SUBMARINE MASS MOVEMENT AND LOCALIZED TSUNAMI POTENTIALITY OF MENTAWAI BASIN, SUMATERA, INDONESIA

By :

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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 depth. 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 mass movement. 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 and the push-up ridge observed on bathymetric image, which suggest that Mentawai fault is not pure a strike slip fault, but consists of a set of back thrusts. Such kind of back thrust movement at the flank of Mentawai basin can trigger mass movement or landslide that can produce localized tsunami causing damages to Sumatera mainland such as Padang, Painan or northern Bengkulu provinces and Mentawai Islands. 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 Sumatera.

Keywords: multi-beam swath bathymetry, 28-channels seismic streamer, seismic reflection, back thrust, mass movement or landslide, tsunami warning system, mitigate tsunami risk

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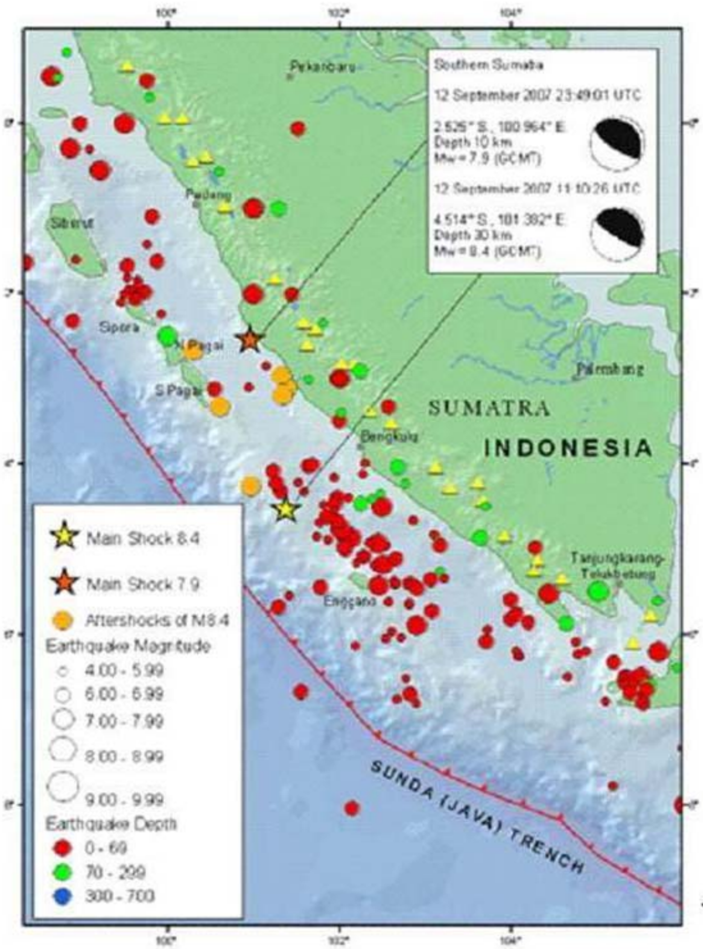
SARI

Data batimetri dan seismik baru telah didapatkan selama survey kelautan PreTi-Gap (15 Februari hingga 6 Maret 2008). Survei dilaksanakan sepanjang tepian timurlaut Kepulauan. Mentawai menggunakan peralatan multibeam batimetri, seismik saluran ganda 28 kanal dengan 4 sumber energi airgun. Sasaran pertama adalah memetakan kawasan perairan P. Mega dekat pusat gempa besar tahun 2007. Kenampakan batimetri dangkal dicirikan dengan adanya dataran paparan terumbu karang sepanjang 200km yang secara perlahan mengalami penurunan tanpa akifitas sesar. Lebih jauh ke utara dari P. Pagai Selatan sampai di utara P. Siberut, morfologi dasar laut memperlihatkan perubahan secara signifikan yaitu lembah dalam dan lebar membentuk morfologi dasarlaut yang kasar dengan beda kedalaman antara 50 hingga 1100 meter. Secara umum, topografi dasar laut memperlihatkan perhentian dua lereng pada kedalaman yang berbeda. Diantara batas lereng yang dicirikan adanya kenampakan perlipatan, perbukitan dan bentuk melingkar diperkirakan sebagai hasil gelinciran batuan/tanah. Punggungan terangkat yang teramati merupakan penahan endapan yang melongsor pada lereng curam pada sisi sebelah timurlaut. Sebanyak 14 lintasan sismik refleksi pada sayap bagian timurlaut Kepulauan Mentawai, dari P. Siberut hingga ke selatan P. Pagai. Patahan anjak belakang yang teramati dengan sudut kemiringan ke arah baratdaya memotong bagian tepian timurlaut dari Kepulauan Mentawai dan punggungan terangkat yang terekam pada peta batimetri menegaskan bahwa Patahan Mentawai bukan murni sebagai patahan geser mengkanan akan tetapi juga memiliki komponen patahan anjak belakang. Setiap pergerakan sesar anjak di sisi Cekungan Mentawai dapat memicu gerakan tanah atau longsoran bawah laut dapat membangkitkan tsunami lokal yang mengakibatkan kerusakan di daratan Sumatera seperti di Padang, Painan atau Propinsi Bengkulu bagian utara dan Kepulauan Mentawai. Oleh karena itu adalah sangat penting untuk merencanakan sistim peringatan tsunami khususnya di kawasan tersebut dengan tujuan untuk melakukan mitigasi resiko bencana tsunami di kawasan pantai barat Sumatera.

Kata Kunci: *multibeam batimetri, seismik saluran ganda 28 kanal, sismik refleksi, sesar anjak belakang, gerakan tanah atau longsoran, peringatan dini tsunami, mitigasi resiko tsunami*

INTRODUCTION

The 2004 Sumatera Andaman earthquake triggered a devastating tsunami around northern off Sumatera, Thailand, Ceylon, India and East Africa. This great earthquake of magnitude 9.2, initiated at NE of Simeulue Island, 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, 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. A month later, in April 2005, an earthquake occurred close to the Siberut Island that made the citizen of Padang City panic. Then, on September 12, 2007 an 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). Recently, the Padang and Pariaman cities has destroyed by Mw7,6 magnitude earthquake on September 30, 2009, at depth 80 km and 60 km of SE Pariaman (Figure 2). There is no important tsunami has observed due to the earthquake from this area. The occurrence of these events suggest that the Sumatera subduction zone is very active and more earthquake are likely to occur in the area



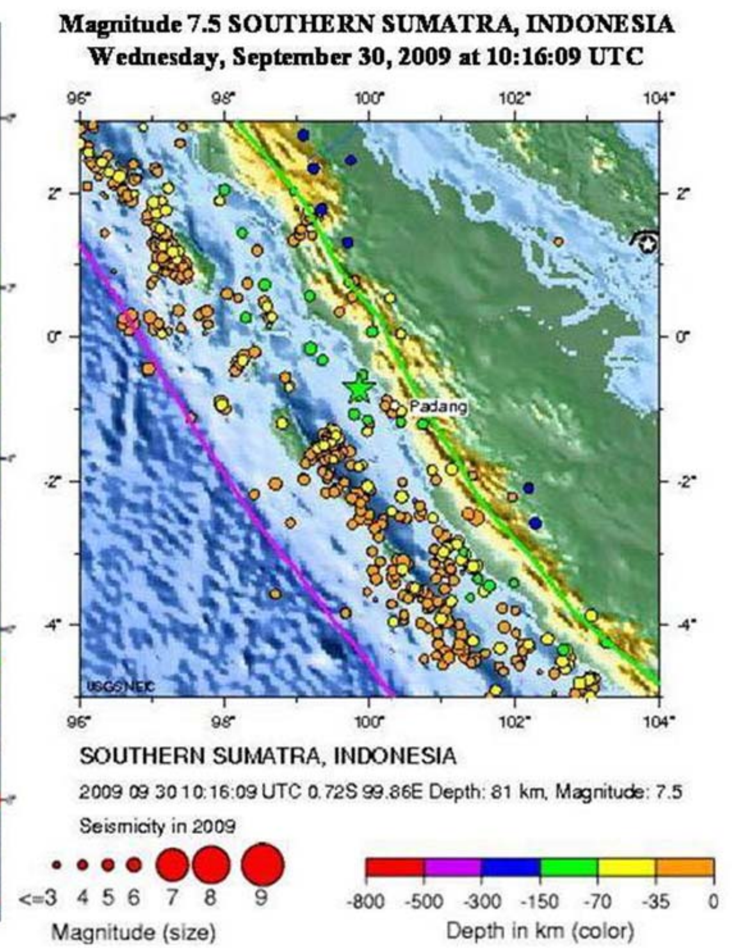


Figure 1 (left). 12-13 September 2007 earthquakes along Mentawai fore-arc basin, near Bengkulu (Source: BMKG, Indonesia, 2007). Figure 2 (right). The last important Mw7.6 magnitude earthquake occurs on September 2009 (USGS, July 2010).

where energy has not been released, such as near Siberut Island.

The earthquakes offshore of West Sumatera result from an oblique convergence of Indo-Australia plate beneath the Eurasia Plate. The active plate convergence have formed subduction zone along western offshore of Mentawai islands (Sunda Trench); Great Sumateran strike slip fault on Sumatera mainland (Natawidjaja, 2003) and Mentawai strike slip fault along and parallel to Sumatera 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 Nusa Tenggara 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.

The dense populations live along coastal region of western Sumatera (Padang, Bengkulu Cities), Mentawai Islands and southern coast of Java Island (Sukabumi, Cilacap, Jogyakarta, Banyuwangi) 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* has been done by Institute Physique du Globe de Paris/ IPG-Paris in collaboration with LIPI, MGI, BPPT and KKP. The survey was carried out on board the LIPI Research Vessel Baruna Jaya VIII from February 15 to March 6, 2008. The objective of this survey was to study 12-13 September, 2007 mega-thrust earthquakes offshore Bengkulu, Sumatera, and subsurface geology and the seismic gap near Siberut

METHODS

Marine Survey used a combination of 28 channels shallow seismic reflection and multi beam swath bathymetry using EM-1002 that allow seafloor morphology in shallow water (maximum 1000 m). The survey covered 6 boxes of bathymetry (Figure 3, 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). Related paper was published by Singh et al. (2009).

The first box of bathymetry survey was acquired in the vicinity of 12 September 2007 epicenter, and near Mega Island (Figure 3) 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 Island. The 28 seismic lines were acquired through the Mentawai fault and western margin of Mentawai fore arc basin.

RESULTS

Bathymetry

The new bathymetry imagery of western margin of Mentawai fore-arc basin is significantly different among Mega Island, 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 depth (Figure 4a). The plateau is characterized by a 200 m scarp with a slope of about 20°, with smooth texture without any canyons. It is suggesting a fresh escarp, either may formed by rapid subsidence or sea level change or back thrust. The canyons appear at 300 m water depth and more intensive at about 500 m depth. The seafloor morphology is

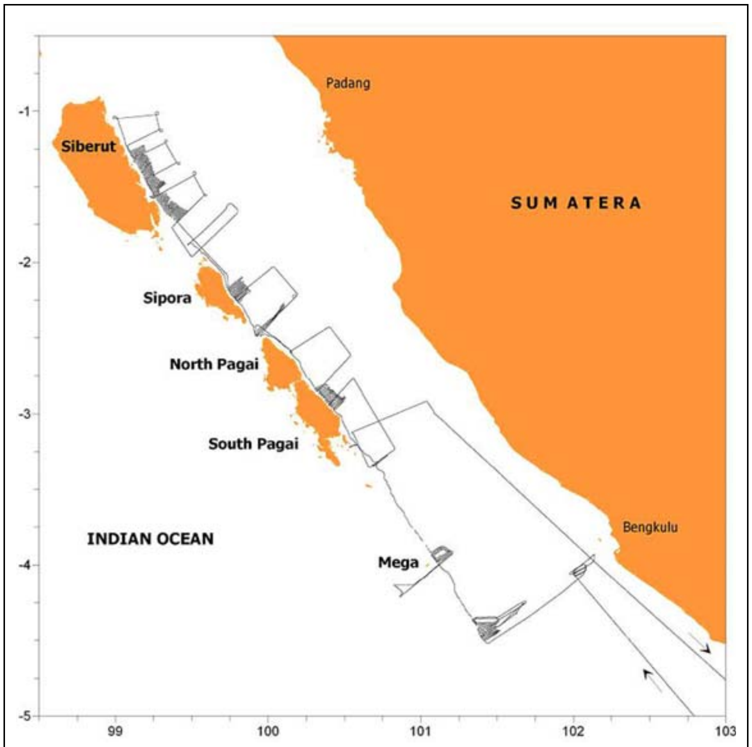


Figure 3. The PreTi-Gap 2008 Marine Survey at the NE margin of Mentawai Islands, Sumatera. Arrow: transit line; Line: seismic survey and polyline: bathymetry survey area.

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 4c) and covers most of the NE margin of South Pagai Island from 100 to 1100 m water depth. In general, morphology in this area shows two slope breaks at 450 m and 880 m water depth. The first escarp is about 15°, cut by a narrow and deep valley in NNE direction. The first foot of slope, are characterized by a wide, circular and elongated valley that indicates the 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 the loose sediment materials go down to the deep basin through these canyons. Therefore the seafloor covered by fine and loose sediments.

Further north, the water depth is shallower, about 50 m, around the eastern of Sipora Island at box (14 km by 14 km, Figure 5a). The bathymetry feature shows three slope

dominated by erosive canyons down to 700 m water depth. Below this 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 4b), where the morphology is almost similar to the Epicenter bathymetry. It is flat and has a smooth morphology, possibly consists of carbonate platform down to 150 m escarpment. Below this depth, dominated by homogeneous morphology and extensive canyons. The shallow water (50 m) on the plateau in this area suggests that the plateau has subsided (uplifting) relatively towards the epicenter region in the recent past. As before, the canyons are very extensive below this depth.

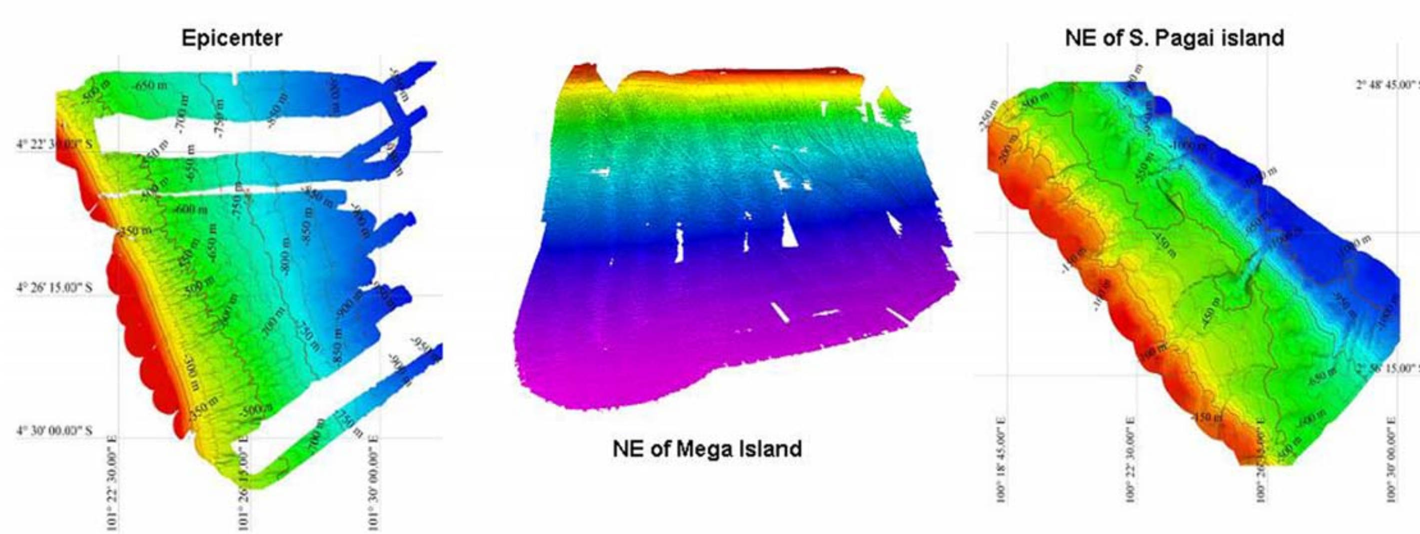


Figure 4a (left). Bathymetry features of Epicenter area; (4b, middle) Mega Island area and South Pagai area (4c, right. Red color is shallow area and close to coastal area.

breaks at 550 m, 850 m and 950 m water depths. Seafloor morphology is characterized by a smooth gentle escarp at 130 m water depth and it has 30° slope. 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, parallel to the north direction ridge at 650 to 700 m depth. The valley continues to the deep sea through a wide, deep and rough valley at 850 m depth (second slope break), whereas circular feature which indicates the unstable mass presence. A smooth seafloor appears at 550 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 45° slope bounds a second slope break and the seafloor more than 1000 m water depth.

The bathymetry area of eastern Siberut Island is 63 km by 12 km (Figure 5b). 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 5., at 1º17'S, 1º33'S, and 1º 37'S. Generally, the bathymetry in this area could be differentiated into four types. First type is the shallowest area 50 up to 200 m water depth as carbonate terrace due to sea level change (subsidence and or sea level rise) or back thrust. The morphology is flat, smooth without erosion features. Partly, the hilly or ridge morphology is parallel to the islands and it is possible carbonate cover present down to 200 - 250 m water depth. Below 200 m, it is observed a steep scarp, 200 - 400 m high, intensively cut by canyon mostly perpendicular to the island or NE direction. The first slope break occurs at different depths from south to the north at 600 m, 700 m or 550 m. At foot of slope between 600 m and 850 m water depths is characterized by smooth and undulating morphology. Some parts, the foot of slope, in the southern part (1º37'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 mass wasting or 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 the sea floor.

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 strike-slip faults accommodating slip partitioning between normal trench and parallel trench components. However, we suggest that these faults and folds are related to back thrusting instead. Our result suggests the Mentawai fault has combined strike slip and back thrust faults. Detail paper on seismic result was published by Singh et al. (2009).

DISCUSSIONS

The present shallow, flat, smooth seafloor morphology of escarp and extensive canyons at depth near 2007 earthquake epicenter and Mega Island suggest that the plateau is submerging and is tilted towards NE. It was confirmed by seismic reflection data (Lines 18 and 19) from the Sumenta cruise (1990), which shows homogenous morphology without any ridge morphology. The ridge or back thrust is covered by flat lying sediments suggesting that these are inactive faults. The difference features on the seafloor morphology between the 2007 earthquake epicenter and Mega Island compared to those on the Pagai, Sipora and Siberut Islands suggest that the seismicity locked zone, occur beneath northern

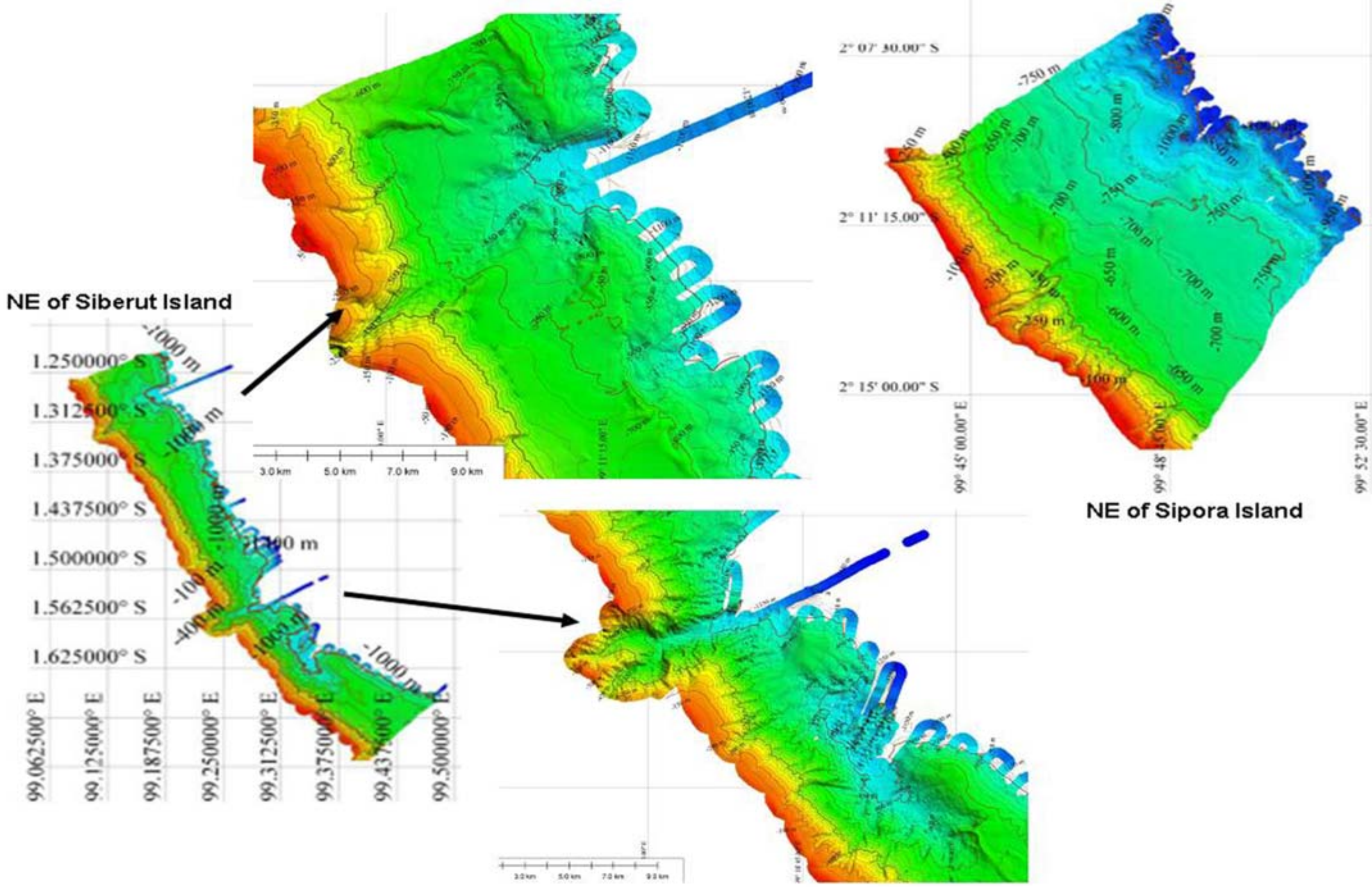


Figure 5a (right). Bathymetry map of Sipora Island and (5b, left and middle) is bathymetry map of Siberut Island. Red color is shallow area and close to coastal area.

the Mega Plateau (Singh and Permana, 2008; Singh et al., 2009).

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. This fact suggests an important landslides or mass wash out was occurred in those areas. The slope breaks or push-up ridges are mostly controlled by back thrust movement.

In the past, Mentawai faults have been interpreted as system of strike-slip faults by Diament et al (1992). They suggested this as 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 to 4 m and 300 m innondation. The low angle slip is responsible for local weak tsunami in Bengkulu (Natawidjaja, 2007). Fortunately, the September 30, 2009 earthquake did not trigger a tsunami and believe no vertical movement or very low slip was caused by quake.

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 localized back thrust or landslide.

A very large extend of mass wasting or landslide observe at NE of the Siberut Island. The scars of these mass wasting looks fresh and it is possible that the 1797 tsunami was generated by a massive landslide due the 1797 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 Sumatera 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. It may produce localized large tsunami causing damages to Sumatera 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 Sumatera. Also is very important to re-map the bathymetry along the basin from western Sumatera to southern of Java. Figure 6 shows propose site for tide gauge or buoy to detect tsunami related submarine landslide. All of the hardware plan must also combine in parallel with public education on natural hazard awareness and preparedness to people who live along the western coastal of Sumatera.

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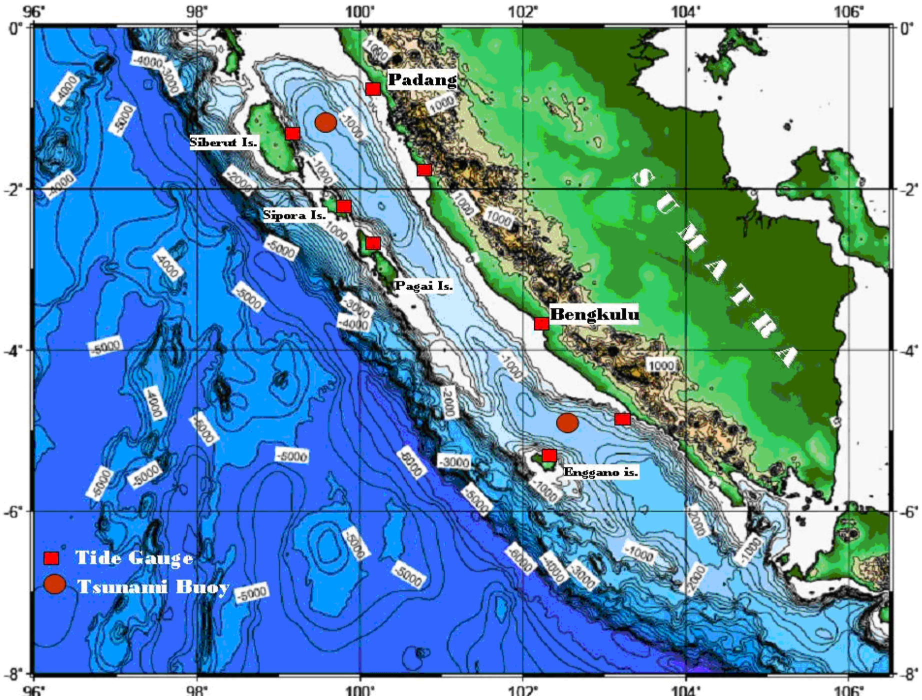

Figure 6. Propose site for tide gauge and tsunami buoy at Mentawai Basin

deliver to Foreigner Research Permit Bureau, Ministry of Research and Technology and also Ministry of Defense to make the survey is possible.

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