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Tsunami Characteristics along The Coast of Biak Island based on the 1996 Biak Tsunami Traces

Karakteristik Tsunami sepanjang Pantai Pulau Biak Berdasarkan Jejak Tsunami Biak 1996

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Abstract

Identification on tsunami traces had been conducted along the coast of Biak Island, Papua, to recognize the character of tsunami potential in this region, referring to the 1996 tsunami event. This study is to observe the influence of tsunami to the environment and tsunami character itself which can be learned from tsunami deposit. According to the 1996 Biak tsunami run up distributions, it can be observed that the maximum tsunami run up was found at the coast which has an undulating to steep morphology rather than other places which has a relatively flat one. The 1996 Biak Tsunami arrival times were approximately between 10 and 15 minutes, such as at the northern and southern coasts of Biak, except for the western one which is about 1 to 5 minutes. This was influenced by the local bathymetry and another possible source triggering tsunami such as a local submarine landslide. The number of tsunami waves were between 2 and 4, and the second one was usually the highest. Based on a sedimentological analysis, the 1996 tsunami deposit is characterized by the dominant coarse sand, while grain size distribution curve shows a character of transportation process similar to an ordinary beach process dominated by saltation current. The foraminifera fossil content tends to indicate that the tsunami deposit was derived from > 200 m seafloor depth (bathyal zone).

Keywords: 1996 Biak tsunami, tsunami deposit, grain size analysis, fossil

Sari

Identifikasi jejak tsunami telah dilakukan di sepanjang kawasan pantai Pulau Biak, dalam rangka mempelajari karakteristik tsunami yang berpotensi untuk terjadi di masa yang akan datang di wilayah ini, dengan merujuk pada peristiwa tsunami tahun 1996. Penelitian ini akan melihat bagaimana pengaruh tsunami terhadap lingkungan dan ciri-ciri tsunami itu sendiri yang dapat dipelajari dari endapannya. Berdasarkan distribusi ketinggian run up tsunami, teramati bahwa ketinggian tsunami maksimum terdapat di kawasan pantai yang memiliki morfologi bergelombang hingga curam dibandingkan dengan tempat lainnya yang memiliki morfologi landai. Waktu tiba gelombang tsunami pada peristiwa tsunami Biak 1996 berkisar antara 10 dan 15 menit, seperti yang terdapat di pantai utara dan selatan Biak, sedangkan kawasan pantai barat Biak memiliki waktu tiba 1 hingga 5 menit. Hal ini dipengaruhi oleh kondisi batimetri setempat dan kemungkinan sumber lain yang dapat memicu terjadinya tsunami di kawasan ini, yaitu longsoran bawah laut lokal. Gelombang tsunami yang datang berjumlah antara dua hingga empat dan yang tertinggi biasanya yang kedua. Berdasarkan analisis sedimentologi, endapan tsunami 1996 memiliki tekstur butiran yang didominasi oleh pasir kasar, sedangkan kurva distribusi ukuran butir memperlihatkan karakter proses transportasi yang mirip dengan pengendapan pasir pantai biasa yang didominasi oleh arus saltasi. Berdasarkan kandungan fosilnya, endapan tsunami yang berada di pantai berasal dari kedalaman lebih dari 200 m (zona batial).

***Kata kunci**: Tsunami Biak 1996, endapan tsunami, analisis besar butir, fosil*

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Introduction

On 17 Februari 1996, there was a big earthquake occurred about 60 km northeast of Biak Island with magnitude of Mw 8.2 at 14:59 local time. This earthquake was followed by a tsunami with the maximum height of 7.7 m above sea level at Madori, western Biak and 5.4 m at Korem, northern Biak. This earthquake and tsunami had killed 107 people, missed 51 people, badly injured 55 people, and destroyed more than 2,700 houses (Puspito, 1996). In order to recognize the characteristic of tsunami in this region that may potentially occur in the future, a study was carried out to identify and analyze the tsunami deposits left by a previous tsunami and how the environment affected to the tsunami. The study was conducted along the coastal area of Biak Island (Figure 1).

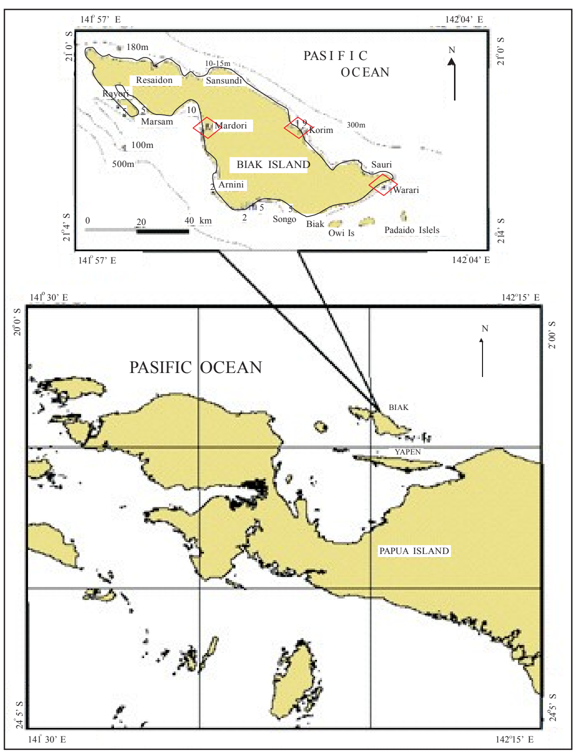

Figure 1. Locality map of studied area.

General Review

Tectonics and Seismicity

Based on the regional tectonics of Papua and its vicinity (Figure 2), Biak Island is influenced by New Guinea trench in the north and Yapen strike-slip fault system in the south. Tsunami could be associated with the New Guinea trench in the north which is dominated by reverse fault mechanisms, shown on the seismotectonic map (Figure 3).

Tsunami potential caused by earthquake could be generated by dip-slip mechanism both normal and reverse faults. According to its focal mechanism, the fault plane has a trend of northwest-southeast direction affected by the maximum compression coming from northeast-southwest.

Tsunamigenic earthquake could be the main source of tsunami generation, but other sources could also be possible to generate tsunami, such as submarine landslide which had ever occurred in 1996.

The 17 February Biak Tsunami

On the basis of a field survey conducted by the International Tsunami Survey Team (ITST), it is observed that the total length of the coast with run up height of more than 4 m is 20 km, starting from Korem to Warsa in the north coast, and some parts in Farusi (Mardori) west coast of Biak (Figure 4). In general, coastal morphology of the Biak Island is relatively flat, causing a wide inundated area, even for 2 m run up height can cause a large inundated area, for instance in Mansoben that could extend about 120 m inland (Matsutomi *et al*., 2001).

Run up height of 7.7 m was found at Farusi (Mardori). This village is in the opposite of another coast which has directly been affected by the tsunami. This run up height is higher than in the other coasts. It is assumed to have been caused by a submarine landslide which was triggered by an earthquake. The highest run up at Korem is 5.4 m at a narrow bay perpendicular to the tsunami source. It was measured at a house wall at 270 m from the shoreline, while 2.5 m run up height was measured at the distance of 450 m from the shoreline, whereas at the southern coast, the run up height is about 2.9 m at 50 m from the shoreline (Table 1).

Table 1 shows that the tsunami went inland three up to five times. The second wave is the highest, started by the ebb tide followed by a subsidence of 0.1 - 0.3 m at Sansudi, northern coast of Biak. The first tsunami arrival time at the northern coast observed in Korem was 10 - 15 minutes after the earthquake, with the wave period of 10 minutes. While at the southern and western coast 1 - 5 minutes arrival time and the wave period of 2 - 3 minutes were observed (Matsutomi *et al*., 2001).

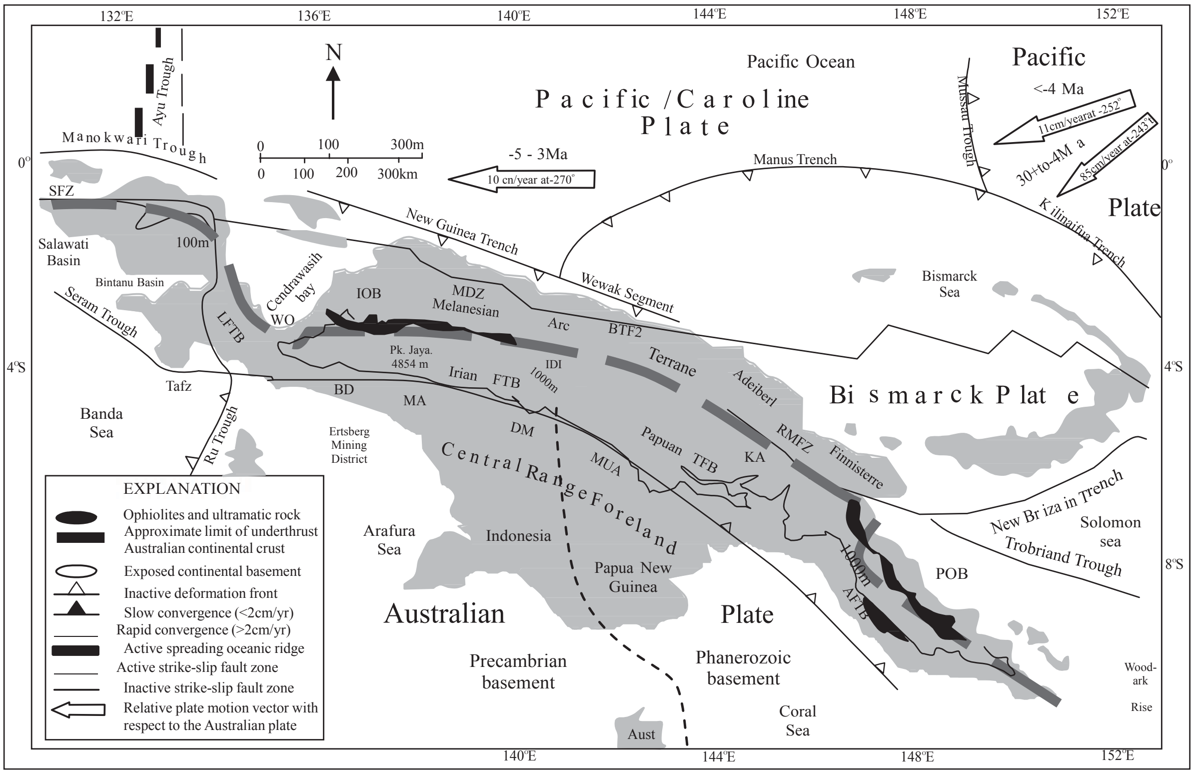

Figure 2. Regional tectonics of Papua and its vicinity (Sapiie *et.al* 1999).

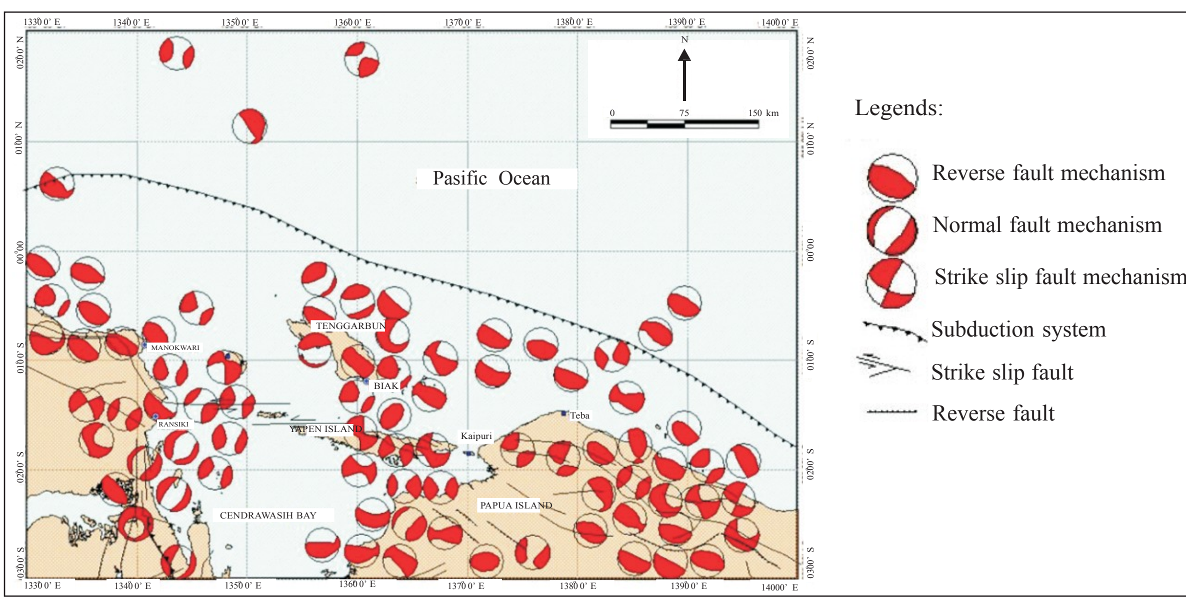

Figure 3. Seismotectonic map of Biak Island and its vicinity (Harvard CMT Catalog, 2010).

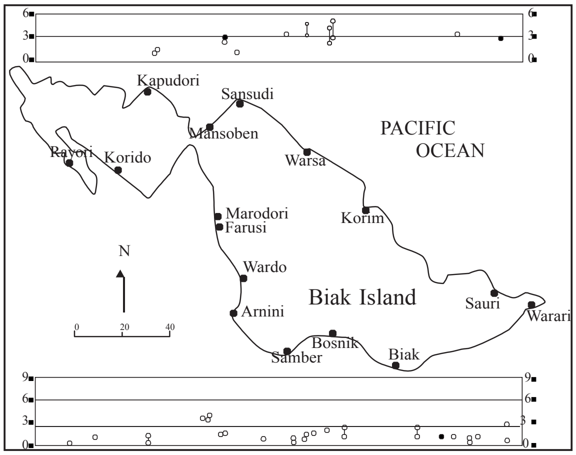

Figure 4. Run up height distribution at Biak Island (Matsutomi *et al*., 2001).

Methods

In 2009, a field survey had been conducted along Biak Island, referring to the 1996 tsunami event which occured in this area. The objective of the survey is to identify the tsunami characteristics along the coast of Biak by finding traces of 1996 tsunami event in this island. Tsunami deposits were traced and tried to be collected at the places of previous field survey. Significant tsunami deposits were found in Korem, northern coast of Biak that have not been found in other locations.

Fieldworks such as visual coastal characteristic mapping, position determination, beach profiling, and tsunami deposit collecting were done by trenching and sampling.The laboratory analysis had been carried out to sediment samples, both grain size analysis and fossil identification. Statistical calculation of grain size analysis results used method of moments, while transformed data were calculated using the phi-transformation of mm = 2-referring to programme of Balsillie *et al.* (2002).

Results And Discussion

Korem, Warsa, and Mansoben are generally wide coastal plains with low lying flat morphology (Figure 5). According to the people along the coastal areas, those villages have been moved farther from the previous areas after the tsunami.

Nowadays, houses were relocated from near shore to higher ground, so if tsunami comes, it will be easier for people to survive.

The southern coast of Biak, such as Warari has also the same morphology as the northern coast, that is flat and wide. While the western coast of Biak, such as Mardori and its vicinity have more undulating to steep morphology.

Bay and other prospecting areas which are undisturbed or less disturbed from human activities and others after the tsunami event. At the Korem Bay, the tsunami deposits were found at a swampy land and a soccer field. According to the local people, this place was a school building which had been destroyed by the tsunami. About 0.5 kg samples below the remnants of construction debris were collected for further laboratory analysis. Samples were also taken from Mardori and Warari, at the western and eastern coasts of Biak respectivelly.

Beach profiling measurement was performed both vertically and horizontally using Total Station type TCR1203+, showing that coastal areas along Biak Island mostly have flat beach profiling.

Based on coastal characteristic mapping, the Korem Bay at the northern coast of Biak Island is located at a low lying area which has a flat and wide coastal morphology. Lithologically, it comprises fine - to coarse-grained yellowish white modern beach sand, containing fossils. This are is still unexplored. According to the people, this area has still undisturbed since 1996 tsunami event. This condition leads to the possibility that tsunami inundation can go farther inland.

At this location, the 1996 tsunami deposits is overlain by the recent soil covering the ancient beach sand. Megascopic analysis shows that the exposure of 1996 tsunami deposits are structureless and homogenous, and contain two sand layers which are separated by a gradual boundary (Figure 6).

To the north coast, at Warsa Bay, the coastal morphology is still flat, but 1.5 to 2.5 m high sea walls are constructed, and people built their houses relatively close to the beach used as a tourism facility. If a tsunami height is more than 3 m, this condition is vulnerable and enables the tsunami to go farther inland and inundate the villages. However, if the tsunami height is less than 3 m, it could be reduced

Table 1. List of Arrival Time, Period, and other Remarks according to Eyewitnesses (Matsutomi *et al*., 2001)

Location	Arrival Time (minute)	Period (minute)	Wave number	Highest wave	Remarks
North coast					
Kapudori	-	2-3	4	2nd	
Mansoben	-	-	3	-	
Sansundi	10-15	-	3	1st	Broke on a coral reef
Korem	10	10	-	-	Broke; 3 fission waves
South coast					
Anggaduber	-	-	3	2nd	
Auki Island	-	-	3	-	From the south
Saba	-	-	3	2nd	From the southeast
Bosnik	-	-	3	2nd	
Owi Island	5	2	3	-	Ebb; Broke; from NNE
Biak	-	-	-	-	5 tsunami traces on wall
Sorido	5	-	-	-	From the southwest
Yendidori	-	-	2	2nd	From the south-southeast
Inpendi	-	-	3	-	From the southwest
Adoki	-	-	5	-	From the south fission waves
Urfa	5	-	3	2nd	From the southeast
Samber	2	-	-	-	From the east
West coast					
Arnini	2	-	-	-	
Wardo	-	2-3	2	2nd	Began with ebb
Mamoribo	-	-	2	2nd	
Farusi	-	2-3	2-3	2nd	
Mardori	1	2	2	2nd	
Marsam	10	-	3	2nd	Began with ebb
Korido	5	-	-	2nd	Ebb, 2 earthquakes within a minute
Ravori	5	-	5	2nd	2 earthquakes

by the sea wall built along the coast. At this location, representative good samples of the 1996 tsunami deposit could not be found.

The western coast of Biak has an undulating to steep coastal morphology, occupied with coral reef and beachs pockets of rock fragments composed of yellowish white modern beach sand comprising coral and shell fragments. This coastal condition has a potential to reduce the energy of tsunami wave, avoiding tsunami inundation to go further from the shoreline, because it is restrained by 10 - 15 m high coastal hills, as found in the Mardori Village. Eventhough 7.7 m tsunami-high has ever been recorded in this area, so far it was only about 50 - 75 m from the shoreline. People now build their houses at the higher ground, to gain a lesser risk of tsunami inundation in this region. In this location, ancient beach sand is found to be overlain by recent soil which was suspected as the 1996 tsunami deposit (Figure 7). Megascopic analysis shows that the suspected 1996

Figure 5. Flat coastal morphology at Korem Bay, northern coast of Biak Island (left) and building foundations remains left by the 1996 tsunami (right).

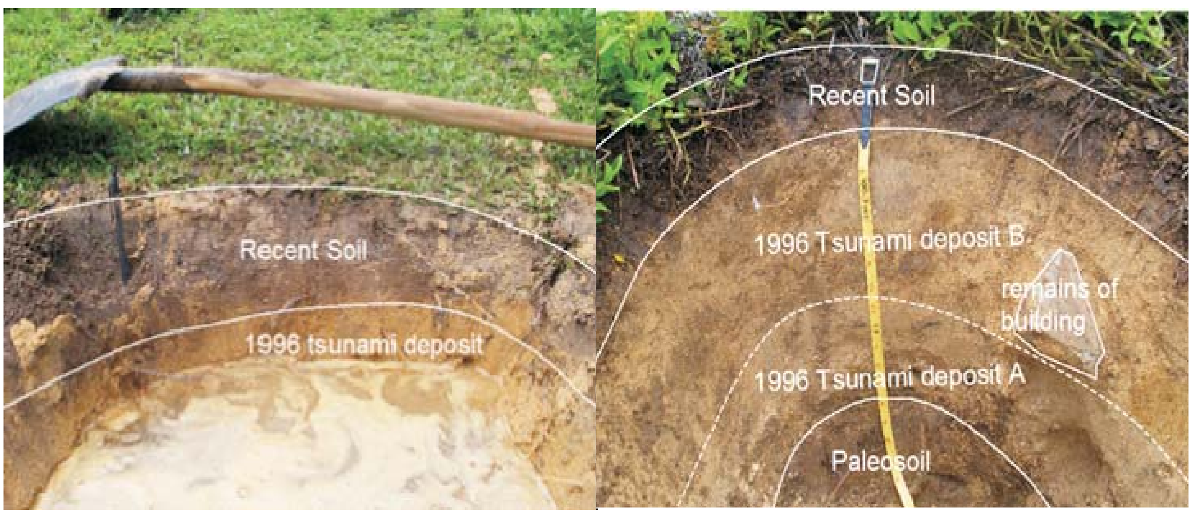

Figure 6. Tsunami deposit found at a swamp area (left) and a soccer field (right).

tsunami deposit occurs as coarse beach sands, containing rock fragments of pebble size embedded,with no sedimentary structures (Figure 7).

The southern coast of Biak Island, mostly covered by conservation forest, has a flat to undulating coastal morphology and lithologically comprises modern beach sands. The unique condition is encountered in Warari region, where there is a forest of big trees growing on a swampy land (Figure 7), overgrown by mangroves. The appearance of the large trees is relatively old in age but they are not longer growing. According to the local people, it is due to salty influence of sea water which inundates the area, so those trees were dead because of sea water contamination.

If it is true, then this area is assumed to have been widely inundated by the 1996 tsunami (about 1 km from the shoreline). This condition should be taken into account as the thing that likely to re-occur in the future, and the people should be prepared.

Laboratory Analysis

Three samples are obtained from three locations: Korem, Warari, and Farusi (Mardori). A sedimento-

Figure 7. Beach situation in Mardori (left) and beach sand deposit overlain by recent soil (right).

logical analysis for both grain sizes and fossil identification was carried out. The laboratory analysis performed for Warari and Mardori could not give any significant result compared with the sample collacted from Korem.

The grain size analysis calculated using excel program of Balsillie *et al*. (2002) gives the statistical result as presented on Table 2.

According to the scale of relative dispersion shown below, it can be determine that the Korem sediments have a good homogeneity, same as ordinary beaches sediments (Table 3).

Grain size distribution curve shows that the 1996 tsunami potential from Korem has two modes, with the maximum frequency of 26%, mean value of 2.2ϕ, and modus of 1.75ϕ (Figure 8). From this curve, it could be identified that the grain size is dominated by fine to medium sand.

The grain size distribution curve shows that the sediment is influenced by a moderate current producing saltation process as one of the bed load transportation mode, similar as beach processes.

Korem sample which is suspected as the 1996 tsunami deposit contains a lot of fossils and based

Table 2. Statistical Result of Sediment Sample from Korem

Statistical Results						
Measure	**Original Data in ϕUnits**		**Transformed Data**		**Original Data**	
Mean:	2.2001	ϕ	0.2176	mm	0.2739	mm
Standard Deviation :	1.0970	phi-units	MV		0.1733	mm
Skewness:	0.9959	NU	MV		1.1903	NU
Kurtosis:	4.0957	NU	MV		4.6921	NU
5^{th} Moment Measure:	7.953	NU	MV		0.15	NU
6^{th} Moment Measure:	23.769	NU	MV		0.21	NU
Median:	0.0008	ϕ	0.9995	mm	0.9996	mm
Relative Dispersion:	MV		MV		0.6327	NU

MV = meaningless value; NU = no units (*i.e.*, dimensionless) on planktonic foraminifera assemblage (Figure 9; Table 4) its relative age is N18 (Late Miocene). However, this age could not be referred due to the tsunami mechanism which could make those fossils to be mixed.

Moreover, on the basis of benthic foraminifera assemblage (Table 5; Figure 10), it is suggested that the foraminifers were derived from a deep sea environment (> 200 m deep); therefore, the Korem tsunami deposits could be estimated to be originated from a shallow marine up to deep sea (bathyal) condition zone.

The 1996 Biak tsunami event was generated by an earthquake having a reverse fault mechanism, with the source that is located at the northeast of Biak Island. Although the tsunami deposit could be observed just after the event, it could not long be stored at the ground due to the morphological condition and disturbance of human activities and other causes. Some of them has disappeared after a couple of years.

The northern coast of Biak has a wide coastal plain, that is flat morphologically but relatively dry compared with the southern coast of Biak which also has a wide and flat morphology, but very wet (a lot of swamps); while the western coast of Biak has an undulating to steep morphology and also relatively wet.

Table 3. Relative Dispersion Scale (Balsillie *et al*., 2002)

Relative Dispersion Scale	
< 0.5	Excellent homogeneity (*e.g.* beaches)
0.5 to 1.0	Good homogeneity
1.0 to 1.33	Fair homogeneity
> 1.33	Poor homogeneity

Figure 8. Swampy forest at Warari, southern coast of Biak.

Table 4. Planktonic Foraminifera Assemblage and of Relative Age Estimation

No.	Name of Foraminifera	Early Miocene					Middle Miocene							L. Miocene			Pliocene			Pleist.	
		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	*Globorotalia tumida tumida*																				
2	*Globorotalia plesiotumida*															—	—	—	—	—	—
3	*Globorotalia multicamerata*														—	—					
4	*Globorotalia acostaensis acostaensis*														—	—	—	—	—		
5	*Globoquadrina dehiscens dehiscens*													—	—	—	—	—	—		
6	*Globigerinoides obliqus extremus*		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
7	*Globigerinoides trilobus trilobus*													—	—	—	—	—			
8	*Orbulina universa*		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	*Puleniatina primalis*							—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	*Sphaeroidinillopsis subdehiscens subdehiscens*														—	—	—	—			

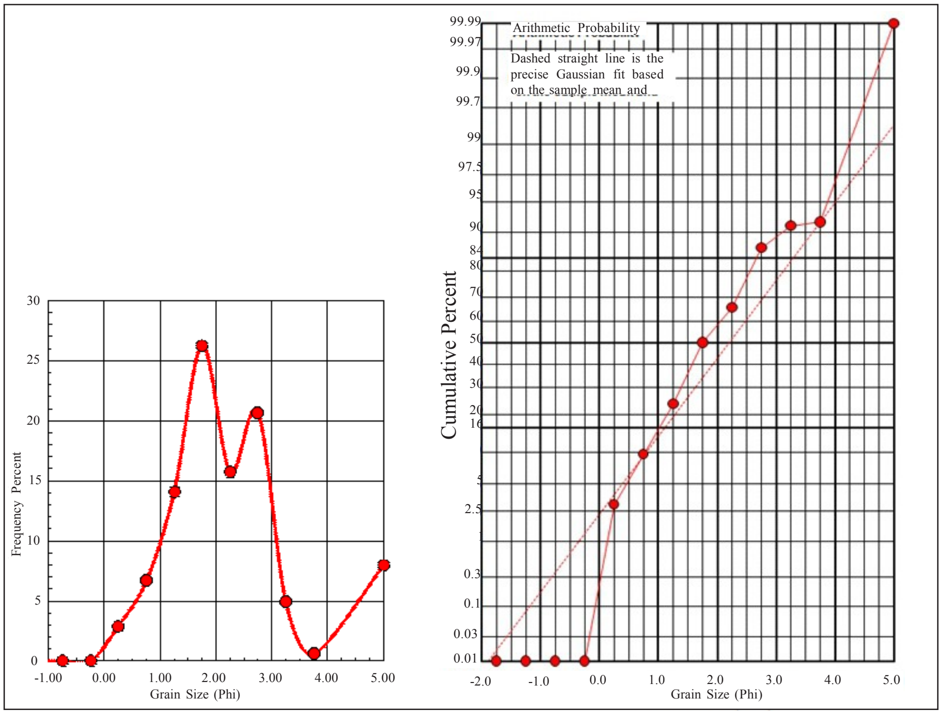

Figure 9. Grain size distribution curve (left) and trans-depositional curve (right).

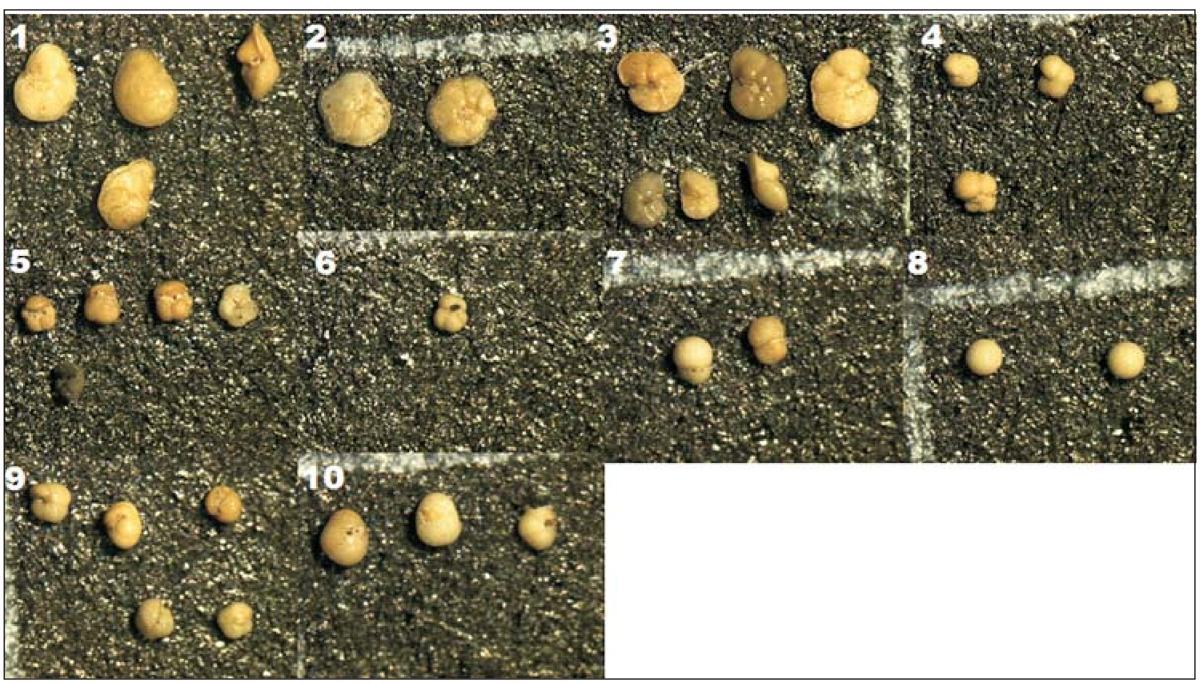

Figure 10. Microphotograph of planktonic foraminifera of Korem tsunami deposit: 1) *Globorotalia tumida tumida*; 2) *Globorotalia multicamerata*; 3) *Globorotalia plesiotumida*; 4) *Globorotalia acostaensis acostaensis*; 5) *Globoquadrina dehiscens dehiscens*; 6) *Globigerinoides obliquus extremus*; 7) *Globigerinoides trilobus trilobus*; 8) *Orbulina universa*; 9) *Pullenia primalis*; 10) *Sphaerodinellopsis subdehiscens*.

Figure 11. Microphotograph of benthic foraminifera from Korem tsunami deposit: 1) *Buliminia* sp.; 2) *Bulimina* cf *spicata*; 3) *Cassidulina subglobosa*; 4) *Cibicides praecintus*; 5) *Cibicides rugosa*; 6) *Dentalina subsoluta*; 7) *Dentalina* sp.; 8) *Eponides umbonatus*; 9) *Gyroidina soldani*; 10) *Nodosaria* sp.; 11) *Nonion* sp.; 12) *Pleurostomella brevis*.

Table 5. List of Benthic Foraminifera Assemblage and Estimation

No	Foraminifera	Depth									
		> 100	100	200	300	400	500	....	1000	2000	3000
1	*Bulimina sp*										
2	*Bulimina cf spicata*										
3	*Cassidulina subgloba*										
4	*Cibicides praencintus*										
5	*Cibicides rugora*										
6	*Dentalina sp*										
7	*Dentalina subsoluta*										
8	*Ephonides umbonatus*										
9	*Gyroidina soldani*										
10	*Nonion sp*										
11	*Nodosaria sp*										
12	*Pleurostomella brevis*										
13	*Ungulina complanata*										

Conclusions

On the basis of those areas with their different environmental condition, it is concluded that there are some requirements to find an ideal tsunami deposit, such as wide coastal plains with low lying flat morphology and moderately wet. Another requirement is that the location has to be free or less disturbed from human, animal, or other activities, in order to make the tsunami deposit to be stored undisturbed. Korem at the northern coast of Biak Island can fulfill those requirements compared with other places, where the tsunami deposit could be found.

The 1996 Biak tsunami deposits, according to the laboratory analysis, are characterized by grain size of 1.75 to 2.2 phi or fine to medium sand, deposited by a saltation process. The fossil identification, indicates that this tsunami deposit was originally derived from a deep sea (bathyal) environment of > 200 m deep.

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