as those from volcanic ash from Merapi Mountain eruption in Yogyakarta.

#### 4. Conclusions

The minerals contained in the sedimentary deposits of tsunami 2004 on the Aceh Besar coast are 55% of SiO<sub>2</sub>, 19% of Fe<sub>2</sub>O<sub>3</sub>, 12% of Al<sub>2</sub>O<sub>3</sub>, 9% of CaO, 3% of K<sub>2</sub>O, and 2% of TiO<sub>2</sub>. The sedimentary deposits of tsunami 2004 on the Aceh Besar coast are crystalline with the average of crystallite size of 67.80 nm (678 Å). There is no heavy mineral observed in the sedimentary deposits of tsunami. The tsunami deposit from Indian Ocean tsunami 2004 at the Aceh Besar coast is found to be similar to those from the southeast coast of India. We found that the composition of mineral contained in sedimentary deposits of tsunami 2004 on the Aceh Besar coast is the same as those from the volcanic ash from Merapi Mountain eruption in Yogyakarta.

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