Sedimentological Properties of The 2010 Mentawai Tsunami Deposit

Sifat Sedimen Endapan Tsunami Mentawai 2010

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ABSTRACT: Post tsunami survey of the October 25, 2010, Mentawai tsunami, has been carried out by a collaboration team of Indonesian-German scientists from 20 to 28 November 2010. One activity of the researches were investigation on tsunami deposits along the coast following the event that devastated the islands of Sipora, North Pagai and South Pagai. Sedimentological properties of Mentawai tsunami deposit were explained by this study, from both megascopic and laboratory result. In general, beaches along the study area are underlying by a stretch of reef limestone, sediments mostly composed of white sand while grey sand was found only at Malakopa. Tsunami sediments were taken from 20 locations, start from Betumonga at Sipora Island until Sibaru-baru Island at the southern tip of the study area. The thickness of tsunami deposits are ranged between 1.5 and 22 cm, which are generally composed of fine to coarse sand in irregular boundaries with the underlying soil. Based on grain size analysis, variation of sedimentological properties of tsunami deposits range between phi=-0,5793 and phi=3,3180 or very coarse to very fine sand. Tsunami deposits mostly have multiple layers which described their transport processes, run up at the bottom and back wash at the top. Structural sediments such as graded bedding of fining upward, parallel lamination and soil clast were found. The grain size distribution curves show two types of mode peak, unimodal and multimodal which are indication of different sorting condition representing the source materials. While segment grain size accumulative plot generally shows domination of dilatation and traction transport mechanism rather than suspension. In general, very rare fossils were found from Mentawai tsunami deposit, but those findings gave information on how depth tsunami start to scour the seafloor and transport it landward, such as an abundance of *Sponge spicule* was found which indicate shallow water environments (20-100 m seafloor depth).

Keywords: 2010 Mentawai tsunami, tsunami deposit, grain size analysis, fossils identification.

ABSTRAK: *Survei pasca-tsunami Mentawai 25 Oktober 2010, telah dilakukan oleh Tim gabungan Indonesia-Jerman pada tanggal 20 - 28 November 2010. Salah satunya adalah melakukan identifikasi endapan tsunami yang ditemukan di sepanjang pantai yang terlanda tsunami di Pulau Sipora, Pagai Utara dan Pagai Selatan. Berdasarkan hasil penelitian baik megaskopik maupun analisis laboratorium, dalam tulisan ini dapat dijelaskan mengenai sifat-sifat sedimentologi dari endapan tsunami Mentawai. Secara umum litologi penyusun pantai di daerah penelitian disusun oleh hamparan batugamping terumbu, sebagian disusun oleh pasir berwarna putih, sedangkan di Malakopa tersusun oleh endapan pasir pantai berwarna abu-abu. Berdasarkan hasil analisis laboratorium, diperoleh variasi sifat sedimentologi, seperti kisaran ukuran butir endapan tsunami antara -0,5793 phi dan 3,3180 phi, yaitu pasir sangat kasar hingga sangat halus. Endapan tsunami umumnya memiliki beberapa lapis yang menunjukkan adanya proses transportasi, seperti saat air naik (run up) di lapisan bagian bawah dan surut di bagian atas, yang ditunjukkan dengan adanya perbedaan ukuran butir. Struktur sedimen ditemukan seperti adanya perubahan besar butir secara berangsur menghalus ke bagian atas, perlapisan sejajar dan fragmen tanah yang terperangkap dalam sedimen. Kurva distribusi ukuran butir memperlihatkan dua jenis model puncak, yaitu unimodal dan multimodal yang memperlihatkan kondisi pemilahan yang berbeda yang menunjukkan kondisi sumber material endapan tsunami, sedangkan grafik akumulasi ukuran butir umumnya memperlihatkan dominasi mekanisme transportasi dilatasi dan traksi daripada suspensi. Secara umum fosil yang terkandung dalam endapan tsunami Mentawai sangat jarang, namun sedikit banyak telah memberikan informasi seberapa dalam gelombang tsunami mulai menggerus lantai* *samudera dan memindahkannya ke darat, misalnya dengan ditemukannya fosil bentonik Sponge spicule yang melimpah, menunjukkan asal lingkungan laut dangkal dengan kedalaman laut 20-100 m.*

Kata kunci: *Tsunami Mentawai 2010, endapan tsunami, analisis besar butir, identifikasi fosil.*

INTRODUCTION

An earthquake of magnitude Mw7.7 had been occurred on 25 October 2010, with epicenter located at the west off Mentawai Islands 3.484 S – 100.114 E, at 20.6 km depth under the seafloor, (USGS, 2010). This earthquake was followed by tsunami and caused about 448 people dead and damage on housing and public facilities. A tsunami survey had been conducted with some measurements, such as tsunami run up, inundation, tsunami flow direction, coastal deformation, local bathymetry and land topography. Identification on tsunami deposit was carried out, as well as information on existing structure and information from Mentawai people.

There are two types of tsunami deposits, boulder and sand size materials, but this paper will only discuss sedimentological properties of sand which has collected from 22 selected locations (Figure 1). From nine locations, grain size analysis and fossil identification were conducted to obtain the characteristics of Mentawai tsunami deposit.

Tectonically, the 2010 Mentawai earthquake was caused by thrusting on subduction interface of Indo-Australian plate beneath Eurasian plate. In this location, Indo-Australian plate moving to north-northeastward in term of Sunda plate with relative motion rate of 57-69 mm/year (Figure 2). According to its focal mechanism and depth, this earthquake has reverse fault mechanism, nodal plane strike 319 , dip 7 , and slip 98 , with seismic moment 6,66 x 10^{27} dyne.cm.

The 25 October 2010 Mentawai earthquake has rupture area near to the 12 September 2007 earthquake (Mw 8.5) and adds a large scale earthquake along the Sunda megathrust. In 2004, an earthquake magnitude Mw 9.3 was taking place 800 miles north of the Mentawai earthquake, in 2005 the region was again hit by an earthquake magnitude Mw 8.6 which is located 700 km north between Nias and Simeulue, and the last earthquake occurred in 2009 about 300 km north of Padang with magnitude Mw 7.5. History also repeated, Mentawai Earthquake, October 25, 2010 is the repetition of the same events in 1797 with magnitude Mw 8.7 to 8.9 and in 1833 earthquake of magnitude Mw

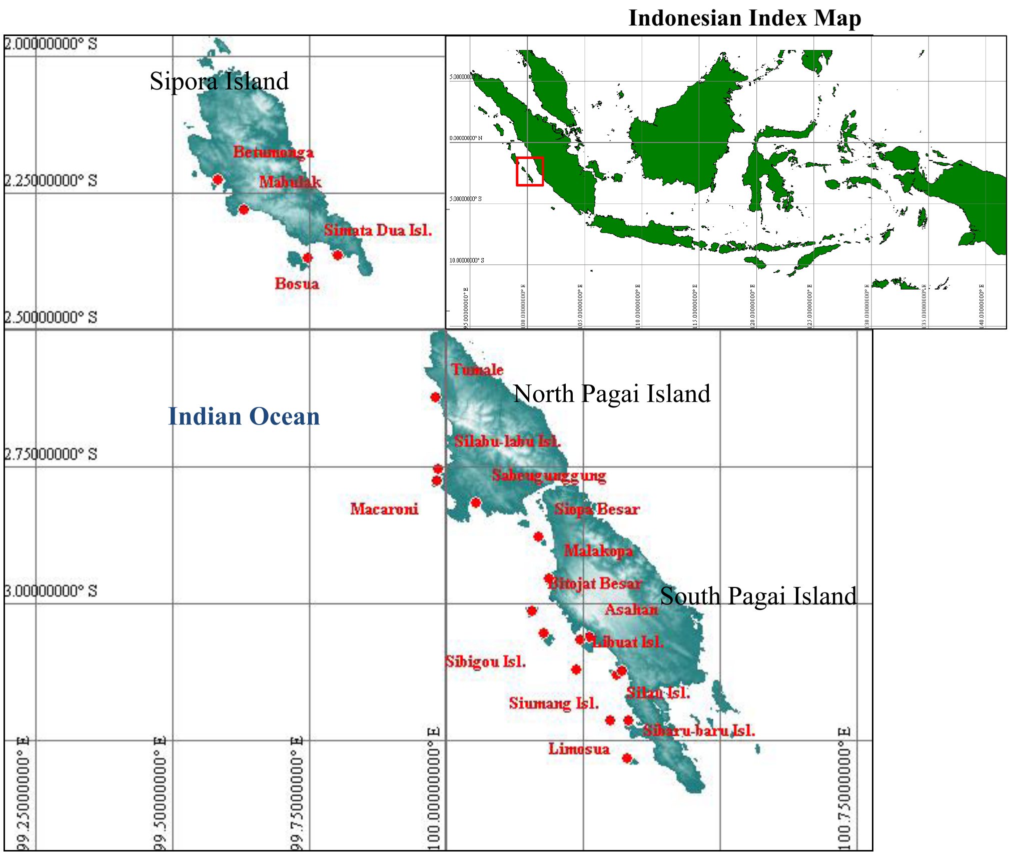

Figure 1. Tsunami deposit observation points (Kongko et al., 2010)

8.9 to 9.1 also occurred in the same rupture area of 1797 event. (Natawidjaja, 2003, Natawidjaja & Triyoso, 2007).

METHODS

Grain size analysis and fossil identification methods were applied to determine the characteristics of the 2010 Mentawai tsunami deposits. Dry sieve technique and statistical analysis from Balsillie et al. (2002) were used to compute the sediment grain and to get statistical information for each sediment. Fossil identification according to Phleger and Parker (1951) was carried out to obtain fossil types and their environment to interpret of which part of seafloor that tsunami wave start to scour sediment and transport it landward.

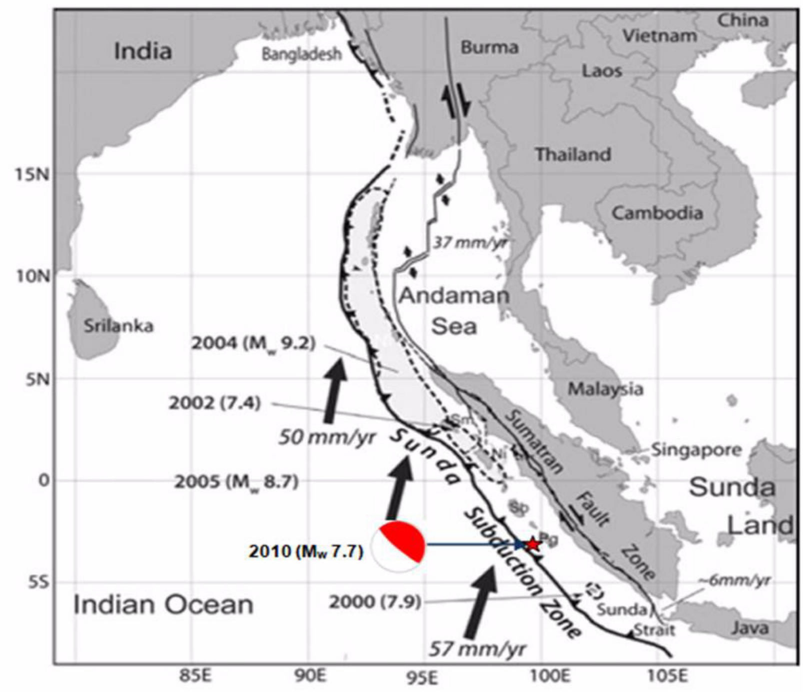

Figure 2. Map of Sunda tectonic settings (Natawidjaja and Triyoso, 2007)

RESULTS

Most coastal lithology along Mentawai islands are consisted of limestone, with white sandy beaches along the shore, except at Malakopa and Tapak which composed of grey sandy beaches. Coral fragments are generally found on coastal deposit. There are two kinds of material carried by tsunami wave, coral reef boulder and fine to coarse sandy deposits.

At some locations, coral reef boulder are found more than 80 tons. The biggest was found at Kasi island. Compare with condition before tsunami, there are significant changes on coastal plain. There are scouring of 1.5 to 2 m along the coast, some part of sand deposits threw far inland form dune with maximum thickness of 40 cm at Sibaru-baru island.

Following survey track, we start to get tsunami deposit at Mabulak, Sipora Island, it was very thin. The maximum tsunami deposit thickness was found at Sibaru-baru island which is the south tip of South Pagai island and the closest location to the epicenter. The thickness range between 1.5 and 40 cm which mostly composed of fine to coarse sandy beaches deposited in terrestrial and marsh environment, while boundary between tsunami deposit and soil as basement was erosional (Figure 4).

There are structural sediments in tsunami deposits, mostly have graded bedding of fining upward, parallel lamination and soil clast. Tsunami deposit distribution were fining and thinning landward. Mentawai tsunami deposit has very few fossils, which include mollusca shell and coral fragment.

Figure 3. Boulder tsunami deposit found at Kasi Island.

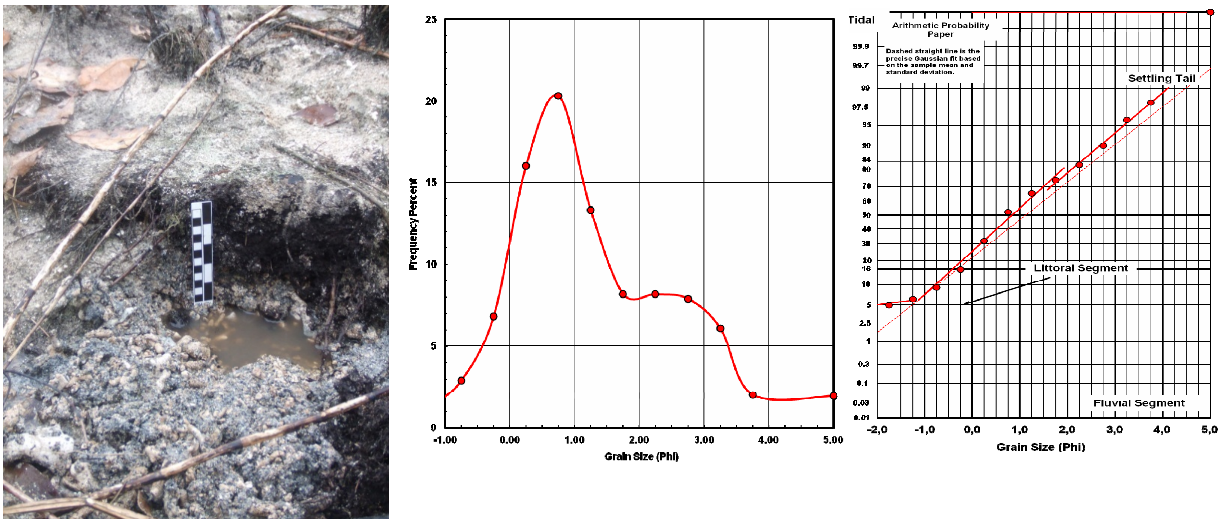

Figure 4. Tsunami deposit of Bosua village

Laboratory analysis results show that most of Tsunami deposit has variation on grain size distribution, such as unimode to multimode, which related to sources of material, and sorting indicated by its curve gradients. Below are description of tsunami deposit from selected locations.

a) Bosua tsunami deposit found very thin, deposited above marshy land. Based on grain size analysis, it yield a unimode curve, with mean value 1.11 which is coarse sand, relatively brought from coastal area by passing through tsunami wave with transport mechanism dominantly saltation (Figure 4).

b) Silabu-labu tsunami deposit has 14 cm thickness, sediment structure paralel lamination and soil clast was trapped inside the sediment. Silabu-labu grain size result showing also only one peak of mode (unimodal) with mean value 2.4911 which is dominantly fine sand. It has sharp gradient of accumulation plot, which indicate material source from single source and has good sorting of grain size distribution. While energy of transport was stationary at the beginning, then move gradually with relatively saltation mechanism (Figure 5).

c) Makaroni tsunami deposit has two layers different on colors and sedimentological properties. The first layer (bottom) has 2 cm thickness, with

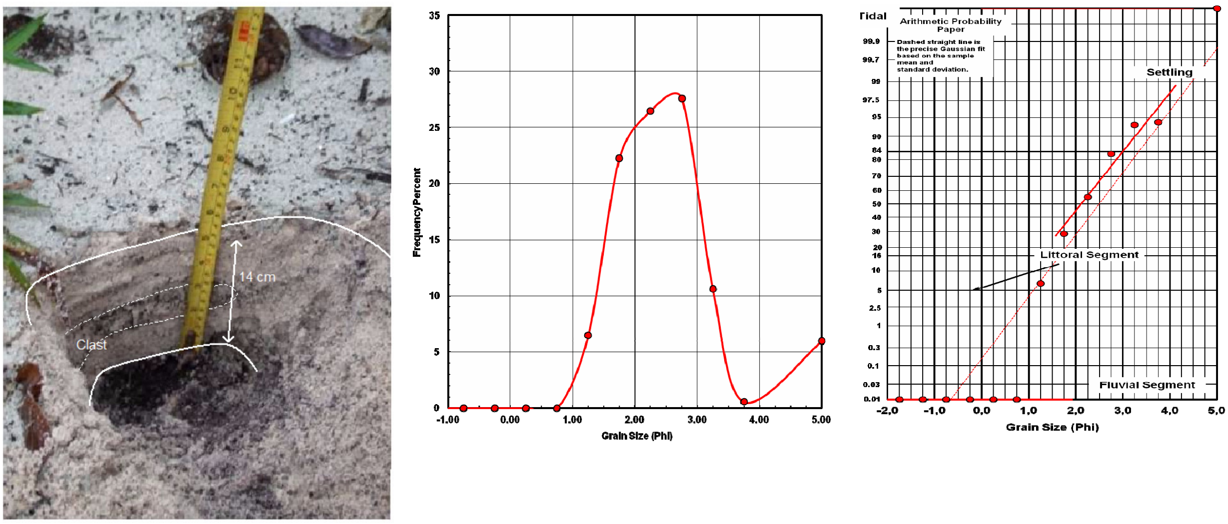

Figure 5. Tsunami deposit from Silabu-labu Island

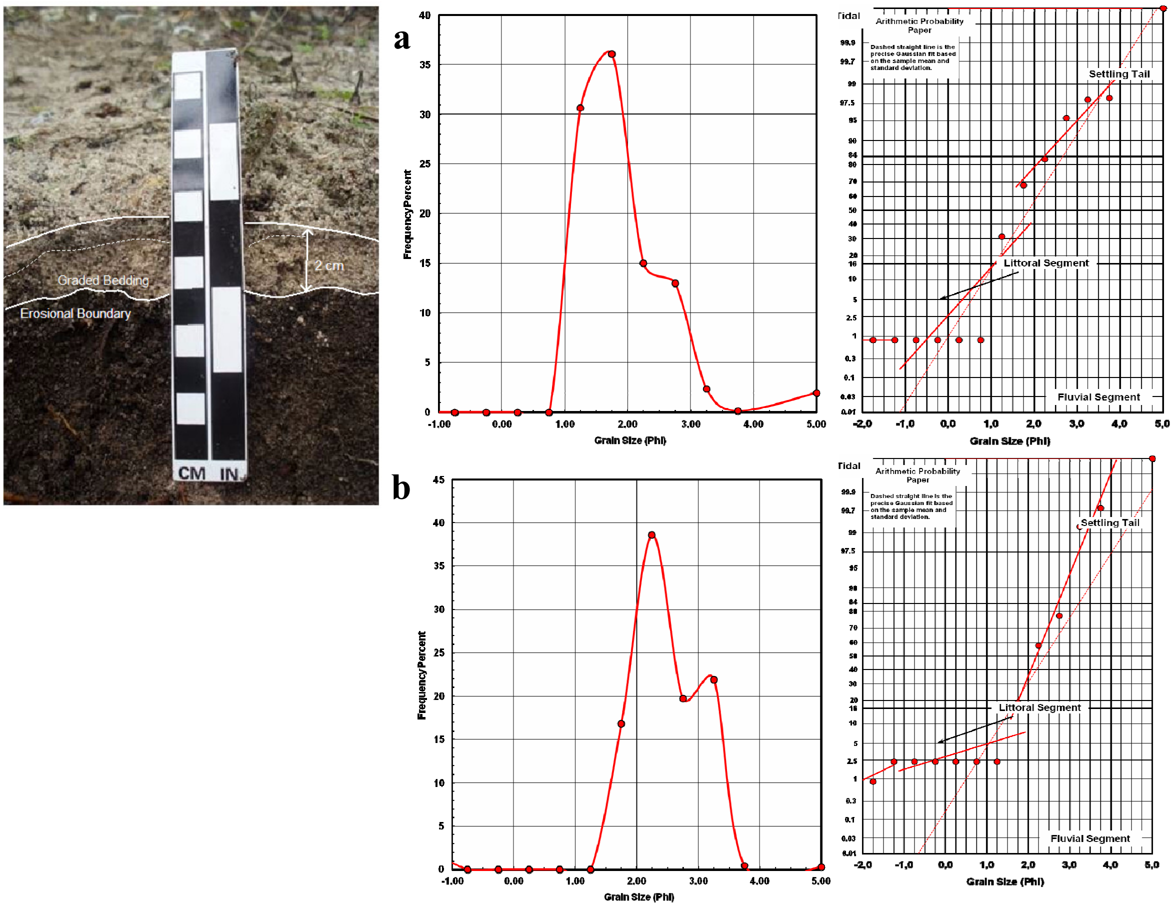

Figure 6. Sample of Makaroni Resort top layer (above) and bottom layer (below).

sediment structure of fining upward and mean value of 1.87 phi of medium grain sand. Curve of cummulative percentage showing of stationary continues to saltation transport mechanism, indicate of main tsunami run up process (Figure 6a). While the second layer (top) has darker color, greyish yellow, about 5 mm thickness, has grain size distribution curve of unimode, indicate of single source of material, has mean value of 2.41 phi of fine grain sand. According to different energy of deposition, it starts with traction at the beginning then suddenly stop, then continued with saltation process. This condition assumes as back wash process (Figure 6b).

d) Sabeugunggung tsunami deposit has 7 cm thickness (Figure7), apparently has three peaks of mode but relatively unimodal curve with different energy of sediment transport, mean value 0.65 phi indicate coarse grain sand, relatively homogeneous, which fining upward. There is liquefaction shown inside the soil.

e) There are three layers of tsunami deposits in Malakopa outcrop, which shows very interesting sedimentological character. Three of them has unimodal curves indicate single source of material. The first layer, which is the bottom layer of tsunami deposit, has about 2-5 cm, fining upward, mean value of 2.23 phi - fine grain sand, and shows traction to saltation transport mechanism. The second layer has very thin about 2-3 mm, mean value 3.27 phi - very fine grain sand, and has domination of saltation transport mechanism. The third layer has very thin 0.5 cm thickness, mean value of 3.20 phi - very fine grain sand, while cummulative percentage showing saltation of transport mechanism (Figure 8).

f) A tsunami deposit at Bitojat Island has white color, relatively homogeneous, has about 12-15 cm thickness, mean value 1.09 phi - medium grain sand. Grain size distribution curve showing unimodal with saltation to suspension transport mechanism (Figure 9). Here the tsunami energy was constant when transported the deposit until it finally settling.

g) The next tsunami deposit was found at Tapak Island, here tsunami thickness 4 cm, grey color, showing unimodal on grain size distribution curve,

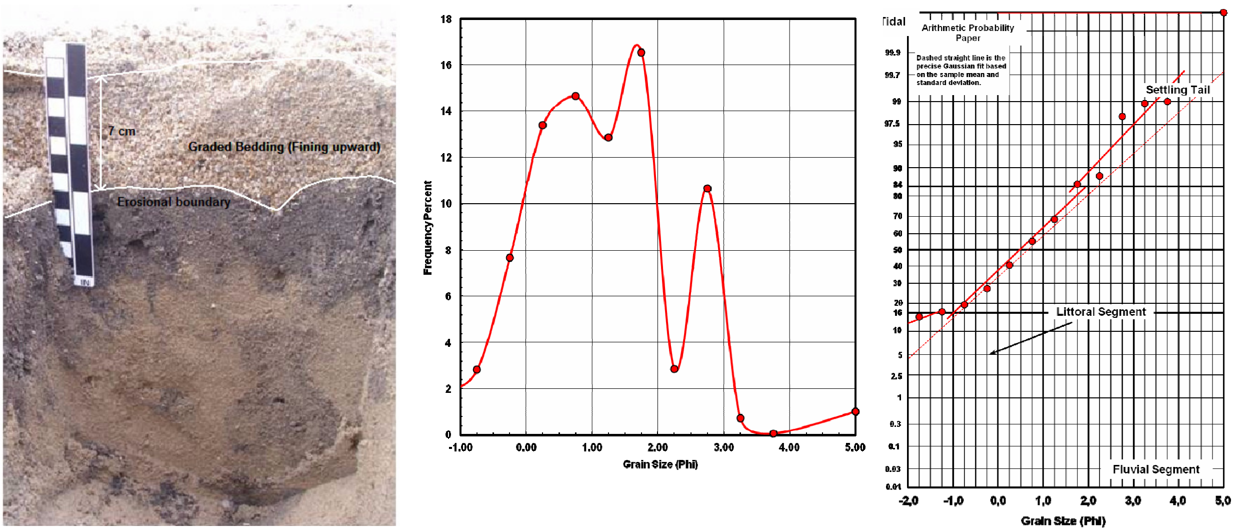

Figure 7. Sabeugunggung outcrop and it grain size analysis

with traction mechanism at the beginning, then saltation transport mechanism was taking role in depositing the sediments (Figure 10).

h) Figure 11 shows three layers of tsunami deposit from Sibaru-baru Island. Whole sample was about 40 cm thick, and has sediment structure of paralel lamination. Grain size analysis of this sample was consisted of three analysis; top, middle and bottom. The first layer at the bottom shows very low energy sediment transport, mean value -1.21 phi - granular grain size, while cummulative percentage shows traction sediment transport mechanism. The second layer is very thin, there is soil clast trapped inside the sediment, has unimodal curve and relatively stay at the beginning then suddenly move with saltation mechanism then settled by gravity force. This sand layer has mean value of 1.28 phi of medium to fine grain sand size. The third layer at the top was about 20 cm thickness, showing unimodal curve, and saltation to suspension deposition transport mechanism, mean value of 2.01 phi of fine grain sand, and relatively well sorted indicate relatively homogeneous sediment (Figure 11).

i) The last point is Limosua village, located at the southern tip of South Pagai island. Here tsunami deposits were thin, about 6 cm, white color and fining upward sediment structure. Grain size analysis shows unimodal grain size distribution curve and process of sediment transport were traction to saltation (Figure 12).

Fossil Identification

Each tsunami deposit from those 20 locations has very few fossil findings, but most of them has the same fossil types. Fossil findings in general from all locations were divided into two types, planktonic and bentonic foraminifera.

Not all the sediments have planktonic foraminifera, but from some of them could be represented by planktonic foraminifera findings, such as: *Globorotalia siakensis* LeRoy (LeRoy, 1939); *Globigerina praebulloides* Blow (Blow, 1969), which is indicated of mixing ages range of N2-N13.

Based on those fossil findings from Mentawai samples, it can determine its environment such as; *Micro mollusc (garstrophods),* indicate of marine environment; Sponge spicule, *Tubinella* sp., *Elphidium crispum*, *Peneropolis pertusus*, *Loxostomum* sp., indicate of shallow water environment (20-100 m depth); *Discorbis* sp., indicate of marine environment; *Rotalia* sp. and *Rotalia beccarii* which is indicate of marginal marine; and *Guembelitria cretacea* (Cushman) indicated as an open marine fossil (Phleger and Parker, 1951). Abundances of Sponge spicule from most of sediments were found, represented of shallow water environment (20-100 m sea depth).

Another benthonic foraminifera found from Mentawai tsunami deposits, are among others: *Strebulus batavus* (Hafner); *Quinqueloculina* sp.; *Bolivina spathulata* Williamson; *Dentalina* sp.; *Cibicides pseudongerianus* Cushman; *Cassidulinoides parkerianus* Brady; *Cibicides lobatus* Walker & Jacob; *Elphidium* sp.; *Eponides punctulatus* d'Orbigny; *Quinqueloculina tropicalis* Cushman; *Bolivina* sp.; *Cibicides* sp.; *Amphistegina* sp.; *Elphidium crisphum*; *Discorbis australis*; *Ephonides* sp.; *Quinqueloculina seminulum* (Linnaeus); *Quinqueloculina lamarckiana* d'Orbigny. This results also indicated of shallow water

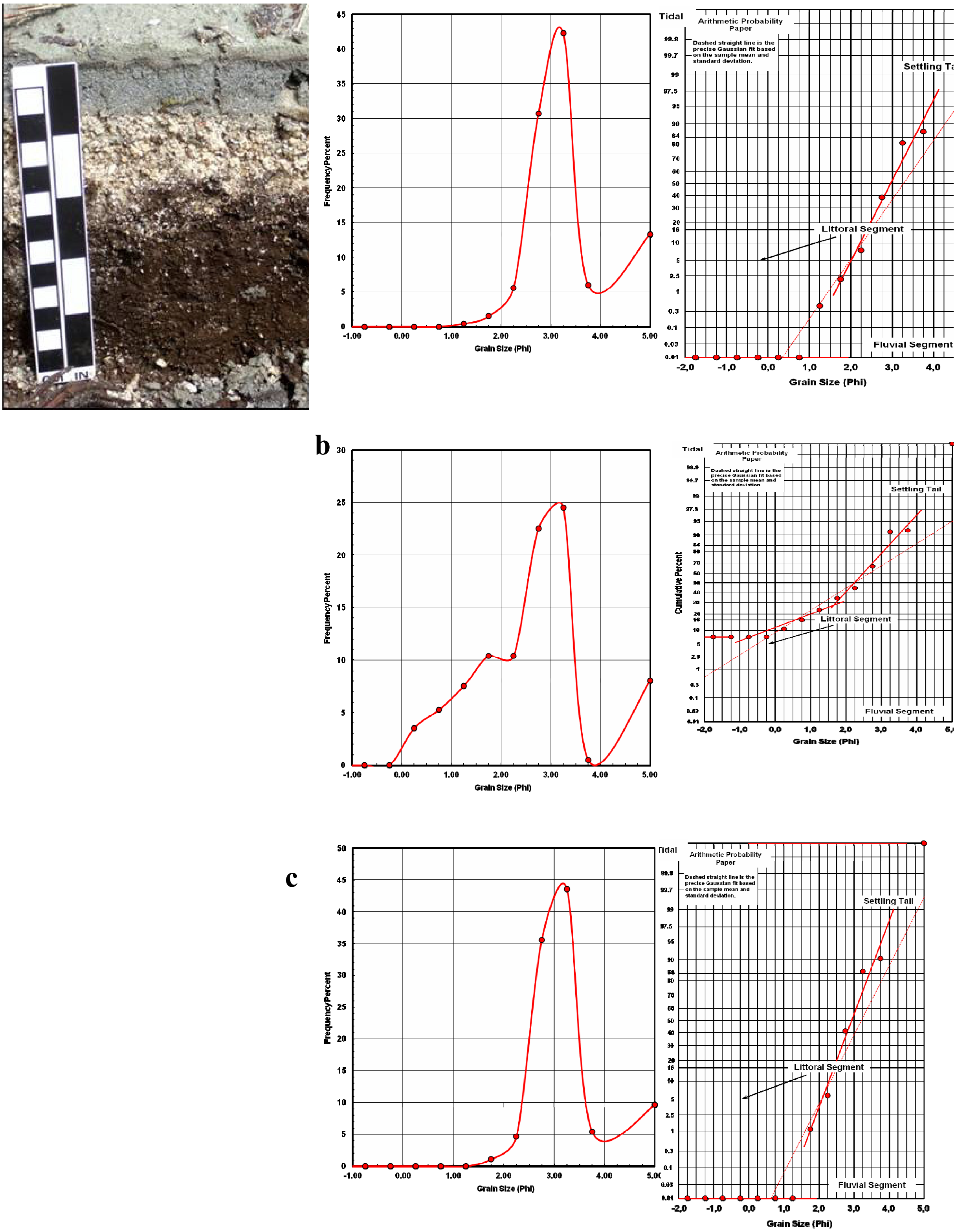

Figure 8. Sample of Malakopa tsunami deposit, a. first layer (bottom), b. second layer (middle) and c. Third layer (bottom).

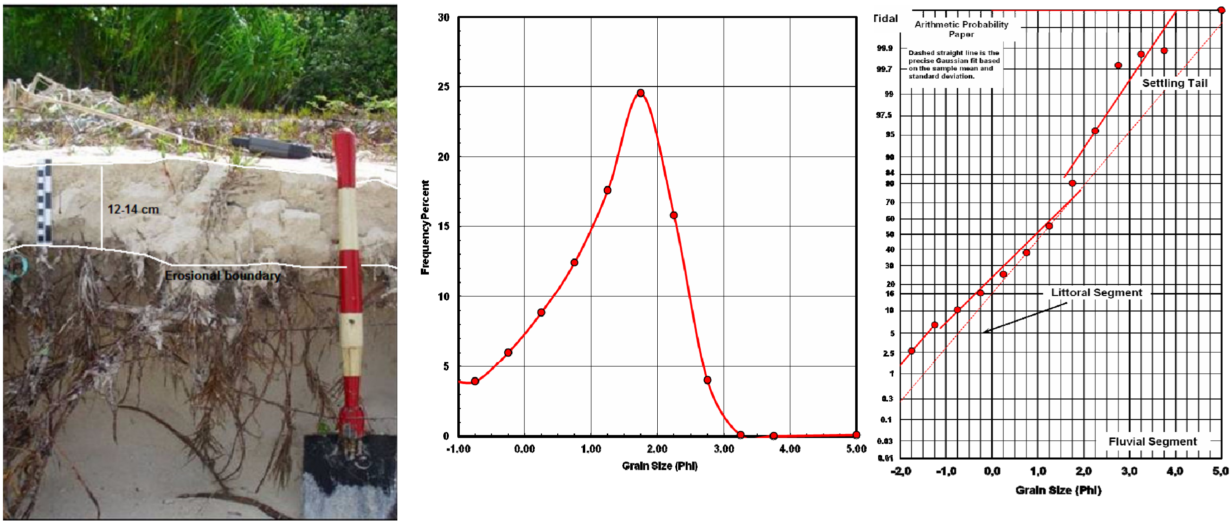

Figure 9. Bitojat tsunami deposit.

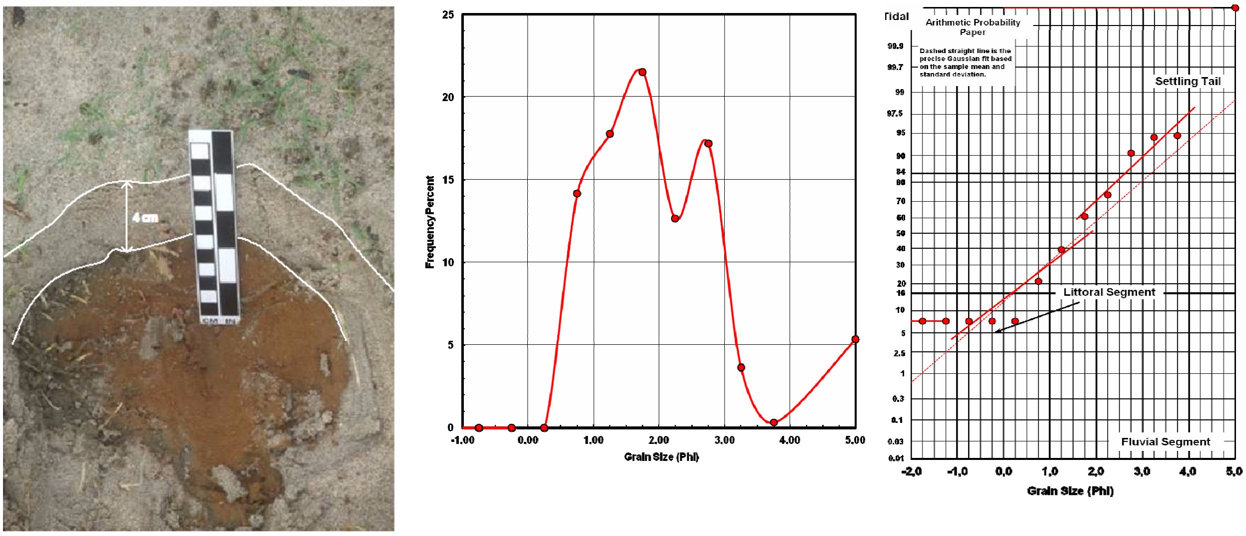

Figure 10. Sample from Tapak tsunami deposit.

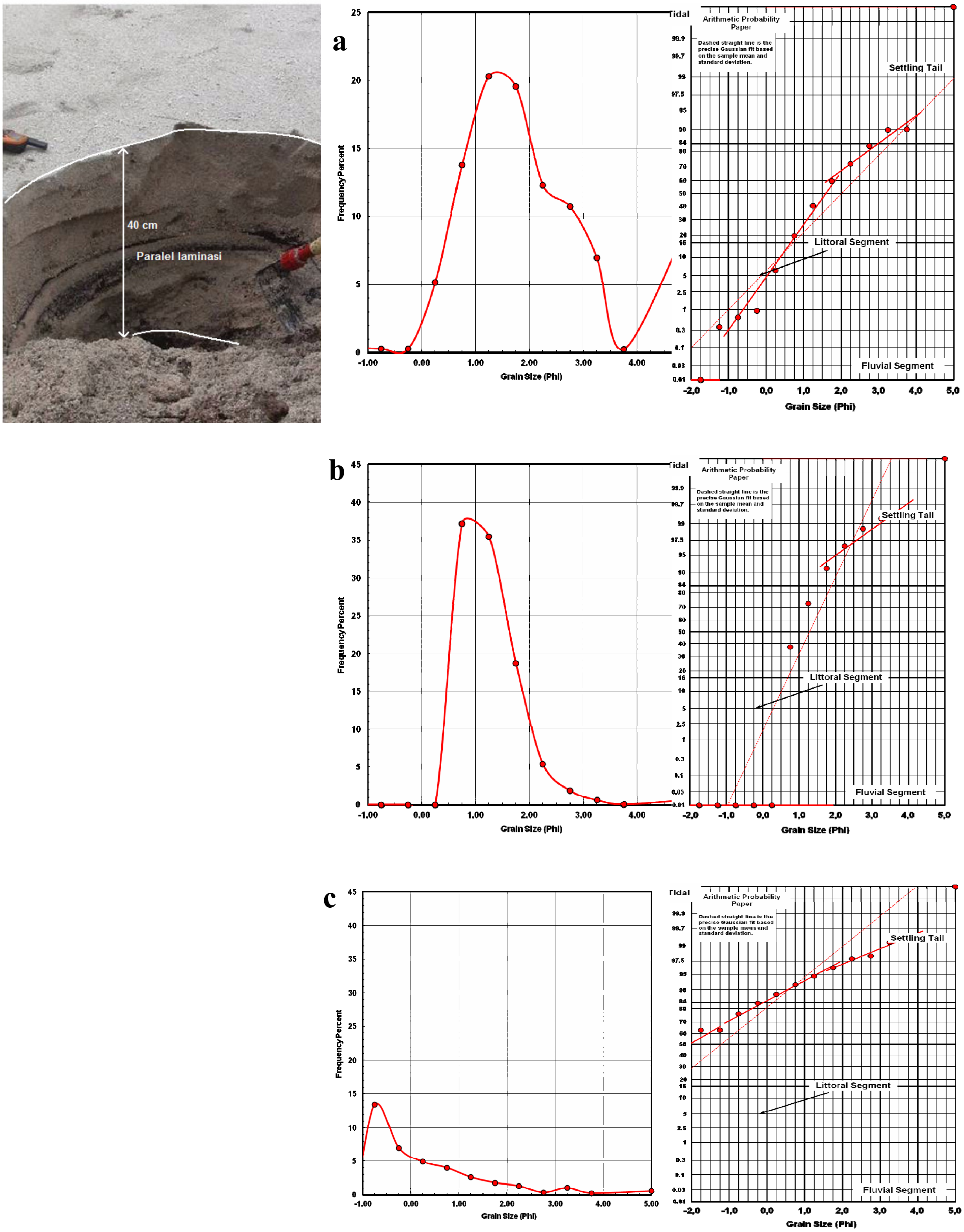

Figure 11. Tsunami deposit sample from Sibaru-baru island.

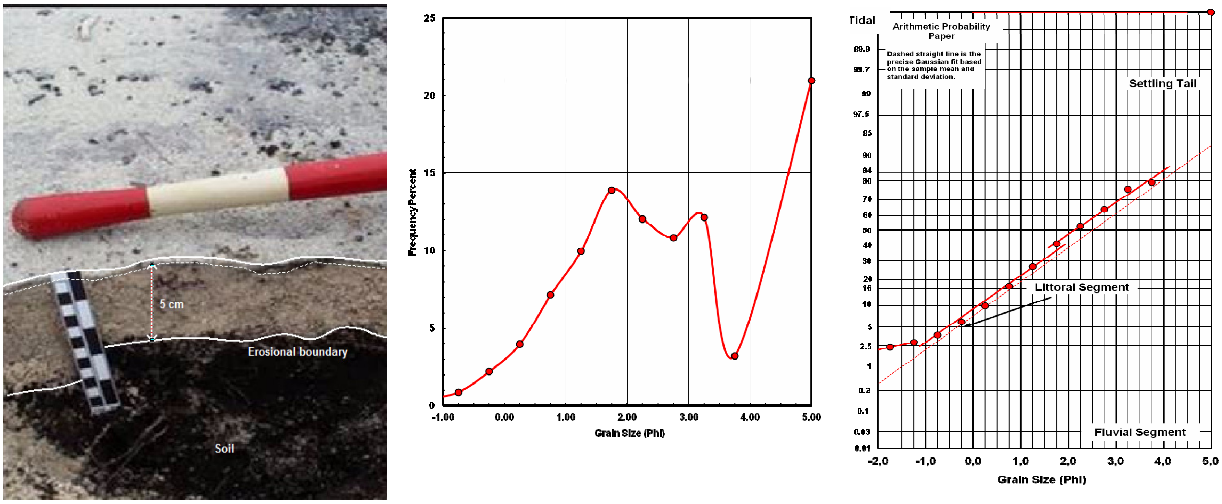

Figure 12. Tsunami deposit sample of Limosua.

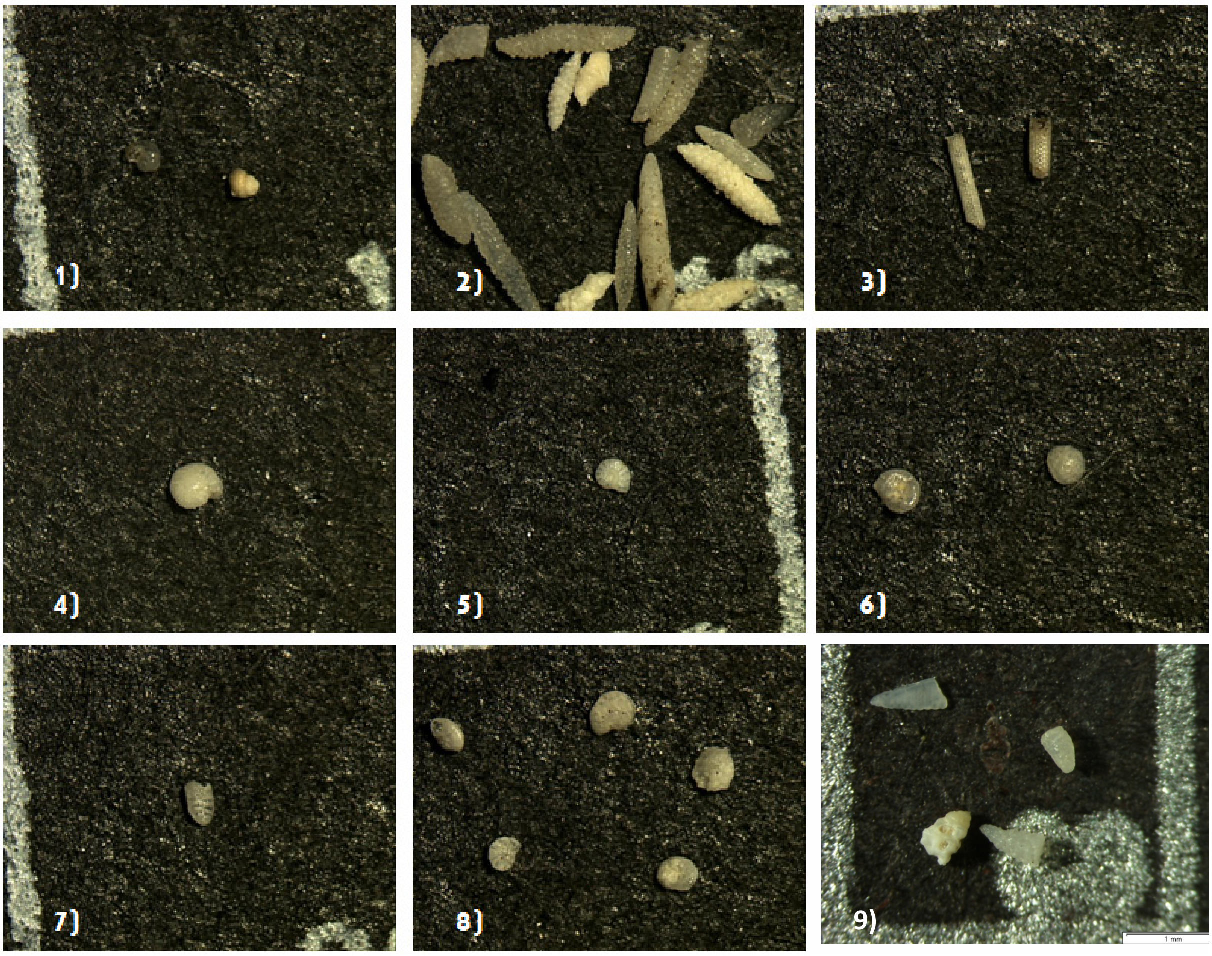

Figure 13. Fossil findings from Mentawai samples; *1) Micro mollusc (garstrophods); 2) Sponge spicule; 3) Tubinella* sp.; *4) Elphidium crispum; 5) Peneropolis pertusus; 6) Discorbis* sp.; *7) Loxostomum* sp.; *8) Rotalia* sp. *and Rotalia beccarii; 9) Guembelitria cretacea (Cushman).*

environment of 20-100 m seafloor depth (Phleger and Parker, 1951).

DISCUSSION

According to the fieldwork and laboratory analysis, it is obtained that the 2010 Tsunami Mentawai generally has characteristics of sedimentological properties as the following:

Tsunami deposit mostly has single source of material, such as come from coastal area and its surroundings and small amounts come from the sea. It can be seen from its unimodal curve of grain size distribution, it is also represented by similarity appearance between tsunami deposit and beach material. Less material come from the sea is caused by Mentawai water mostly composed of coral reef and has small amount of sand.

Mentawai tsunami deposit has sediment structures such as graded bedding of fining upward, parallel lamination and soil clast. There are also remnant grass or root and rocks fragments trapped into the sediment.

Tsunami deposit has relatively one to three layers of sediments indicate of their deposition processes, the first layer at the bottom deposited above soil with erosional boundary. This layer was deposited when tsunami run up, reflected by traction and saltation transport mechanism which more dominant than suspension. Second layer shows sediment was deposited in stagnant condition, and suspension process more dominant than other processes, reflected by very fine grain size, shown by samples from Makroni and Malakopa. The third layer at the top has coarser grain size, indicate of current involvement when tsunami wave return to the sea (back wash), but most tsunami deposit from other locations has only single layer and relatively homogeneous.

Fossil of micro mollusc and benthonic foraminifera indicate of mixing between coastal and shallow water environment (20-100 m). It means that tsunami wave start to scour the sea floor from about 100 m depth and transport it landward.

CONCLUSIONS

Characteristics of tsunami deposit from 2010 Mentawai event, according to determination of sedimentological properties, that source material mostly derived from coastal area and its surroundings, only small amount come from shallow water (start from 100 m). It is due to Mentawai water mostly composed by coral reef which some of them were ejected up and carried up landward, while less sand grain could be brought. It is correlated with fossil occurence, which derived from about 100 m sea depth. Tsunami wave may start to scour the seafloor at about that depth (shallow water environment).

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REFERENCES

[1] Balsillie, J. H., Donoghue, J. F., Butler, K. M., and Koch, J. L., 2002, *Plotting equation for Gaussian, percentiles and a spreadsheet program for generating probability plots:* Journal of Sedimentary Research, 72(6):929-933

[2] Blow, W. H., 1969. *Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy*, First Int. Conf. Plankt. Microfossils, Proc, Geneva 1967, 1:199p

[3] Kongko, W., Kerpen, N.B., Kraemer, K.F.F., Kunst, O., Asvaliantina, V., Pranowo, W., Yudhicara, Ibrahim, A., Nugroho, S, and Suranto, 2010, *Post Tsunami Survey of the 25 October 2010 Mentawai Tsunami, Preliminary Report of German-Indonesia Tsunami Survey Team (GITST)*, unpublished.

[4] LeRoy, L.W., 1939, *Some Small Foraminifera, Ostracoda and Otoliths From The Neogene (Miocene) of the Rokan-Tapanoeli Area, Central Sumatra.* Natuurk. Tijdschr. Nederl.-lndie, 99(6) :215-296

[5] Natawidjaja, D.H., 2003, *Neotectonics of the Sumatran fault and paleogeodesy of the Sumatran Subduction Zone.* Doctoral Thesis, California Institute of Technology, Pasadena, California.

[6] Natawidjaja, D.H., and Triyoso, W., 2007, *Sumatra Fault: From Source to Hazard.* Journal of Earthquake and Tsunami, Vol. 1, No. 1, 21-47, World Scientific Publishing Company.

[7] Phleger, F.B., and Parker, F.L., 1951, *Ecology of Foraminifera, Northwest Gulf of Mexico., Part II Foraminifera species.* The Geological Society of America Memoir 46, l, 88. p. 1-64