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RESISTIVITY AND CHARGEABILITY SIGNATURES OF TSUNAMI DEPOSITS AT ACEH BESAR AND BANDA ACEH COASTAL AREA, INDONESIA

Muhammad Syukri [1,2], Rosli Saad [3]*, Sabrian Tri Anda[2], and Zul Fadhli[2]

[1]Department of Physics, Faculty of Sciences, Syiah Kuala University, Banda Aceh, Indonesia
[2]Department of Engineering Geophysics, Syiah Kuala University, Banda Aceh, Indonesia
[3]School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia

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ABSTRACT: The study was conducted at the coastal area of Aceh Besar and Banda Aceh using 2-D resistivity and IP methods to investigate the changes/response of resistivity and chargeability toward sediment. The study is aimed to identify the post-, pre- and tsunami sediment deposits. The results are validated with hand auger performed on the study line. Generally, the study identified that the coastal sediments of Aceh Besar and Banda Aceh consist of clay/silty clay/sand/silty sand. Based on the results, the sediments are categorized into three layers; the top layer (post-tsunami sediment), tsunami sediments and pre-tsunami sediments. The tsunami sediment consists of a mix of sand or clay or silty clay or silty sand. Each layer was represented by different resistivity and chargeability values depending on the sediment types.

Keywords: Resistivity, Chargeability, Hand Auger, Post-, pre-, and tsunami sediment deposits.

1. INTRODUCTION

The great earthquake and tsunami that occurred at Aceh on 26 December 2004, affecting several countries in South East Asia have left many pieces of evidence to be observed. The event triggered researchers to investigate in detail and gain knowledge for future hazards related to earthquakes and tsunamis. It is believed that the tsunami deposit sediments left by the event can be used to improve risk assessment. Studies on the tsunami deposit sediments play an important role in identifying the past earthquake and tsunami event and expand the knowledge of magnitude and frequency of the event [1]. Jaffe and Gelfenbaum [2] stated that the world record of tsunamis studies is limited, thus contributing to the imprecise tsunami risk assessment. Moore et al. [3] ascertain that tsunami deposit sediments have been studied in several locations but only in smaller modern tsunamis event such as the Flores incident in 1992 [4], [5]; 1993 Okushiri [6], [7]; 1994 Java [8]; and 1998 Papua New Guinea [9]. Nevertheless, research about the tsunami deposit sediments caused by large scale tsunamis such as Aceh tsunami is limited since the natural event itself rarely occurs. This paper discusses the tsunami deposit sediments caused by the great earthquake and tsunami events that occurred in Aceh in 2004. The study takes place at two sites along the coastal line of Banda Aceh and Aceh Besar, Indonesia. Identifications of the tsunami deposit sediments are done by employing geophysics method (2-D resistivity and induced polarization) and validated with hand auger data.

2. GEOLOGY OF STUDY AREA

Generally, the lithology of Aceh Besar district is made up of alluvium composed of gravel, sand, sandy clay, sandy silt, clayey silt, silty clay and sediments originated from the swamp. The topography of the area is considered as undulating, spread out from northwest to southeast. The district is also known as Krueng Aceh basin [10], [11]. The rock types are classified as Tertiary and Pre-tertiary rock while the eastern part delimited with hills composed of Plio-Plistosen which originated from Seulawah Agam Volcano [12]. Generally, Banda Aceh district is situated at the deltaic plains of Krueng Aceh which is specifically located between the low Tertiary and Quaternary volcanic hills on eastward and Cretaceous limestone hills in the west. According to Culshaw et al. [13], the soil of the area was made up by alluvium and marine sediments with an approximate thickness of 179 m which is deposited from the graven structure in the Sumatran Fault System. The rocks of this area are classified as limestone, slates and phyllites at the western part while the east side is composed of deposited andesitic tuffs and subsidiary flows (Figure 1).

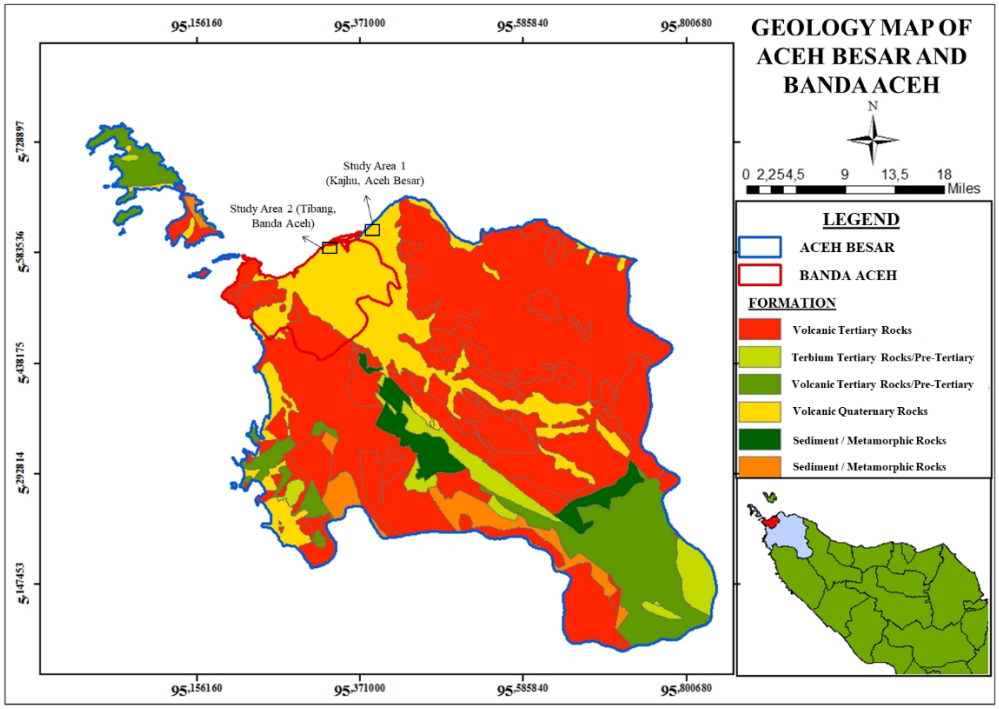

Fig. 1: General geology of Aceh

The tsunami deposit sediments study was conducted at two locations (Kajhu 1 and Kajhu 2) in Aceh Besar district and two locations (Tibang 1 and Tibang 2) in Banda Aceh district using electrical method (2-D resistivity and induced polarization) together with hand auger (Figure 2).

Fig. 2: Study locations of tsunami deposit sediments; two in Aceh Besar district and two in Banda Aceh district (Google Earth, 2018).

3. METHODOLOGY

The electrical method applied in the study areas is 2-D resistivity and induced polarization (IP) using the ABEM SAS4000 Terrameter system. Two sets of Lund cables with 21 take-outs each and 41 electrodes were employed by applying pole-dipole array considering this type of array has the deepest depth penetration and provides a good horizontal and vertical resolution. Table 1 shows the acquisition settings of ABEM SAS4000 in measuring the resistivity and IP values for all the survey lines. The data acquisition applied multiple period windows of time of 20 ms and the cut-off

frequency of 50 Hz used to suppress power line noise.

Table 1: ABEM SAS4000 settings for data acquisition of resistivity and IP.

Item	Setting
Current on	1.0 second
Current off	1.0 second
Acquisition delay	0.4 second
Acquisition time	0.6 second
Measuring window	10

The first study area is at Kajhu sub-district of Aceh Besar district. Two survey lines were set at two locations and each location consists of one survey line, Kajhu 1 and Kajhu 2 respectively (Figure 3a and 3b). Kajhu 1 survey line was conducted using 2-D resistivity and induced polarization using minimum electrode spacing of 0.2 m and pole-dipole array. The hand auger (HA1) for the Kajhu 1 was located at 4 m along the survey line. Kajhu 2 survey line was conducted using 2-D resistivity and induced polarization using minimum electrode spacing of 0.5 m and pole-dipole array, but the hand auger for the Kajhu 2 was not performed due to site restriction. The second study area is at Tibang sub-district of Banda Aceh district. Two study locations are set, each location consists of one survey line, Tibang 1 (Figure 3c) and Tibang 2 (Figure 3d). The survey lines (Tibang 1 & 2) were conducted using 2-D resistivity and induced polarization using minimum electrode spacing of 0.2 m with the pole-dipole array. Hand augers (HA2 and HA3) were performed at 4 m along each survey line respectively. Table 2 shows the coordinate of the survey lines and hand augers.

Fig. 3: Survey lines at Aceh Besar; (a) Kajhu 1, (b) Kajhu 2, and Banda Aceh; (c)Tibang 1 and (d) Tibang 2 (Google Earth, 2018)

Table 2: The coordinates of the survey lines and hand augers.

Name	Distance (m)	Latitude (º)	Longitude (º)
Kajhu 1	0	5.606306	95.373361
	8	5.606250	95.373306
Kajhu 2	0	5.597918	95.372060
	20	5.597767	95.372169
Tibang 1	0	5.588222	95.342306
	8	5.588154	95.342336
Tibang 2	0	5.593203	95.335600
	8	5.593131	95.335611
HA1	4	5.606280	95.373336
HA2	4	5.588189	95.342322
HA3	4	5.593171	95.335607

4. RESULTS AND DISCUSSION

Figure 4 depicts the range of resistivity values obtained. Generally, the resistivity values of the study sites are in the 0 to 15 Ohm. m range and the chargeability values are between -15 to 850 ms (Figure 4).

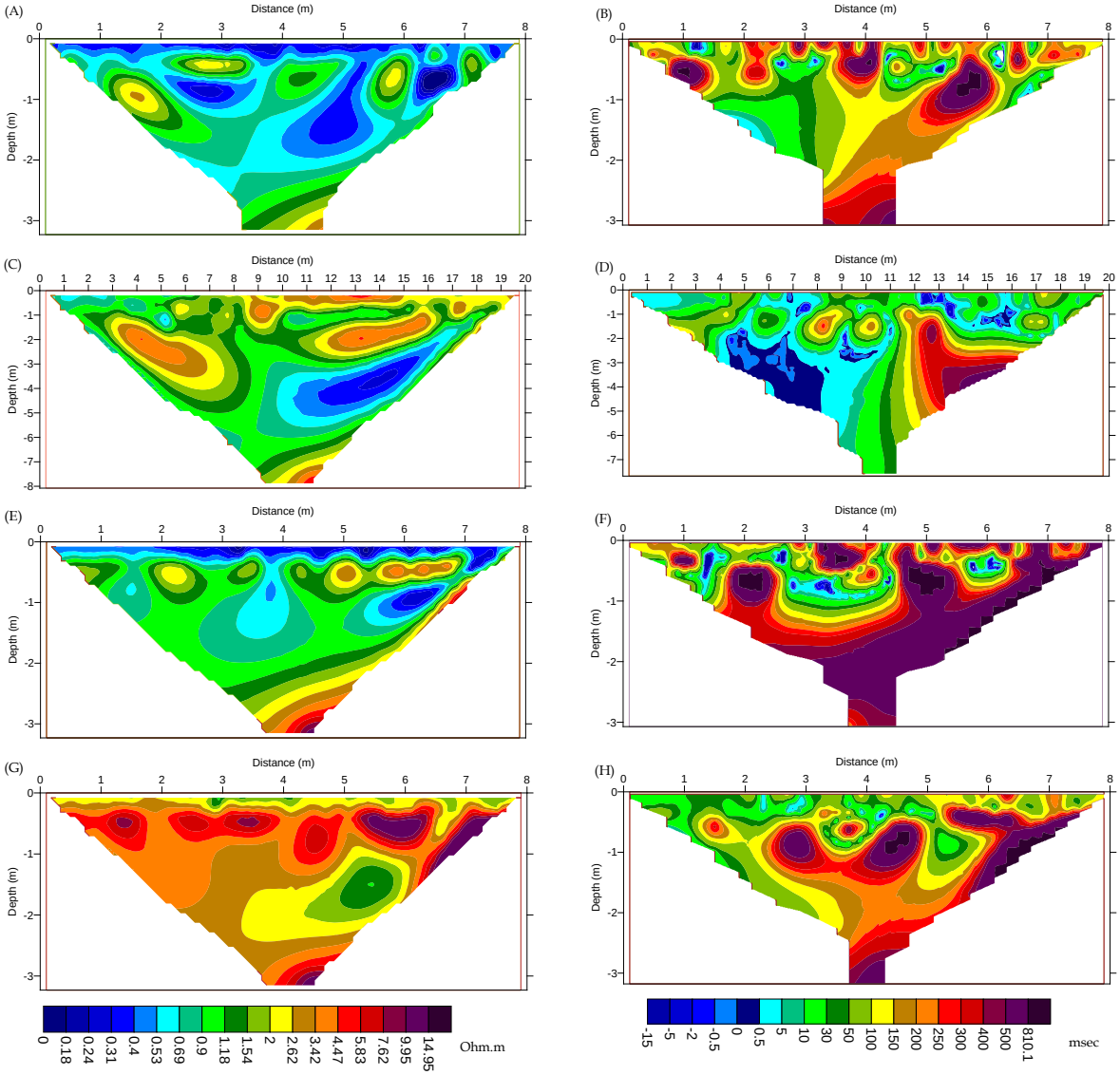

Fig. 4: 2-D resistivity and IP results for the study areas; (a-b) Kajhu 1, (c-d) Kajhu 2, (e-f) Tibang 1, and (g-h) Tibang 2.

Figure 5 shows the hand auger results. The results indicate HA1 and HA2 are dominated by clay/silty clay while HA3 is dominated by sand/silty sand. Generally, the hand auger results show three types of sediments deposit. Post-tsunami sediments are located at the top of the ground surface with a depth of 0.11-0.8 m, followed by tsunami sediments deposit with the depth of 0.29-1.58 m while pre-tsunami sediment deposit was identified beyond the tsunami sediments deposit.

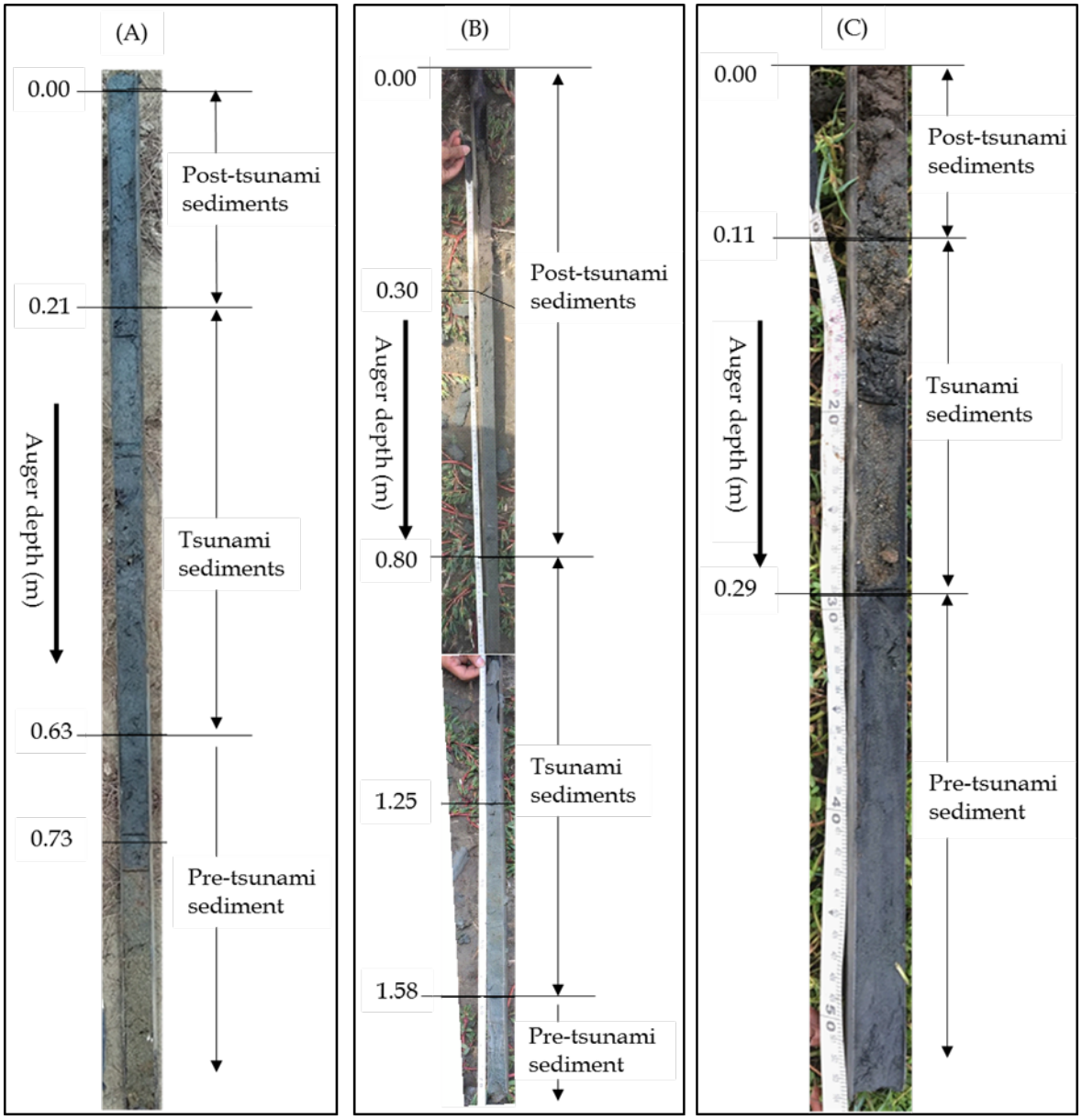

Fig. 5: Hand auger results of the study area; (a) HA1, (b) HA2 and (c) HA3

Figure 6 and 7 show the 2-D resistivity sections of Kajhu 1 and Tibang 1, correlated with hand auger results (HA1 and HA2 respectively). The results indicate the post-tsunami sediment resistivity value is <0.53 Ohm.m, tsunami sediment is 0.53-0.9 Ohm.m and pre-tsunami sediment is >0.9 Ohm.m. The hand auger samples show that the sediments are dominated by clay/silty clay. Tibang 2 (Figure 8) results indicate the post-tsunami sediment resistivity value is <2 Ohm.m, tsunami sediment is 2-3.42 Ohm.m and pre-tsunami sediment is >3.42 Ohm.m, and the hand auger samples show that the sediments are dominated by sand/silty sand. Referring to the resistivity values of Kajhu 1, Tibang 1 and 2, the Kajhu 2 section (Figure 9) is interpreted as tsunami sediment (2-3.42 Ohm.m) and pre-tsunami sediment (>3.42 Ohm.m), and the sediments are dominated by sand/silty sand.

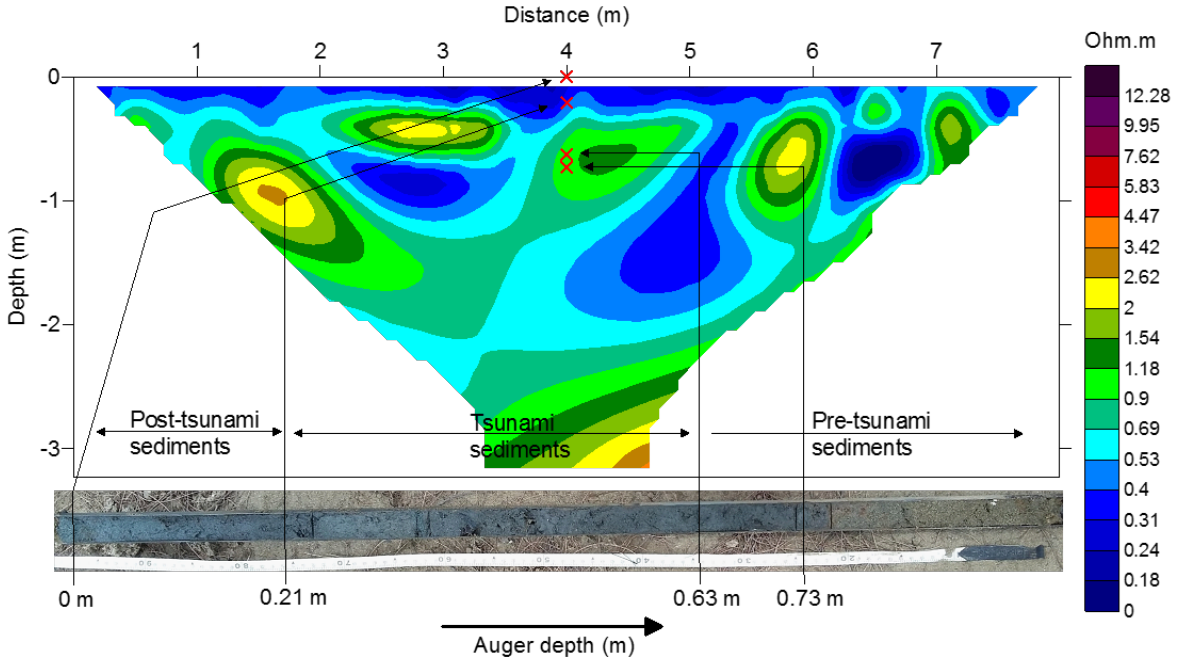

Fig. 6: Correlation between resistivity section of Kajhu1 and hand auger for sediment identification

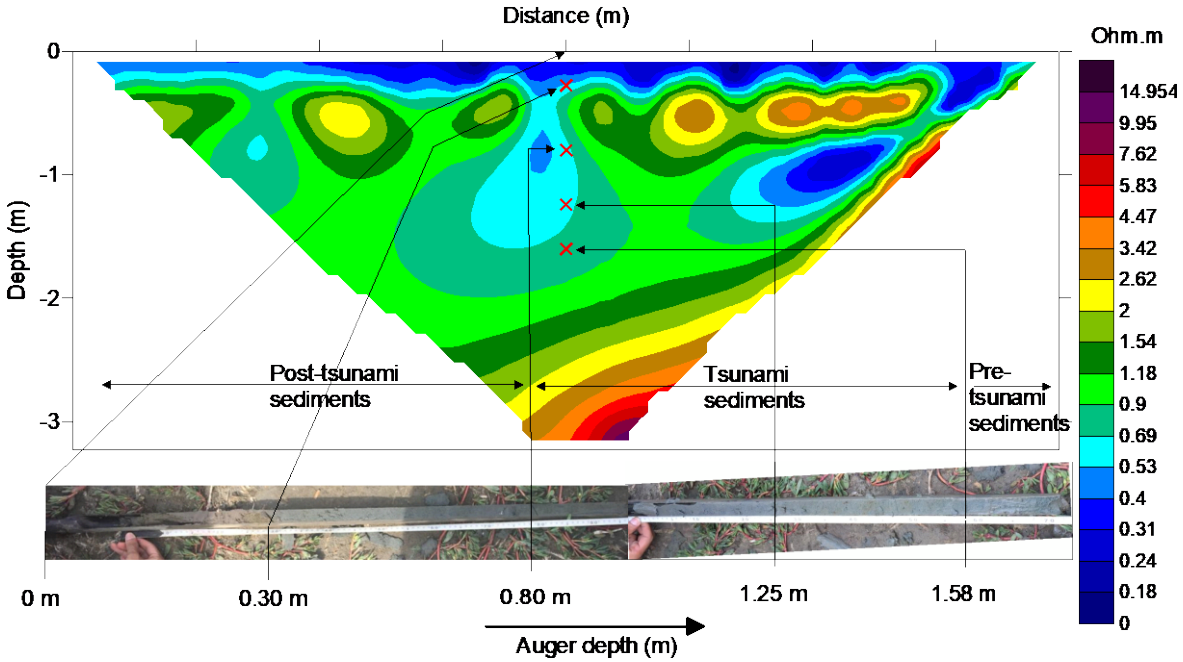

Fig. 7: Correlation between resistivity section of Tibang 1 and hand auger for sediment identification

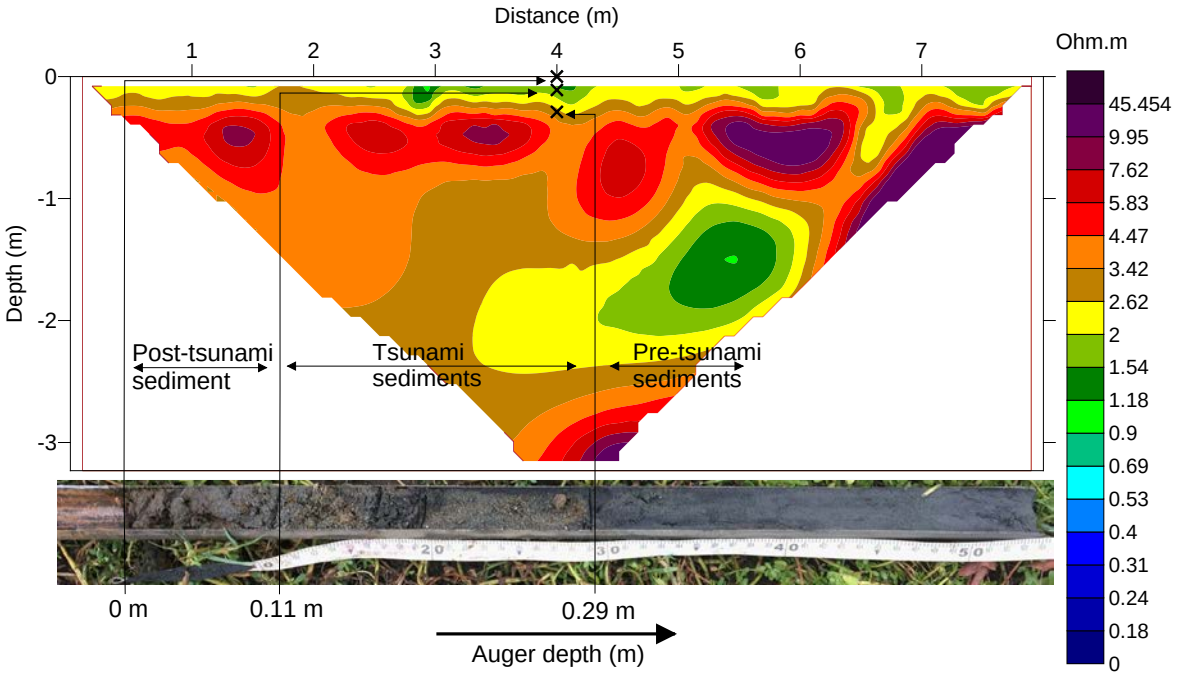

Fig. 8: Correlation between resistivity section of Tibang 2 and hand auger for sediment identification

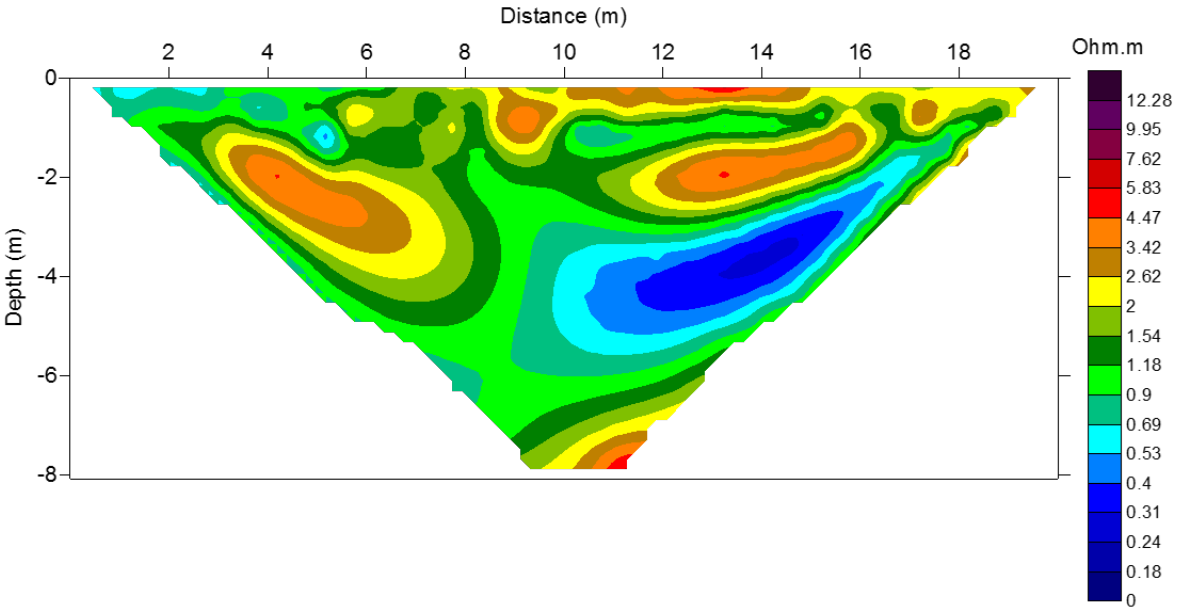

Fig. 9: Correlation between resistivity section of Kajhu2 and hand auger for sediment identification

Figures 10 and 11 show the 2-D chargeability sections of Khaju 1 and Tibang 1, correlated with hand auger respectively. The results indicate the post-tsunami sediments chargeability value is 150-300 ms, tsunami sediment is 0.5-500 ms and pre-tsunami sediment is >100 ms. The hand auger samples show that the sediments are dominated by clay/silty clay. Tibang 2 (Figure 12) results indicate that the post-tsunami sediment chargeability value is 50-100 ms, tsunami sediment is 10-50 ms and pre-tsunami sediment is >10 ms, and the hand auger samples show the sediments are dominated by sand/silty sand. Referring to the chargeability values of Khaju 1, Tibang 1 and 2, the Khaju 2 section (Figure 13) is interpreted as tsunami sediments (0.5-500 ms) and pre-tsunami sediments (>100 ms), and the sediments are dominated by sand/silty sand.

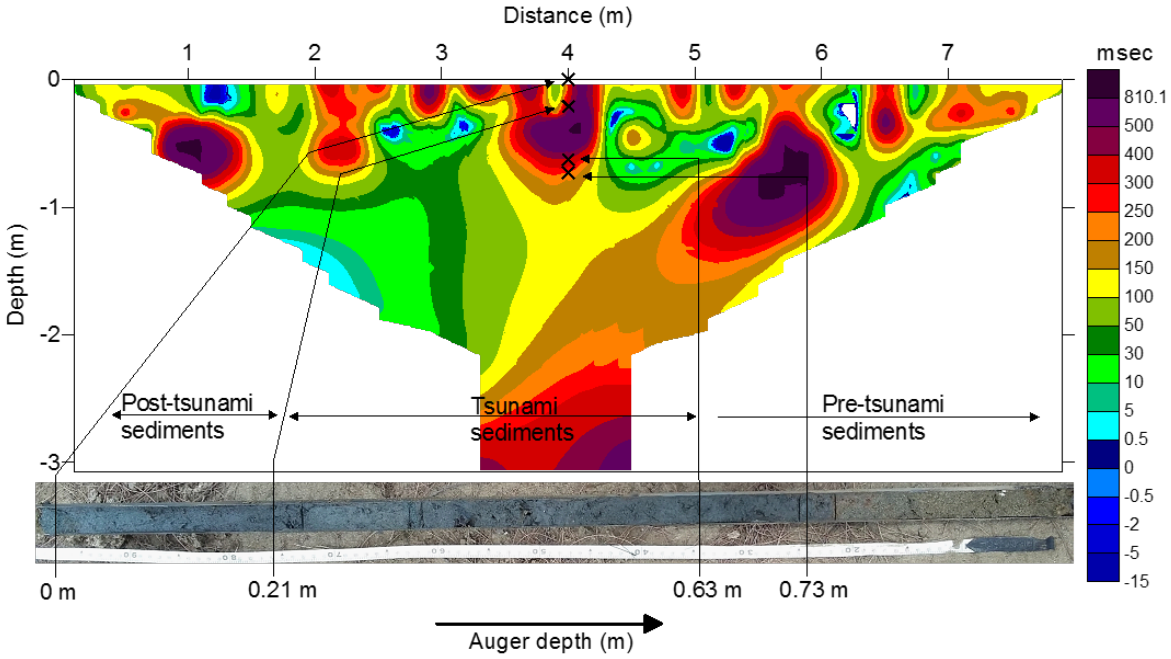

Fig. 10: Correlation between IP section of Kajhu1 and hand auger for sediment identification

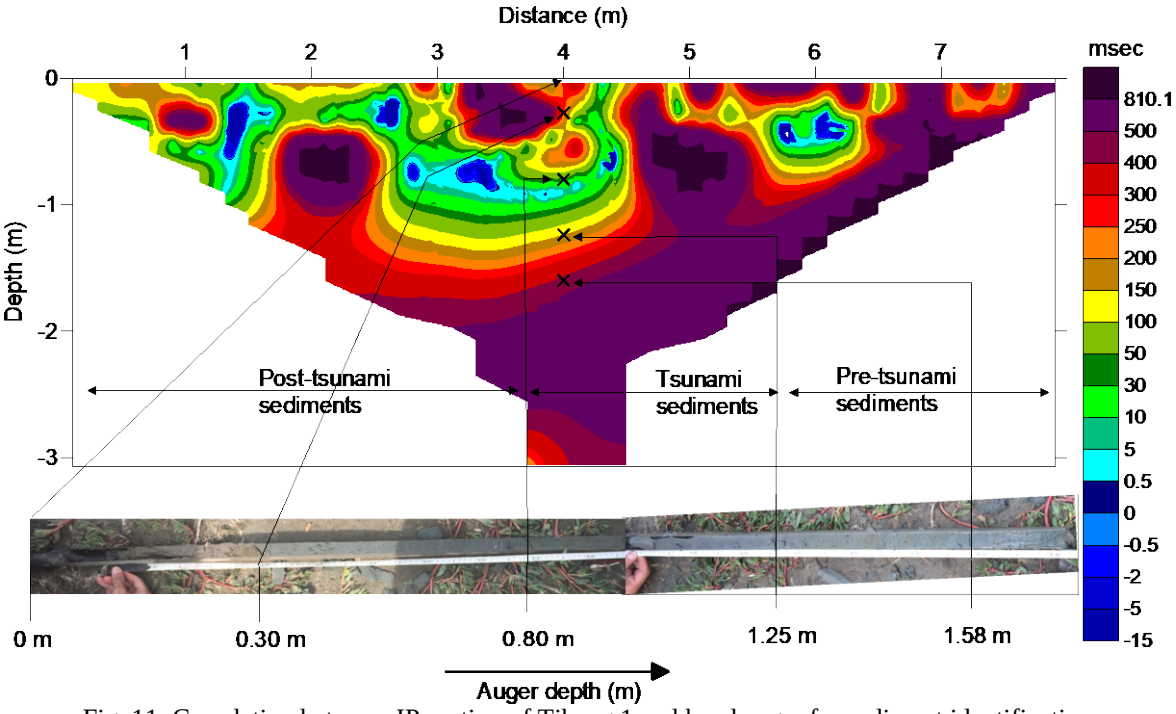

Fig. 11: Correlation between IP section of Tibang 1 and hand auger for sediment identification

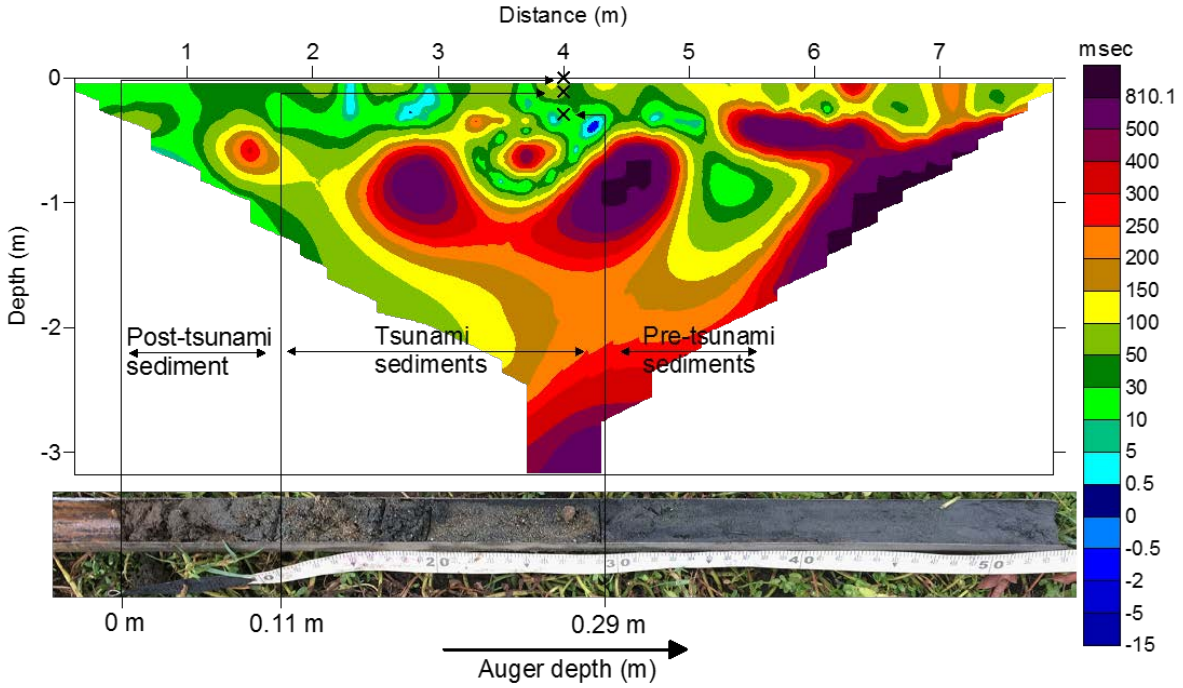

Fig. 12: Correlation between IP section of Tibang 2 and hand auger for sediment identification

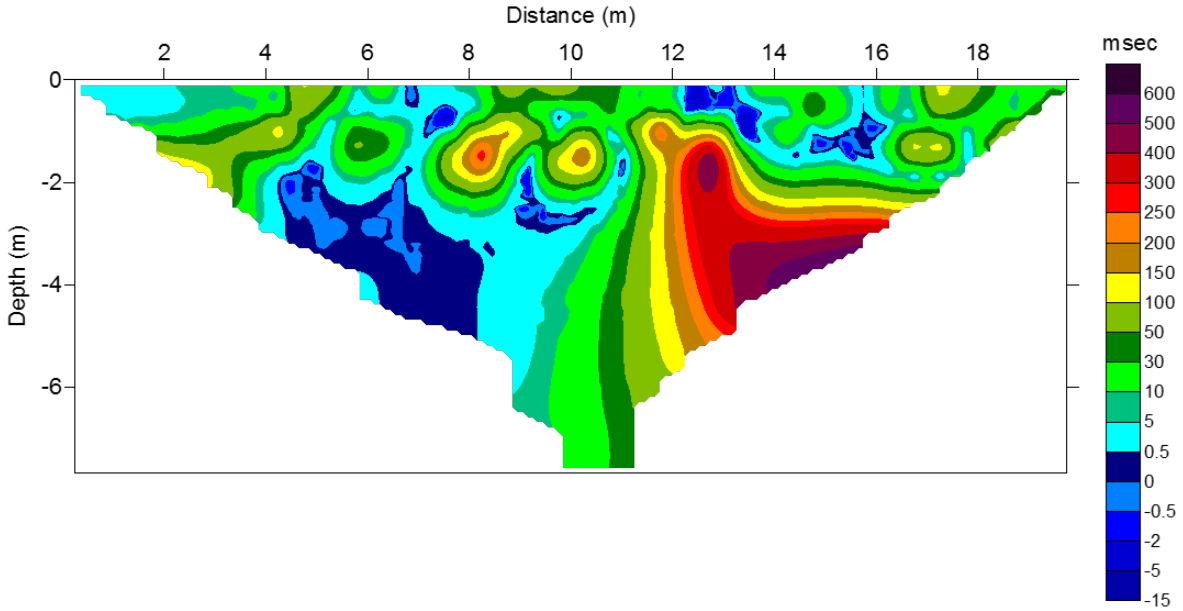

Fig. 13: Correlation between IP section of Kajhu 2 and hand auger for sediment identification

5. CONCLUSIONS

Tsunami sediment consists of a mix of sand or clay or silty clay or silty sand. The mixture depends on the size of the water waves and ground topography. Post-tsunami sediments refer to sediments that occur after the tsunami event which comes from erosion or seawater wave activities, meanwhile pre-tsunami sediments refer to sediments that occur before tsunami event which also comes from erosion or seawater wave activities. Table 3 shows the distribution of resistivity and chargeability values for post-tsunami, tsunami and pre-tsunami sediments related to sediments types.

Table 3: Resistivity and chargeability values of the post-tsunami, tsunami and pre-tsunami sediments at Aceh Besar, Indonesia.

Event	Sediment type	Resistivity (Ohm.m)	Chargeability (ms.)
Post-tsunami	clay/silty clay	<0.53	150-300
	sand/silty sand	<2	50-100
Tsunami	clay/silty clay	0.53-0.9	0.5-500
	sand/silty sand	2-3.42	10-50
Pre-tsunami	clay/silty clay	>0.9	>100
	sand/silty sand	>3.42	>10

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