SUBMARINE LANDSLIDE AND LOCALIZED TSUNAMI POTENTIALITY OF MENTAWAI BASIN, SUMATRA, INDONESIA

H. Permana[1] S. C. Singh[2] & Research Team

(N. Hananto[2], A. Chauhan[2], M. Denolle[2], A. Handryana[2], Sumirah[3], A.W. Djaja[4], E. Rohendi[4], C. Sudjana[3], J. Prihantono[5], D.D. Wardhana[1])

ABSTRACT

The new bathymetry and seismic data were acquired during the PreTI-Gap marine survey (February 15 to March 6, 2008). The survey was carried out along the NE margin of Mentawai Island using multi-beam swath bathymetry equipment, and 28-channels seismic streamer and four-airgun source. The first target was the Mega Island region near the epicenter of the 2007 great earthquake. The shallow bathymetry is characterized as a flat coral platform suggesting that 200 km elongated plateau is slowly subsiding without any active faults. Further north, from South Pagai to North of Siberut Islands, the seafloor morphology changes significantly. The deep and wide canyons or valleys produce very rough seafloor morphology between 50 and 1100 m water. In general, the submarine topography shows two break slopes at different depths. Between slope breaks, the undulating, hilly and circular features dominate, possibly caused by landslides. A push-up ridge is observed that dams the sediments eroded within a steep slope northeastward side. The seismic reflection data acquired along 14 dip seismic lines at the NE flank of Mentawai Islands, from Siberut to the South of Pagai Islands. We observed a set of southwestward dipping back thrust bounding the NE margin of the Mentawai Island.

Keywords: submarine landslide, tsunami, Mentawai basin, Sumatra.

SARI

Data batimetri dan seismik baru telah dihasilkan selama survey kelautan PreTi-Gap (15 Februari hingga 6 Maret 2008). Survei dilaksanakan sepanjang tepian timurlaut P. Mentawai menggunakan peralatan multibeam, seismic saluran ganda 28 kanal dengan sumber energi airgun. Sasaran pertama adalah memetakan kawasan pulau dekat pusat gempa tahun 2007. Kenampakan batimetri dangkal dicirikan dengan adanya dataran terumbu karang yang secara

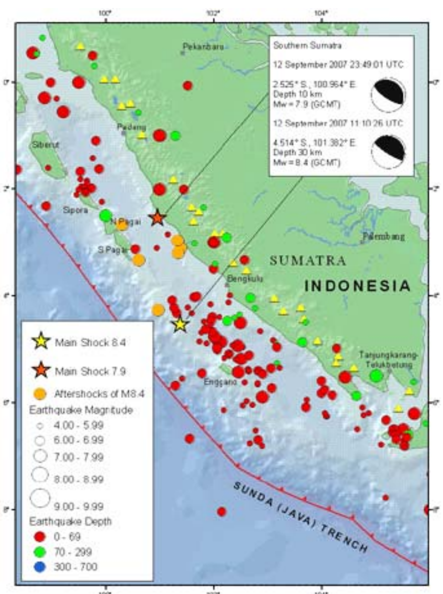
1. Research Center for Geotechnology, LIPI. Jl Sangkuriang, Bandung-40135, Indonesia; permhp@yahoo.com
2. Laboratoire de Géoscience Marines, IPG Paris, 4 Place Jussieu, Paris 75252, France; singh@ipgp.jussieu.fr, +33 1 44279967
3. Agency for the Assessment and Application of Technology, Jakarta, Indonesia
4. Marine Geological Institute, Ministry of Energy and Mineral Resources, Bandung, Indonesia
5. Marine and Fishery Department, Jakarta, Indonesia

perlahan mengalami penurunan tanpa aktifitas sesar. Lebih jauh ke Utar, dari Pagai Selatan ke utara P. Siberut, morfologi dasar laut memperlihatkan perubahan secara signifikan, dimana lembah dasar laut memiliki lebar dan beda kedalaman antara 50 hingga 1100 meter. Secara umum, topografi dasar laut memperlihatkan dua kemiringan pada kedalaman yang berbeda dengan dicirikan adanya kenampakan perlipatan, perbukitan dan bentuk yang melingkar diperkirakan sebagai hasil gelinciran. Sebanyak 14 line data seismik refleksi pada sayap bagian timurlaut P. Mentawai, dari Siberut hingga ke selatan P. Pagai memperlihatkan adanya bukti sesar naik yang miring ke arah baratdaya yang masih satu set dengan tepian timurlaut P. Mentawai.

Kata kunci: longsoran bawah laut, tsunami, Cekungan Mentawai, Sumatra.

Introduction

The 2004 Sumatra Andaman earthquake triggered a devastating tsunami around northern off Sumatra, Thailand, Ceylon, India and East Africa. This great earthquake of magnitude 9.2, initiated at NE of Simeulue islands, propagated toward the N-NW along the Andaman trough and broke 1200-1300 km long plate boundary (Ammon et al, 2005). The disastrous tsunami swept out the coastal area from Banda Aceh, Calang, Lhok Nga until Meulaboh, Simeulue and Nias Islands and took over 150,000 lives. Three months later on March 28, 2005, an earthquake of magnitude 8.7 destroyed Nias Island. In April 2005, an earthquake occured close to the Siberut islands that made the citizen of Padang City panic.



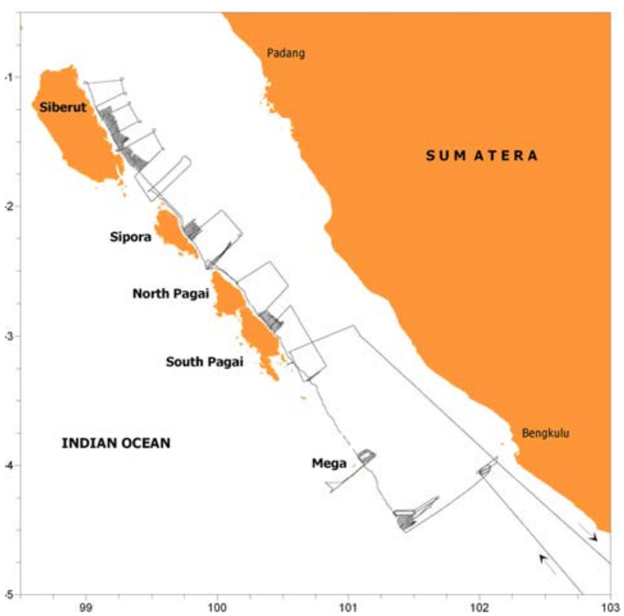


Figure 1 (left). Recent earthquake of 12-13 September 2007, along Mentawai fore-arc basin, near Bengkulu (Source: BMG, Indonesia, 2007).

Figure 2 (right). The PreTi-Gap 2008 Marine Survey at the NE margin of Mentawai Islands, Sumatra. Arrow: transit line; Line: seismic survey and polyline: bathymetry survey area.

Recently, on September 12, 2007 a 8.4 magnitude earthquake occurred near Enggano Island followed by a 7.9 magnitude earthquake 12 hours later. Later, in February 2008, an earthquake occurred near Sipora Island (Figure 1). The occurrence of these events suggest that the Sumatra subduction zone is very active and more earthquake are likely to occur in the area where energy has not been released, such as near Siberut Island.

The earthquakes offshore Sumatra are result from an oblique convergence of Indo-Australia plate beneath the Eurasia Plate. The active plate subduction have formed subduction zone along western offshore of Mentawai islands (Sunda Trench); Great Sumatran strike slip fault on mainland of Sumatra (Natawidjaja, 2003) and Mentawai strike slip fault along and parallel to Sumatra fore-arc basin (Diament et al., 1992). Historically, many great earthquakes (Mw≥8.0) have occurred since 1600. Some of the earthquake has generated tsunami in Padang and Bengkulu (Natawidjaja et al., 2004, Newcomb and McCann, 1987). To the east, the active subduction of Sunda Trench continues along southern of Java and Nusatenggara Islands. Even though big earthquakes rarely occur in this region, two of them generated tsunami, such as Banyuwangi earthquake of magnitude 6.8 in 1994 and Pangandaran earthquake of magnitude 7.3 in 2006.

Marine Survey

As we know, the dense populations that live along coastal region of western Sumatra and southern coast of Java Islands are prone natural risk, e.g. earthquake and tsunami. Therefore, it is important to understand the behavior and frequency of the earthquakes and tsunami that occurred along Sunda Trench, which is crucial for risk mitigation plan. A cruise named PreTI-Gap or Pre–Tsunami Investigation of Seismic Gap was planned and realized by IPG (Institute Physique du Globe) de Paris in collaboration with LIPI, MGI, BPPT and DKP. The survey was carried out on board the LIPI Research Vessel Baruna Jaya VIII from February 15 to March 6, 2008. The scientific objective was to study 12-13 September, 2007 mega-thrust earthquakes offshore Bengkulu, Sumatra, and subsurface geology and the seismic gap near Siberut using a combination of 28 channels shallow seismic reflection and multi beam swath bathymetry using EM1002 that allow seafloor morphology in shallow water (<1000 m). The survey covered 6 boxes of bathymetry (Singh and Permana, 2008). The previous seismic survey close to our study area are Sumenta Cruise (1990-1991), Ginco Cruise (1998-1999) and Sea Cause Cruise (2006, 2007).

The first box of bathymetry survey was acquired in the vicinity of 12 September 2007 epicenter, and another near Mega Island (Figure 2) where GPS provided a maximum uplift of 1.5m during the main event. Further north, the bathymetry data were acquired near the northeastern of South Pagai and Sipora Islands and a wide area NE of Siberut islands. 28 seismic lines were acquired through the Mentawai fault and western margin of Mentawai fore arc basin.

Results

a. Bathymetry

The new bathymetry imagery of western margin of Mentawai fore-arc basin is significantly different between Mega Island and epicenter areas and the area close to the Pagai, Sipora and Siberut islands.

The morphology of the epicenter area (a box of 25 km by 20 km) is a flat plateau at 130 m depths (Figure 3a). The plateau is characterized by a 200 m scarp with a slope of about 20°, with smooth texture without any canyons suggesting that it is fresh escarp, either formed by rapid subsidence or sea level

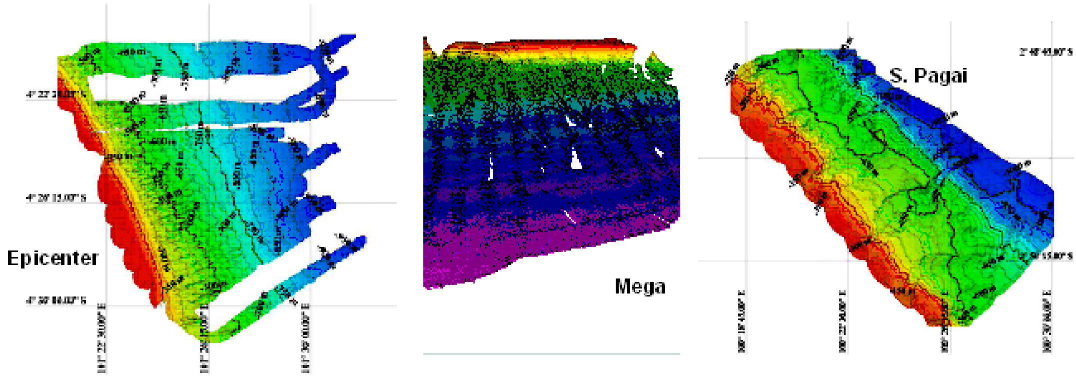


Figure 3a (left). Bathymetry features of Epicenter area; (3b, middle) Mega Island area and South Pagai area (3c, right)

change or due to a back thrust. The canyons appear at 300 m water depth and intensify at about 500 m depth. The seafloor morphology is dominated by erosive canyons down to 700 m water depth. Below this water depth, the seafloor morphology is smooth down to 950 m. In general, the morphology shows three break slopes at 375 m, 500 m and 725 m.

The Mega Island box is about 12 km wide and 12 km long (Figure 3b), where the morphology is almost similar to the Epicenter bathymetry. It is flat and has a smooth morphology, possiblly consists of carbonate platform down to 150 m escarpment. Below this depth, homogeneous morphology and extensive canyons are dominant. The shallow water (50 m) on the plateau in this area suggests that the plateau has subsided (uplifting) more (less) towards the epicenter region in the recent past. As before, the canyons are very extensive below this depth. Most of the canyons terminate at about 330 m water depth suggesting the presence of a slope break. Two other slope breaks occur at 400 m and 450 m depths. Most of the canyons bend towards NE, suggesting that the basin is tilting towards NE. However, the presence of the shallow basin more than 1000 m depths, the hypocenter location, and rupture during the 12 September earthquake suggest that the portion of the locked zone is limited beneath the Mega Plateau, which is consistent with Natawidjaja's observation (2007).

The bathymetric box 3 is 23 km long and 12 km wide (Figure 3c) and covers most of the NE margin of South Pagai Island from 100 m depth down to 1100 m water depth. In general, morphology in this area shows two slope breakes at 450 m and 880 m water depth. The first escarp is about 15°, cut by a narrow and deep valley in NNE direction. At the first foot of the slope, a wide, circular and elongated valley is dominant, indicative of sediment cover wash out from this area. The circular morphology is interpreted as pathway of old large landslide. The second step escarp is very rough and is characterized by intensive, wide and deep canyon. It is possible all loose sediment material go down to the deep basin through these canyons. The seafloor covered by fine and loose material shows a smooth texture.

Further north, the water depth is shallower, about 50 m, around the eastern of Sipora Island box (14 km by 14 km, Figure 4a). The bathymetry feature shows three slope breaks at

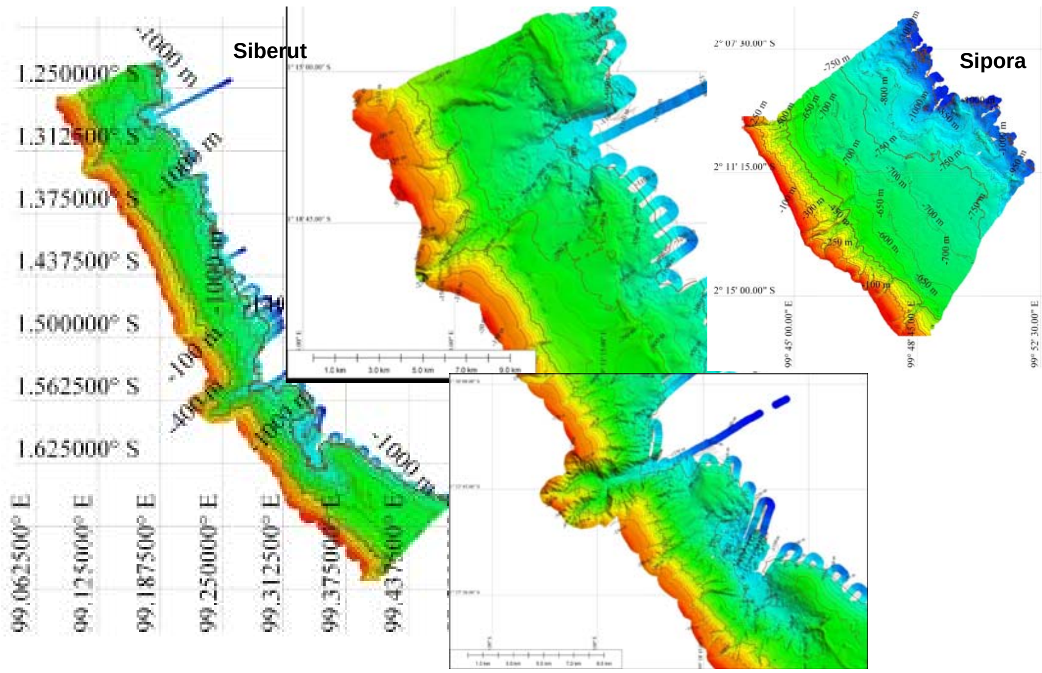


Figure 4a (right). Bathymetry map of Sipora Island and (5b, left and middle) is bathymetry map of Siberut Island.

550 m, 850 m and 950 m water depths. The morphology is characterize a smooth gentle escarp at 130 m water depth has 30° dip. The canyons, mostly bend towards NE, are very extensive below this depth and terminate at about 500 m water depth. A narrow and deep valley cut the escarp at 2º13’ S, follows a north-direction ridge at 650 m to 700 m depth. The valley continues to the deep sea via rough, wide and deep valley at 850 m depth or a second slope break whereas circular feature which indicates mass failure presence. A smooth seafloor appears at 550 m – 700 m to 800 m water depths or on a second foot slope. A NNW ridge is present at 850 m water depth. A rough and steep escarp with a dip of 45° bounds a second slope break and the sea floor more than 1000 m water depth.

The bathymetry area of eastern Siberut Island is 63 km by 12 km (Figure 4b). The most impressive and dominant features on the bathymetry are mass wasting. At least three areas of the large mass wasting have observed in the box, at 1º17’S, 1º33’S, and 1º 37’S. Generally, the bathymetry in this area could be differentiates into four types. First type is shallowest area 50 to 150 m up to 200 m water depth look like carbonate terrace due to sea level change (subsidence and or sea level rise) or back thrust. The morphology is flat, smooth without any erosional features. Partly, the hilly or ridge morphology is parallel to the islands and it is possible carbonate present down to 200 - 250 m water depth. Below 200 m, a steep scarp, 200-400 m high, intensively cut by canyon or gorge mostly perpendicular to the island or NE direction is observed. The first slope break occurs at different depths from south to the north at 600 m, 700 m or 550 m. The smooth and undulating morphology characterize foot slope at 600 m to 850 m water depths. Some parts of the foot slope, in the southern part (1º 37’S), is cut by 10 km to 3 km deep canyons, 250 m high. In the middle part (1º33’S), a steep deep canyon, least 500 m high over 8.5 km by 2 km, cut the western flank of Mentawai basin in NNE direction. Further north at 1º17’S, a foot slope at 550 m to 850 m depths is cut by circular feature of 8 km by 7.5 km and has 250 m height. Such a circular feature is interpreted as important mass wash out that is possibly related to large submarine landslide. A NNW push-up ridge within a steep margin, 100 -150 m height is limited by the foot slope from more than 1000 m water depth of a sea floor.

b. Seismic

Seismic reflection data show sub-horizontal sediments in the Siberut basin, folding and faulting near NE margin Mentawai Island. Diament et al (1992) interpreted these features are a strike-slip fault accomodating slip partitioning between trench normal and trench parallel component. However, we suggest that these faults and folds are related to back thrusting instead. A paper is under review (Singh et al,2008) discussing these results and hence we cannot present these results here due to publication limitation. However, these results will be presented during the oral session.

Concluding Remark and Discussion

The present shallow, flat, smooth seafloor morphology of escarp and extensive canyons at depth near 2007 earthquake epicenter and Mega Islands suggest that the plateau is submerging and is tilted towards NE. It was confirmed by seismic reflection data from the Sumenta cruise (Lines 18 and 19, 1990), that show homogenous morphology without any ridge morphology. The ridge or back thrust is covered by flat lying sediments suggesting that these faults are inactive. Unfortunately, the cruise did not recorded new seismic line in this area. The difference in features on the seafloor morphology between the 2007 earthquake epicenter and Mega Islands compared to those on the Pagai, Sipora and Siberut Islands suggest that the seismicity locked (?) zone occur beneath northern the Mega Plateau (Singh and Permana, 2008).

Further north, from South Pagai and Sipora Islands, the bathymetry was dominated by slope breaks, circular features, push up-ridges and intensive, wide and deep canyons. It is clear that important landslides or mass wash out has occured in those areas. The slope breaks or push up ridges are mostly controlled by back thrust movement.

In the past, Mentawia faults have been interpreted as system of strike-slip faults by Diament et al (1992). They suggest this by using seismic reflection data that show flower structures, which are generally associated with strike-slip faults. The presence of island was used as an explanation for the lack of tsunami during the 2005 Nias earthquake. Borrero et al (2007) reported that the 12th September 2007 earthquake caused tsunami along Bengkulu, from Air Rami to Manna within wave height 1 m to 4 m and 300 m innondation. The low angle slip is responsible for local weak tsunami in Bengkulu (Natawidjaja, 2007).

In the past, the largest tsunami observed in Padang was during the 1797 earthquake, which has a magnitude of 8.4. However, tsunami in Bengkulu was very small. Similarly, during the Mw=9 earthquake of 1833, tsunami was large in Bengkulu but only 2-3 m in Padang, which suggest that these tsunami might have been produced by local source, such as localised back thrust or landslide.

A very large extend of mass wasting or landslide observe at NE of the Siberut Islands. The scars of these mass waste looks fresh and it is possible that the 1797 tsunami was generated by a massive landslide due the 1797

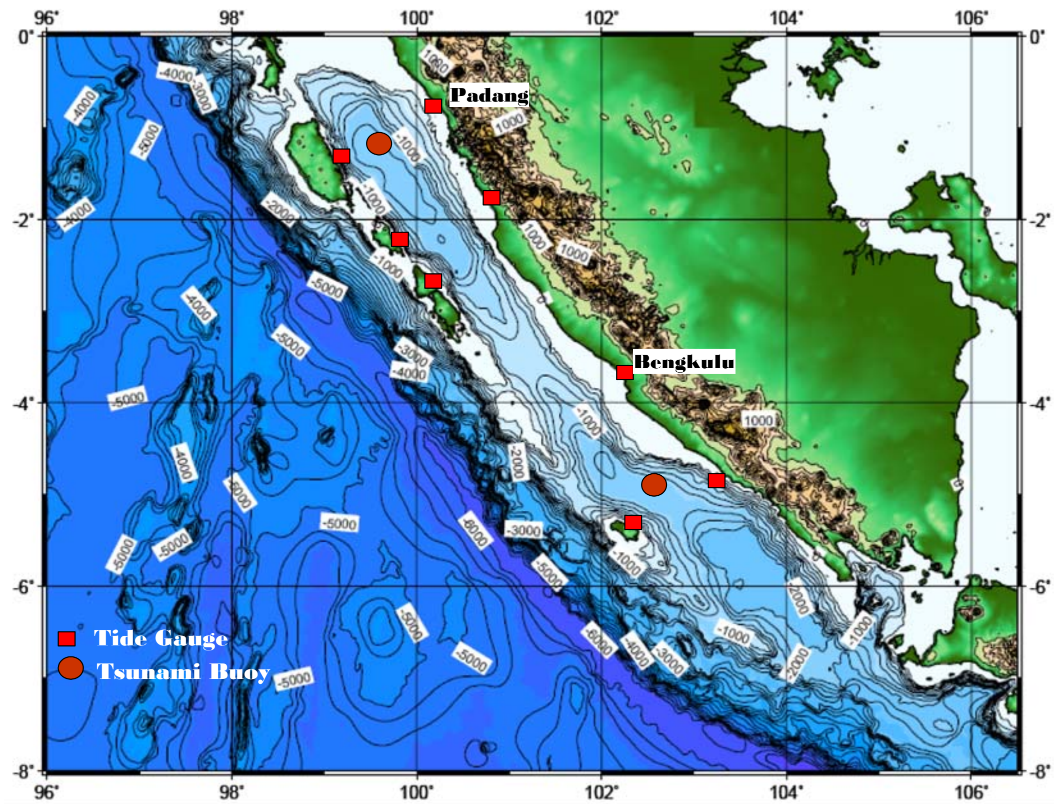


Figure 5. Propose site for tide gauge and tsunami buoy at Mentawai Basin

earthquake; it is not possible to have a 5 m tsunami in Padang if it was produced by mega thrust SW of Siberut. Since there is a seismic gap around Siberut, the risk due to mass wasting is very high for population living around the coast of Sumatra and Mentawai Islands. Recently, slumpy or landslide caused tsunami in PNG in 1998 (Watts, 2008; Carayannis, 2008) left a thick sedimentary deposits (Gelfenbaum et al., 2001).

Recommendation

Such kind of back thrust movement at the flank of Mentawai basin can trigger mass movement or landslide that can produce localized large tsunami causing damages to Sumatra mainland such Padang, Painan or northern Bengkulu Provinces. Therefore, it is important to re-design the tsunami warning system, especially in this region, in order to mitigate tsunami risk to coastal region of western Sumatra. Also is very important to re-map the bathymetry along the basin from western Sumatra to southern of Java. Figure 5 shows propose site for tide gauge or buoy to detect tsunami related submarine landslide.

Acknowledgement

This article was limited electronic-publish during International Conference on Tsunami Warning System, 11-14 November 2008 in Nusa Dua, Bali, organized by Ristek. This survey is funded by the French Ministry of Foreign Affairs under the program Délegation

Inter-gouvernmental Post Tsunami after 2004 tsunami to develop a strong Franco-Indonesian research collaboration. This research realized under responsible of IPG Paris in partnership LIPI and also BPPT, MGI and DKP. Special thanks to Captain of Baruna Jaya VIII and crew who work very hard during unfriendly weather and equipment trouble. Also thank you very much deliver to Foreigner Research Permit bureau, Ministry of Research and Technology and also Ministry of Defense to make the survey is possible.

References

Ammon, C.J., Ji, C., Thio, H-K., Robinson, D., Ni, S., Hjorleifsdottir, V., Kanamori, H., Lay, T., Das, S., Helmberger, D., Ichinose, G., Polet, J., Wald, D. 2005. *Rupture Process of the 2004 Sumatra-Andaman Earthquake*. Science v. 308, May 20, 2005.

Borrero, J.C., Hidayat, R., Suranto. 2007. *Field Survey of the Tsunami Generated by the Mw 8.4 Earthquake of September 12, 2007.* Bengkulu Province, Sumatra

Carayannis, G.P. 2008. *The earthquake and tsunami of 17 July 1998 in Paqpua-New Guinea (PNG).* http://www.drgeorgepc.com/Tsunami1998PNG.html

Diament, M., H. Harjono., K. Karta, C.Deplus, D. Dahrin, M.T. Zen Jr., M.Gerard, O.Lassal., A. Martin, J. Malod, 1992, Mentawai Fault Zone off Sumatra: A new key to the geodynamic of western Indonesia, Geology, 29, 259-262.

Gelfenbaum, G., Jaffe, B., Nongkas, M. And Davies, H.L. 2001. *Sedimentary deposits from the 17 July 1998 Papua New Guinea Tsunami. ITS 2001*. Proceedings, Session 2, Nu. 2-13.p. 449-452

Natawidjaja, 2007 (unpublish). Laporan Singkat: Rentetan Gempa Besar di Kawasan Mentawai, Bengkulu dan Sumatra Barat. Lembaga Ilmu Pengetahuan Indonesia

Natawidjaja, D.H. 2003. *Neotectonics of the Sumatran Fault and Paleogeodesy of the Sumatran Subduction Zone*, Ph. D. thesis, California Institute of Technology, Pasadena.

Natawidjaja, D.H., K. Sieh, S. Ward, H. Cheng, R.L. Edwards, J. Galetzka, and B.W. Suwargadi. 2004. Paleogeodetic records of seismic and aseismic subduction from central Sumatran microatolls, Indonesia, *Journal of Geophysical Research, 109.*

Newcomb, K.R., and W.R. McCann. 1987. Seismic history and seismotectonics of the Sunda Arc, *Journal of Geophysical Research*, 92, 421-439.

Scientific Team. 1991. Mentawai Cruise. Preliminary Onboard Report.

Singh and Permana. 2008. *PreTIGAP. Pre-Tsunami Investigation of Sesismic Gap*. Cruise Report.

Watts, P. 2008. Some Opportunities of the landslide tsunami hypothesis. www.appliedfluids.com/SciTsuHaz.pdf