IDENTIFICATION OF SUSPECTED PALEOTSUNAMI DEPOSITS STUDY FROM KARAPYAK BEACH, PANGANDARAN AREA, WEST JAWA, INDONESIA

STUDI IDENTIFIKASI ENDAPAN PALEOTSUNAMI DI PANTAI KARAPYAK, PANGANDARAN, JAWA BARAT, INDONESIA

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ABSTRACT : Identifying and determining paleotsunami deposits can be a vital tool for establishing the periodicity of earthquakes and their associated tsunami events beyond historical records. However, their deposits can be difficult to establish and to date. In this study, we used the characteristics of the 2006 Pangandaran tsunami deposit as a reference to identify paleotsunami deposits in Karapyak Beach, Pangandaran area, West Java, Indonesia. Similar to the 2006 Pangandaran tsunami deposit, the Karapyak Beach paleotsunami deposit is characterized by light brown loose sand materials overlying a dark brown paleosol layer with erosional contact. A thin layer of tsunami deposit, although varies in thickness, is locally found just above erosional contact. The deposit reveals non-laminated coarse grain size in the lower part that gradually changes into medium to fine sand in the upper part. The base of this lower part is rich with broken mollusc shells and corals. The mid to top of the lower part may contain several still-intact mollusc shells and corals, rock fragments, and anthropogenic products (roof tiles). Those types of fragments are absent in the upper part of this thin tsunami deposit. Grain size analysis shows a mixture of fine and coarse grains in the lower part of the 2006 tsunami deposits, as well as in the suspected paleotsunami deposits, suggesting an uprush of high energy flow during the sedimentation. The fining upward sequence above the mixed grain layers reflects a waning flow in pre-backwash deposition. Foraminifera analysis also shows a mixture of shallow and deep marine foraminifera in both recent tsunami and paleotsunami deposits. Based on the characteristics of the 2006 tsunami deposits, there are at least four paleotsunami deposits identified in Karapyak Beach, Pangandaran area.
Keywords: tsunami; paleotsunami; deposit; Pangandaran; Indonesia

ABSTRAK*: Identifikasi dan determinasi endapan paleotsunami merupakan hal yang penting dalam usaha untuk menetapkan periode gempa bumi (earthquake periodicity) yang menyebabkan tsunami-tsunami di luar catatan sejarah. Namun endapan paleotsunami ini masih sulit dipastikan dan diketahui kapan terbentuknya. Dalam penelitian ini, kami menggunakan ciri-ciri endapan tsunami Pangandaran 2006 sebagai standar untuk mengidentifikasi endapan-endapan paleotsunami di Pantai Karapyak, Pangandaran, Jawa Barat, Indonesia. Seperti halnya pada endapan tsunami 2006, endapan paleotsunami memiliki karakteristik berupa pasir lepas-lepas berwarna coklat terang yang posisinya berada di atas lapisan paleosol berwarna coklat gelap dengan kontak erosional. Lapisan tipis endapan tsunami dengan ketebalan yang bervariasi dijumpai di atas kontak erosional. Bagian bawahnya berbutir kasar dan tidak berlapis, dan semakin ke atas berubah secara gradasi menjadi berbutir sedang sampai halus. Dasar dari lapisan bagian bawah ini kaya akan pecahan cangkang moluska dan pecahan koral, dan semakin ke bagian tengah lapisan dijumpai fragmen moluska yang utuh dan koral, fragmen batuan dan bahan antropogenik (pecahan genteng). Fragmen-fragmen ini tidak ditemukan lagi pada bagian atas lapisan endapan tsunami. Hasil analisis ukuran butir menunjukkan adanya indikasi percampuran butir halus dan kasar pada bagian bawah endapan tsunami dan paleotsunami. Hal ini mengindikasikan adanya pengaruh arus berenergi relatif kuat selama pengendapannya. Klastik yang semakin menghalus pada bagian atas endapan tsunami/ paleotsunami merefleksikan melemahnya arus selama pengendapan pre-backwash. Analisis foraminifera* *juga menunjukkan adanya percampuran antara foraminifera laut dangkal dan laut dalam, baik pada endapan tsunami 2006 maupun endapan paleotsunami. Berdasarkan asosiasi ciri-ciri endapan tsunami 2006 ini, paling tidak dapat dikenali empat endapan paleotsunami di Pantai Karapyak, daerah Pangandaran.*

Kata kunci: tsunami; paleotsunami; endapan; Pangandaran; Indonesia

INTRODUCTION

Earthquakes and their resulting tsunamis have had a devastating effect on the Indonesian Pangandaran coastline, killing 650 people, displacing hundreds of people, and costing more than US$5 million in the destruction of infrastructure (Ambarjaya, 2006). What is needed is a better understanding of the pattern of tsunami events to predict more accurately these devastating events (Rhodes et al., 2006; Prendergast et al., 2012). The timing of earthquakes and their associated tsunami events can be established by constraining paleotsunami deposits (De Martini et al., 2012; Jackson, 2008; Løvholt et al., 2012; Nentwig et al., 2018; Aswan et al., 2017; Rizal et al., 2019). The resulting chronologies can be used to establish the periodicity in which these earthquakes and subsequent tsunami events occur. However, paleotsunami deposits must first be identified. Generally, their characteristics are relatively loose unconsolidated sediments with a light-colored carbonate layer of sand overlying a darker-colored paleosol layer or remnant former soil (Yawsangrat et al., 2012; Rhodes et al., 2006; Aswan et al., 2017). The overlying layer contains light-colored molluscs, corals and organic materials, deposited from beach and shallow marine environments. Paleotsunami deposits are also characterized by fining-upward sequences with more variable fragments at the bottom parts which are due to high energy transportation capacity by a non-gravitational mass flow (Naruse et al., 2012; Cuven et al., 2013; Schicchitano et al. 2010 and Hawkes et al. 2007). Occasionally, parallel laminations occur only if there is lower velocity deposition during the backwash process.

Tsunami deposits formed by high energy depositional current will show a mixed environment from which the sediments pass through (Hawkes et al., 2007; Yudhicara et al., 2013; Pilarczyk et al., 2020; and Lespez et al., 2021). The sediments may contain a mixture of shallow marine and deep marine faunal benthic foraminifera (Hawkes et al., 2007; Dahanayake and Kulasena, 2008; Aswan et al., 2017; Pilarczyk et al., 2020; and Lespez et al., 2021) and grain size ranges that reflects more than one ocean current systems (Yawsangratt et al., 2012; Aswan et al., 2017). As tsunami events regularly occur in Pangandaran area (with the last event occurring as recently as 2006), the observation sites offer a good opportunity for finding potential paleotsunami deposits.

In this study, a comparison to verify the status of the suspected deposits against the 2006 tsunami deposits was carried out. The parameters comprise characteristics of the outcrops, grain size analysis, and inferring depositional environment based on foraminifera analysis. Fieldworks were conducted on May 26, 2015, and on January 17, 2018.

METHODS

The excavation site in Pangandaran area is located about 50 meters from the shore line of Karapyak Beach and falls on 7°41'44.21"S, 108°45'42.47"E (Figure 1). The observation and sampling location points are along small and short walls of river estuaries that lead to the sea. Most of the time, the locations are dry except when it rains. The height of this river wall is about 1.5 meters from the riverbed (Figure 2).

The paleotsunami deposit identification is carried out by comparing their outcrop characteristics to the 2006 tsunami deposits, such as their contact with the underlying paleosol or other deposits, the color difference to the underlying sediments, and their constituent fragments. Fragments to observe in those typical tsunami deposits are rock fragments, anthropogenic materials (e.g., roof tiles), molluscs, and/or coral fragments, commonly found at the bottom part of tsunami deposits and usually embedded in a non-laminated matrix. Several characteristics of the suspected paleotsunami deposit were observed in the field, including grain size variation (done through grain size analysis) to find out any evidence of a mixture between shallow (0 – 20 m) and deep marine sediments (20 – 200 m).

Sediment sampling for foraminifera content and grain size analyses was conducted on each layer, suspected as tsunami and paleotsunami deposits. A 100 g sediment from each layer was then analyzed for faunal content,

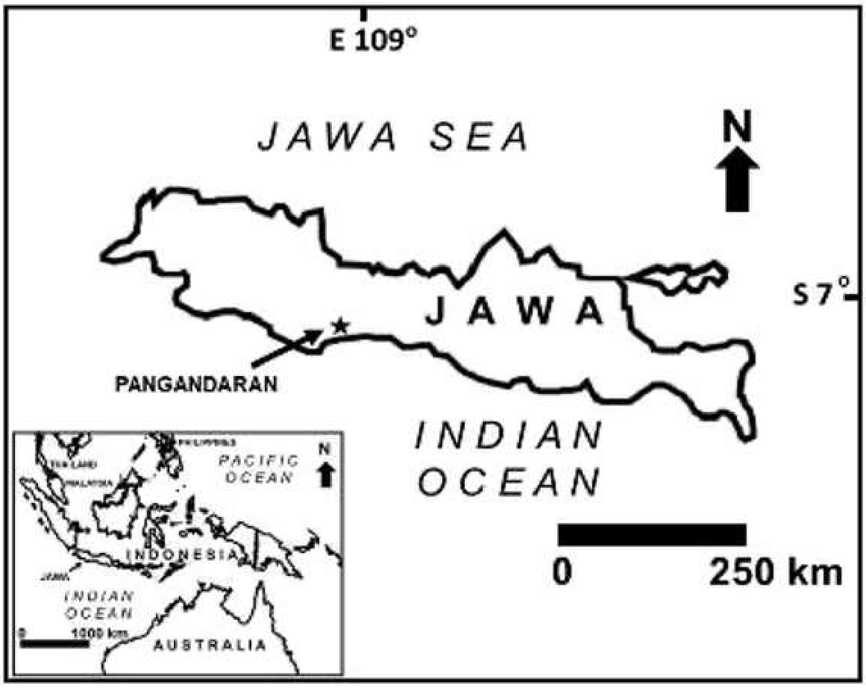

Figure 1. Location map of the Pangandaran tsunami and paleotsunami deposits in Java Island, Indonesia (star sign: 7°41'44.21"S; 108°45'42.47"E).

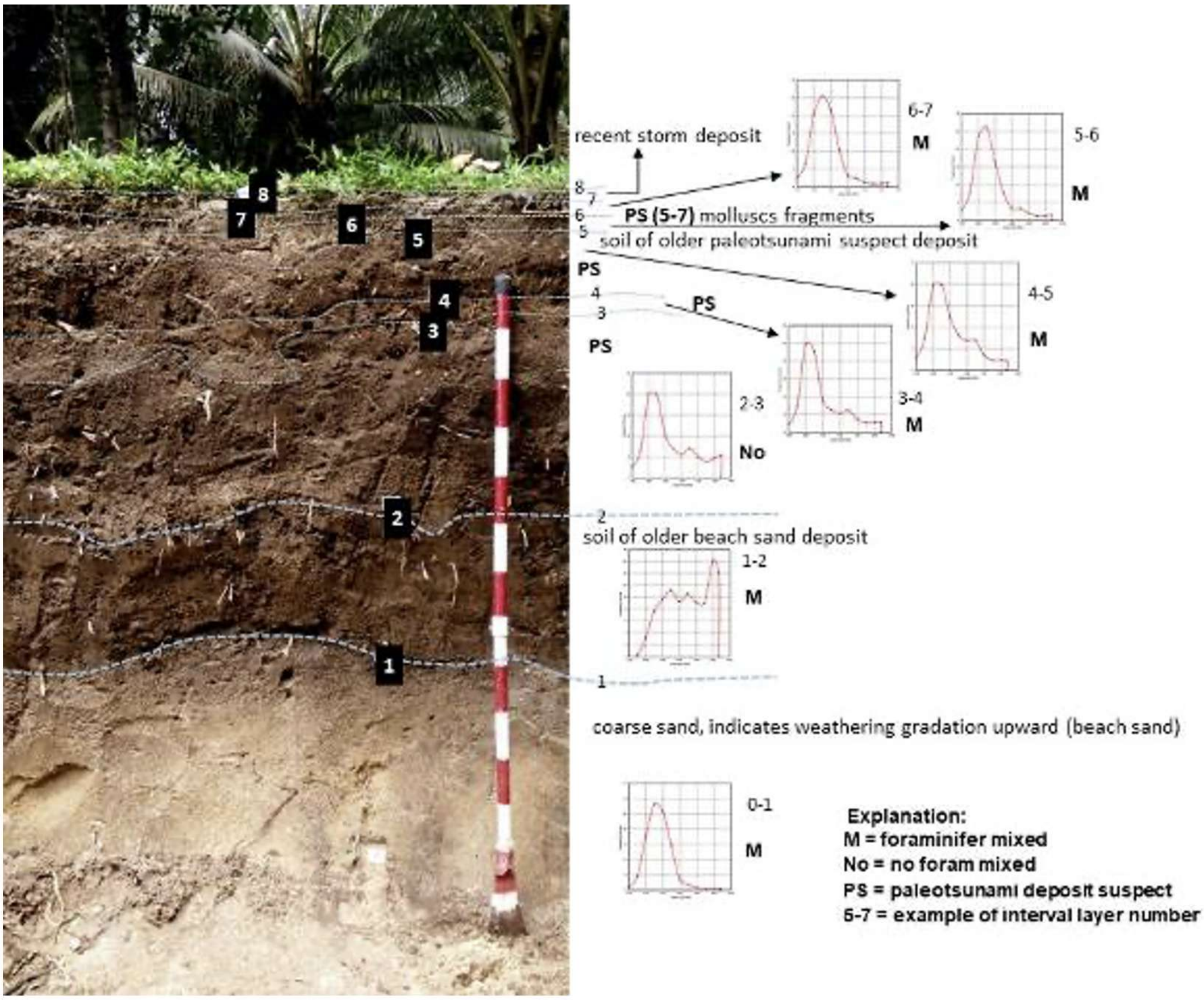

Figure 2. Stratigraphic profile of tsunami and paleotsunami deposits in Karapyak Beach, Pangandaran area. Grain size distribution curves for each layer are shown on the right-hand side. One scale bar in the red-and-white stick is 10 cm-long.

pounded, and soaked for one day in 0.1 M hydrogen peroxide to accelerate the disintegration process to get sample residues. After this process, the powder was washed several times through 74 – 125 µm sieves. The wet residues were dried in the oven for six hours. Faunal content was identified from the dry residues using a Nikon SMZ15000 binocular microscope. The results of faunal analysis were used to determine the depositional paleoenvironment based on benthic foraminifera content (Adisaputra et al., 2010) and on bathymetric reference (Tipsword et al., 1966). It was also used to determine whether a mixing had occurred between shallow marine (less than 20 m depth) and deeper marine (20 – 200 m depth) fauna.

Grain size analysis was carried out to understand the processes of paleotsunami sediment deposition (Visher, 1969) and to assess whether the sedimentation was influenced by one or more ocean current systems (Yawsangratt et al., 2012). Total sediments weighing 100 grams were sieved to 4760-44 µm fractions and were weighed for each designated fraction. The weight was normalized against the total amount of sediments, and by then the resulting grain sizes were plotted to generate a grain size distribution curve.

RESULTS

The 2006 Tsunami Deposit

The 2006 tsunami deposit is characterized by light brown loose sand with thicknesses varying from 7 to 3 cm (Layers 5-7 in Figure 2), overlying a dark brown paleosol layer with erosional contact. A thin layer that varies in thickness is locally present just above the erosional contact, with coarser grain embedded in a non-laminated matrix in the lower part of the layer that gradually changes into medium to fine sand-size in the upper part. The lower part contains several unbroken mollusc shells of *Neritina* sp. (Figure 3) and coral clasts, igneous rock fragments, and anthropogenic products (roof tiles). The grain size distribution curves

Figure 3. A 2006 tsunami deposit layer in Pangandaran, characterized by light brown color with still-intact mollusc clasts of *Neritina* sp. (M) and lithic fragments (L). The top of deposit layer is marked with number 7 label. Scale bar = 5 cm.

for the bottom part are slightly bimodal and become unimodal at the top. According to Adisaputra et al. (2010), analysis of the tsunami deposit origins based on foraminifera study suggests a mixture of materials from inner neritic (0 – 20 m), middle neritic (to a depth of about 60 m) and outer neritic (100 – 200 m) as indicated by the presence of benthic foraminifera *Ammonia* sp., *Lagena* sp., *Bulimina* sp., *Bolivina* sp., and *Gyroidina* sp.

Paleotsunami Deposit

The stratigraphic section presented in Figure 2 is delineated as follows:

Layer 1-2 (Figure 2) comprises lighter brown materials (compared to the underlying paleosol layer), shows erosional contact with the paleosol layer below, and locally contains fine-sized molluscs and coral clasts at the contact area. This layer got more intensely weathered upwards and formed paleosol, on which the next sediments were deposited. The layer thicknesses vary on average by about 35 cm thick with a polymodal grain size distribution curve. Benthic foraminifera analysis indicates a mixture of materials from inner neritic (0 – 20 m) and shallow middle neritic (20 – 50 m), carried from the ocean to the coast. Index benthic foraminifera found in this layer are *Ammonia* sp. and *Bolivina* sp.

Layer 2-3 (Figure 2) contains lighter brown materials (compared to the underlying paleosol layer) and shows erosional contact at the bottom. Fine-sized molluscs and coral fragments are found in some bottom parts of the contact area. This layer was more intensely weathered upwards and forming paleosol, on which the next paleotsunami deposits were deposited. The average thickness of the layer varies from 35 to 40 cm with a polymodal grain size distribution curve. Benthic foraminifera analysis shows no evidence of paleotsunami material mixing from different bathymetric levels. Foraminiferal test in this layer is composed mainly of *Ammonia* spp. without the presence of other index foraminifera. The result indicates that some parts of the deposits are erosional products in the inner neritic environment (less than 20 m depth). Nevertheless, a large amount of still-intact mollusc shells (genus *Turbo* sp. in Figure 4) and coral fragments (Figure 5) is found floating in a coarse sand-sized matrix.

Figure 4. A mollusc clast (still-intact; genus *Turbo* sp.) is embedded in a paleotsunami deposit (Layer 2-3).

Layer 3-4 (Figure 2) shows bottom erosional contact and the materials have lighter brown color compared to the paleosol layer below. It locally contains fine-sized broken mollusc shells, coral clasts, and rock fragments, embedded in a coarse sand-sized matrix at the bottom of its contact area. This layer was more intensely weathered upwards to form paleosol, on which the next paleotsunami deposits were deposited. The average thickness of the layer is about 5 – 7 cm with a bimodal grain size distribution curve. Benthic foraminifera analysis indicates a mixture of paleotsunami deposit materials from inner neritic (0 – 20 m) and outer neritic (100 – 200 m) of the bathymetric zones. Index benthic foraminifera found in this layer are an association of *Ammonia* sp., *Dentalina* sp., and *Gyroidina* sp.

Layer 4-5 (Figure 2) reveals lighter brown materials with an erosional contact to the underlying paleosol layer. Fine-sized mollusc clasts and coral fragments are locally found in the bottom of the contact area. This layer became more intensely weathered upwards to form paleosol, on which the next layer was deposited. The average thickness of the layer is 10 – 15 cm with a bimodal grain size distribution curve. Benthic foraminifera analysis implies a mixture of paleotsunami material origins from inner neritic (0 – 20 m) and shallow middle neritic (to a depth of about 60 m). Foraminifera found in this deposit layer are *Ammonia* sp. and *Lagena* sp. Anthropogenic products (e.g., roof tiles) and rock fragments are found floating in a medium to coarse sand-sized matrix.

Figure 5. A coral fragment floating in a paleotsunami deposit. Number 2 label is the bottom contact of paleotsunami deposit (overlain, lighter color) upon the underlying paleosol (darker color).

DISCUSSION

Characteristics comparison with the 2006 tsunami deposit in Karapyak Beach, Pangandaran leads to exposing four suspected paleotsunami deposits that share similar characteristics. They comprise coarse sand materials with a lighter color appearance, compared to the underlying paleosol layers. Some areas of the bottom part of the layers contain fine particle sizes of broken mollusc shells and coral fragments. They have different thicknesses and each layer shows lateral thickness variations with bottom erosional contacts. Similar to the 2006 tsunami deposit, several layers in paleotsunami deposits contain still-intact mollusc shells and rock fragments that are floating in a coarse sand-sized matrix. Benthic foraminifera analysis on Layer 2-3 shows no evidence of mixing of paleotsunami materials from various bathymetric levels and is assumed to be transported from a depth of less than 20 m. Nevertheless, Layer 2-3 shows similarities to those of the 2006 tsunami deposit with regard to their outcrop characteristics, the still-intact mollusc shells and coral fragments that locally found in the layer, and their grain size distribution curves.

CONCLUSION

Based on the comparison to the 2006 tsunami deposits, four suspected pre-2006 paleotsunami deposits can be identified at Karapyak Beach, Pangandaran area. They share similar characteristics yet still can be observed and distinguished. The deposits consist of loose sand materials overlying dark brown paleosol layers and show bottom erosional contacts. Their overall thicknesses vary, showing lateral changes from the thinnest variation of 5 – 7 cm (Layer 3-4) to the thickest one of 35 – 40 cm (Layer 2-3). The bottom parts of the deposits contain coarse grains that gradually change into medium to fine sand-sized grains in the upper parts. Fine-sized broken mollusc shells, embedded in a non-laminated (homogeneous) matrix, are locally present at these bottom parts. Coral and rock fragments, as well as anthropogenic products (e.g., roof tiles), may also be found. The upper parts of the deposits, however, generally lack those types of fragments. Grain size analysis indicates a mixture of fine and coarse grains, as shown by bimodal grain size distribution curves, inferring that poor sorting at the lower part of tsunami and paleotsunami deposits was due to high energy flow. The fining upward sequences in the upper part of tsunami and paleotsunami deposits are regarded as having been deposited by a waning flow during pre-backwash deposition. Similarly, benthic foraminifera analysis indicates a mixture of materials from shallow and deep marine environments, i.e., from inner neritic (0 – 20 m) to middle - outer neritic (20 – 200 m).

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