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TOPOGRAPHIC CHANGES AFTER 2004 AND 2005 EARTHQUAKES AT SIMEULUE AND NIAS ISLANDS IDENTIFIED USING UPLIFTED REEFS

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ABSTRACT

Research on the topographic changes due to Aceh earthquake, December 2004 and Nias earthquake, March 2005 was carried out at Weh, Simeulue and Nias islands from end of July until August 2005. The topographic changes were measured based on the present position of uplifted coral reefs with geodetic methods. Research results shows northwest part of Simeulue Island uplifted 1.55 up to 1.60 meters after earthquake on December 2004 and three months later southeast part of Simeulue Island and northwest part of Nias Island uplifted 1.70 up to 2.70 meters due to earthquake on March 2005. The raised shallow water reef flats become new land and apart of previously shallowest reef slope become new reef flats.

Key word: earthquakes, coral reefs, uplift, Simeulue, Nias islands.

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INTRODUCTION

Topographic is a graphic representation of the surface features of a region or place indicating their relative positions (to the bench mark) and elevations (to the sea level). Deformation of the earth crust will always followed by sudden displacements both vertical and horizontal directions associated with the earthquakes events. Displacements in vertical direction then will change in elevation relative to sea level. The position of sea level in coastal area will form various coastal morphologies (beach ridge, sea notch, dunes) and coastal ecologies (mangrove, reefs, etc). The position changing of land relative to sea level can be divided into two geologic events, there are 1) transgression/regression which is sea level up and down relative to the land, 2) eustatic change which is land (earth crust) up and down relative to sea level (Schwartz 1982). Track record of sea level change then can be shown in their relics. Tjia (1996) used the relics of coastal morphologies and (Horton *et al.*, 2005) used fossils of mangroves to reconstruct sea level change during holocene transgression when the sea level was 5 meters above the present sea level. Coral reefs is one among those of relics which live in abundance in the research area. Corals are anthozoans, the largest class of organism within the phylum Cnidaria, comprising over 6000 known species. Corals make up the largest order of athozoans, and are the group primarily responsible for setting up the foundations of and building up to make the reef structures.

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Based on their shapes coral reefs can be classified more than six form, that are branching, digitate, table, foliose, sub massive, massive, cup etc. Corals grow in to two directions, vertically and laterally. Massive corals tend to grow slowly while the branching corals grow faster. Corals grow optimally in water temperature between 23^{o}C up to 29^{o}C in the high light penetration. Upward growing of the corals reefs can reach just the low water in the tidal cycle (Laly and Parson 1995), while downward growing can reach 70 meters depth (Barnes 1987, Laly and Parson 1995).

When the upward growth in to the low water of the tide cycle has been reached, the growth will change to the lateral directions (Zachariasen *et al.*, 1999, Yamano *et al.*, 2001, Piller & Riegl 2003 and Briggs *et al*,. 2006).

Due to environment limitation of the corals growth, the presence of the corals reef fossils has been used to reconstruct phenomena history to the past. Taylor *et al.* (1982), Jouannic *at al.* (1988), Zachariasen *et al.* (1999), Zachariasen *et al.* (2000), Briggs *et al.* (2006) and Konca *et al.* (2007) used the corals reef fossils to calculate the magnitude of land uplift due to tectonic activity. Gabioch *et al.* (1999), McLean & Woodroffe (1994) and Yamano *et al.* (2001) used coral reef fossils to reconstruct oscillations of sea level and evolution of coastline since a hundred thousand years ago and also Piller & Riegl (2003) used to study the Paleo-oceanography in Bali waters.

Based on the tectonic frame of the western Indonesian region, there is collision between Indian - Australian oceanic plate descending beneath the Southeast Asian continental plate. The descending plates are moving north–northeast in the subduction zone located along the Sumatera trench western offshore of Simeulue – Nias - Mentawai archipelago with relative velocity in the order of 60 - 74 mm/year (Zachariasen *et al.*, 2000, Briggs *et al.*, 2006). Simeulue and Nias islands are located just on the overriding plate while Sumatera dan Weh islands lie a few hundred kilometers from the subduction zone (**Fig.1**). The Sumatran Subduction Zone activity is marked by the high intensity and big earthquake. The giant earthquakes have also been recorded in this area occurred in 1833 and 1861 (Zachariasen *et al.*, 1999).

There were two major earthquakes in the waters offshore of Aceh during 2004 and 2005. The first earthquake occurred on December 26, 2004 and generated the destructive tsunami in Aceh and it surrounding was reported to measure magnitude 9.15 Richter scale. Previously U.S. Geological Survey reported location of epicenter was 50 km north of Simeulue Island. Later scientists viewed that this earthquake triggered the other earthquakes series at Andaman Sea (400 km northwest of Weh Island) (Briggs *et al.* 2006, McCloskey *et al.*, 2007) then generate waves radiated across the Indian Ocean. The height of waves reached 30 meters (in Banda Aceh), 12 – 14 meters (Thailand), 11 meters (Sri Lanka) and killing more than 283,000 people (Bell *et al.*, 2006). The second earthquake occurred on March 28, 2005 was reported to measure magnitude 8.7 Richter scale destroyed buildings on the land in Nias Island. Both of two earthquakes raised several islands including Simeulue, Nias and Banyak, pushed shallow water reef flats and its ecosystem to the present position of dried corals reefs spread along the coast. "ABC News in Science" April 13, 2007 reported that after Aceh and Nias earthquake, Simeulue island raised 1.2 meters. The research discus how high the coastal zone tilted after earthquakes.

MATERIALS AND METHODS

Research activities divided into two locations, the first locations was carried out at Sabang Bay, Weh Island which is none lifted area after earthquakes (**Fig.1**). Instruments used at the Sabang Bay are tide

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gauge to record tidal movement and wood measuring stick to be used to measure the targets. Targets are head corals (table corals, stony corals or micro atoll) especially from the *Porites* genera, which the upper part shows black color of turf algal cover. *Porites* is used in the research except widespread and easily found, it has smooth surface hence when the wood measuring stick put it on will give high accuracy than the others genera. Algal covers indicate that upward growing is terminated and die while the lower part is still growing to the outward. Such phenomena can easily be found at nearest to the coastline and at the reef crest area. Mean Sea Level calculation based on harmonic constant over hourly interval of 20 days tidal data. The average depth under mean sea level of shallowest living corals over 25 targets are used as a *constant value.* The constant value means the minimum depth of survival of corals under Mean Sea Level by self growing upward. When the constant value reached, upward growing of corals will terminate and change to outward growing (**Fig.2**).

The second locations are at Simeulue and Nias islands as for lifted areas after earthquakes. Instruments used for these areas are geodetic instrument (leveling - Sokhiza type B2C), rods / staffs, global positioning system and tide gauge. Geodetic instrument is used to measure distance and height deference between targets and the benchmark. Distance and height difference among benchmark, points, targets and water level position at measuring time, the coastal profiles can be drawn, height of targets to both the water level at measuring time and to mean sea level can be calculated. Calculation of Mean Sea Level is based on hourly interval over 20 days measurement of tidal data. Hence the magnitude of land uplift can be calculate by using with formula:

Magnitude of uplift = constant value + height average of targets to Mean Sea Level.

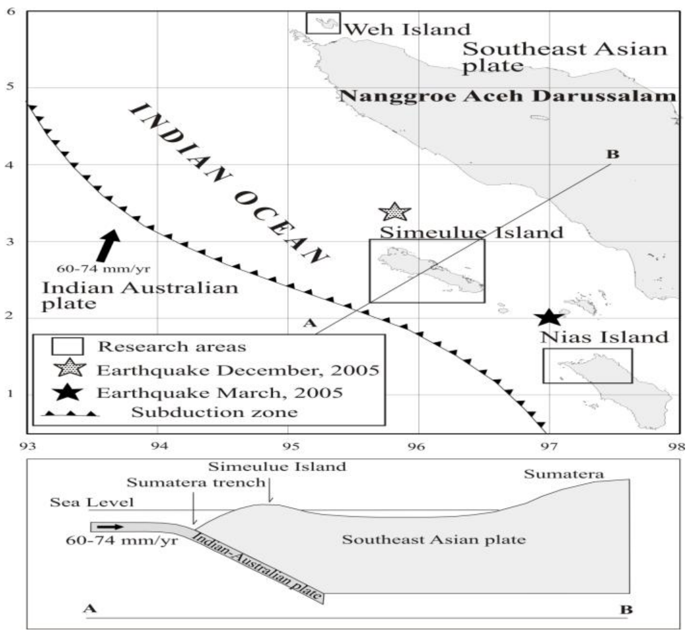

Fig.1 Tectonic map of western Indonesian region shows the subduction zone, motion of Indian – Australian plate and research locations at Weh, Simeulue and Nias Islands (upper). Cross section Indian - Australian plates subducts beneath the Southeast Asian plate (lower).

RESULTS AND DISCUSSION

Common morphology on the most reefs system can be classified into three divisions, from coastline to the seaward that are: reef flat, reef crest, and the reef slope (Barnes 1987 & Laly and Parson 1995). Reef flat is sheltered side of reef, various in width from several meters to more than hundreds meters with a few meters depth. This zone generally occupied by stony living corals, sandy formed of coral fragments and sea grasses, and some parts may be exposed at low tide. The reef crest is the highest point of the reef and it is exposed at low tide. The reef slope (common called fore reef) extends from low tide to more than 20 meters depth.

Sabang Bay located at Weh Island 30 km north of Banda Aceh classified as none lifted area after earthquakes. This bay facing to north, gently slope, suffered significantly less damage. Broken of branching corals are scattered over the land. Buried of living corals were found in many places especially in reef flats area. An interesting phenomenon found in the Sabang Bay was the up-lifted of 3 hectares mangroves plant with the roots hanging over the sea. Buried of living corals was cleaned by local people and start to recover. This is evidence that the damage at Weh Island was likely caused by the falling water in a breaking wave.

Death coral due to oceanographic phenomena such as increasing of water temperature and turbidity usually covers in wide area within the various depth and called *coral bleaching* (Barnes 1987, Lalli and Parson 1995). Death corals due to gradual self-growing upward can easily be identified especially through the stony corals. Upper part of death stony corals due to changing in gradual depth mainly *Porites* shows black color of turf algal cover, indicate the depth for suitable living is exceeded, the growing upward has terminated and changes to the outward direction (Barnes 1987, Lalli and Parson 1995, Zachariasen *et al.*, 2000). Depth measurement on such phenomena over 25 targets in Sabang Bay shows the average value *(constant value)* 1.10 meters below Mean Sea Level.

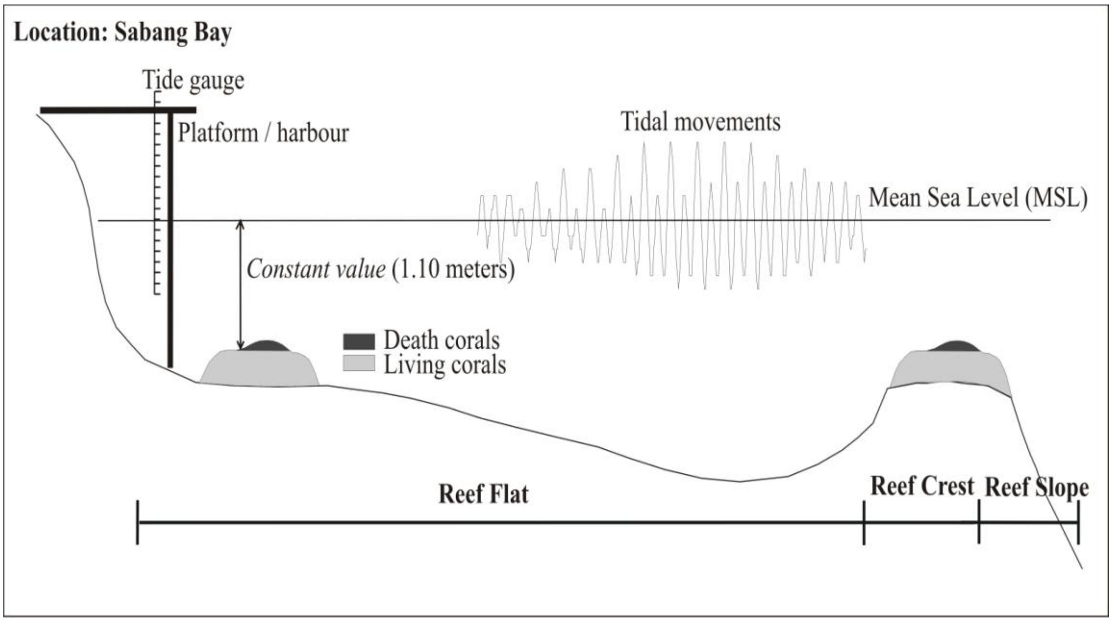

Fig. 2 Coral reef morphology and depth measurement for stony corals that growing outward at Sabang Bay.

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At Simeulue Island and Nias Island, earthquakes destroyed building in land and up-lifted several meters. Hectares of reef flats at Simeulue Island and Nias Island were up-lifted above the high tide resulting in total mortality of corals and other associated organism.

Based on analyzing of Landsat imagery recorded August 2000 over Simeulue Island showed coastal covers, reef flats (6407 hectares) and mangroves (3164 hectares) (**Fig. 3**). Reef flats at the northeast coast spread wider than the southwest coast, varying in width from 70 up to 700 meters. During the research there was dried coral with bad smell spread along the coast. Result of topographical measurements through the targets at several transect stations at Simeulue Island is shown in (**Fig. 4 and Fig. 5)**. The targets are stony corals especially *Porites* which shows outward growing pattern after the upper part is occupied by turf algal. Substrates found on the areas are dried seagrass and algal, sand with coral fragments and rubble of branching corals. This is suggested that the environments were previously reef flats area. From the position of targets on the coastal profiles, magnitude of uplift at Simeulue Island were varies in height. The southeast of island ranging from 1.70 meters up to 2.60 meters and at the northwest of island ranging from 1.55 meters up to 1.60 meters.

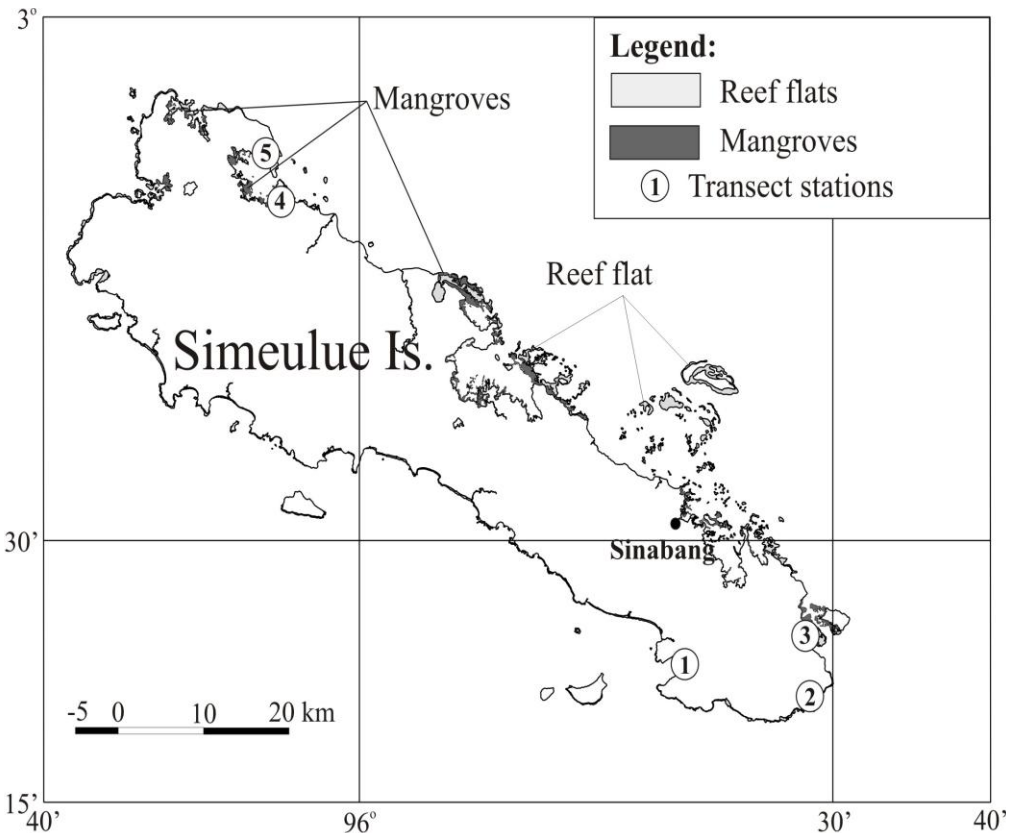

Fig. 3 Show coastal covers and transect stations at Simeulue Island, based on Landsat imagery recorded August 2000.

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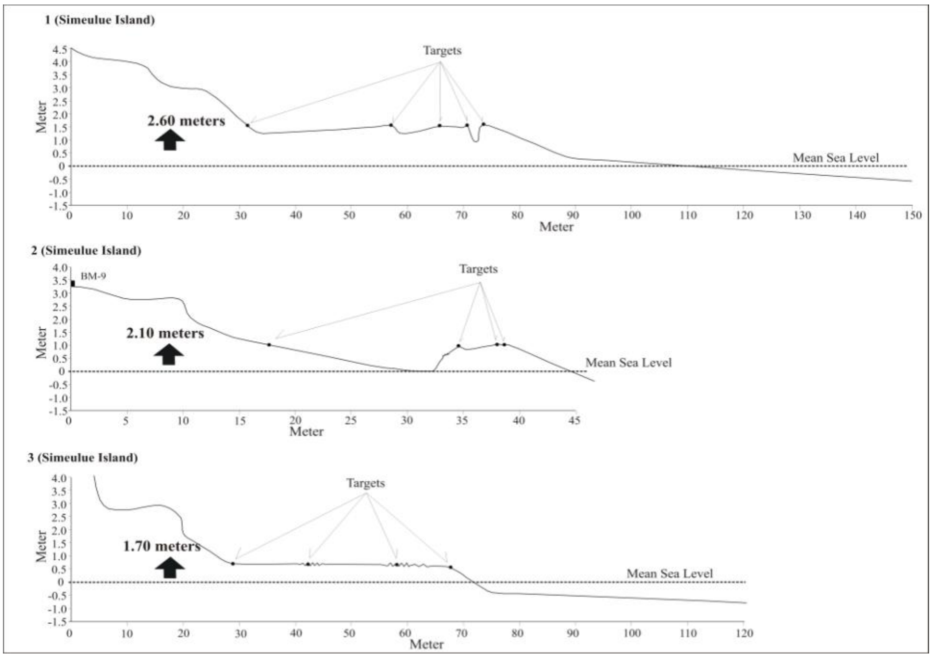

Fig. 4 Coastal profile collected at southeast part of Simeulue Island. The figure show the magnitude of land uplift range from 1.70 meters (lower) up to 2.60 meters (upper).

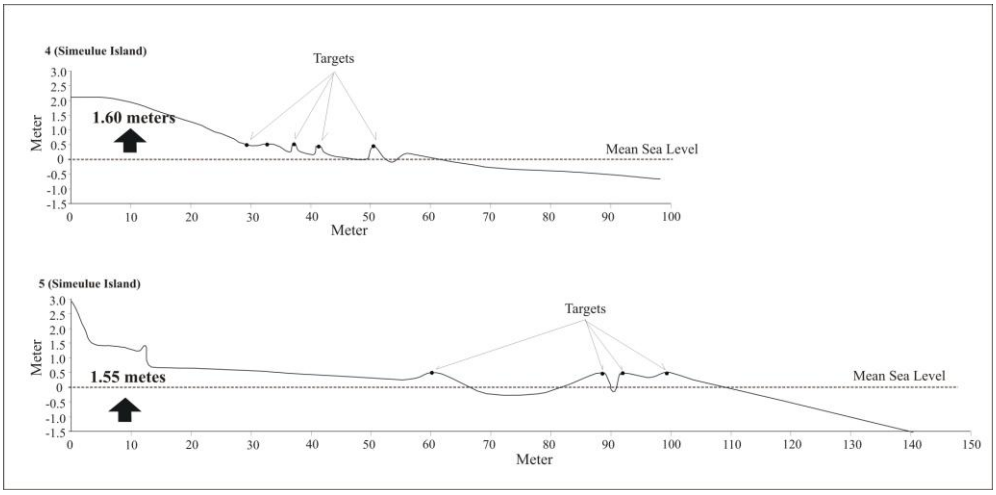

Fig. 5 Coastal profiles collected at northwest part of Simeulue Island. The figures show the magnitude of land uplift range from 1.55 meters (lower) up to 1.60 meters (upper).

Based on analyzing of landsat imagery recorded December 2000 over Nias Island identified coastal covers, reef flats (12073 hectares) and mangroves (1021 hectares) (**Fig. 6)**. Reef flats and mangroves spread wider at northwest part of island, reef flats at this area varying in width from 70 up to 1200 meters.

Topographical measurements on the targets at several transect stations at Nias Island is shown in (**Fig. 7**), where as the uplifted coral reefs near transect station 7 is shown in **(Fig. 8)**. The targets are stony corals especially *Porites* which shows outward growing after the upper part was occupied by turf algal. Substrates on this

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area are dried seagrass and algal, sand with coral fragments and rubble of branching corals. It is suggested that the environments was also reef flats area. From the position of targets on the coastal profiles, magnitude of uplift at northwest of Nias Island are varies in height, ranging from 2.50 meters up to 2.60 meters. No transect data carried out at southeast of Nias Island.

No research publication reported on land uplift after December 2004 earthquake. Based on the primary data collected it is still difficult to explain the relation between the two earthquakes in 4 months interval and land uplift.

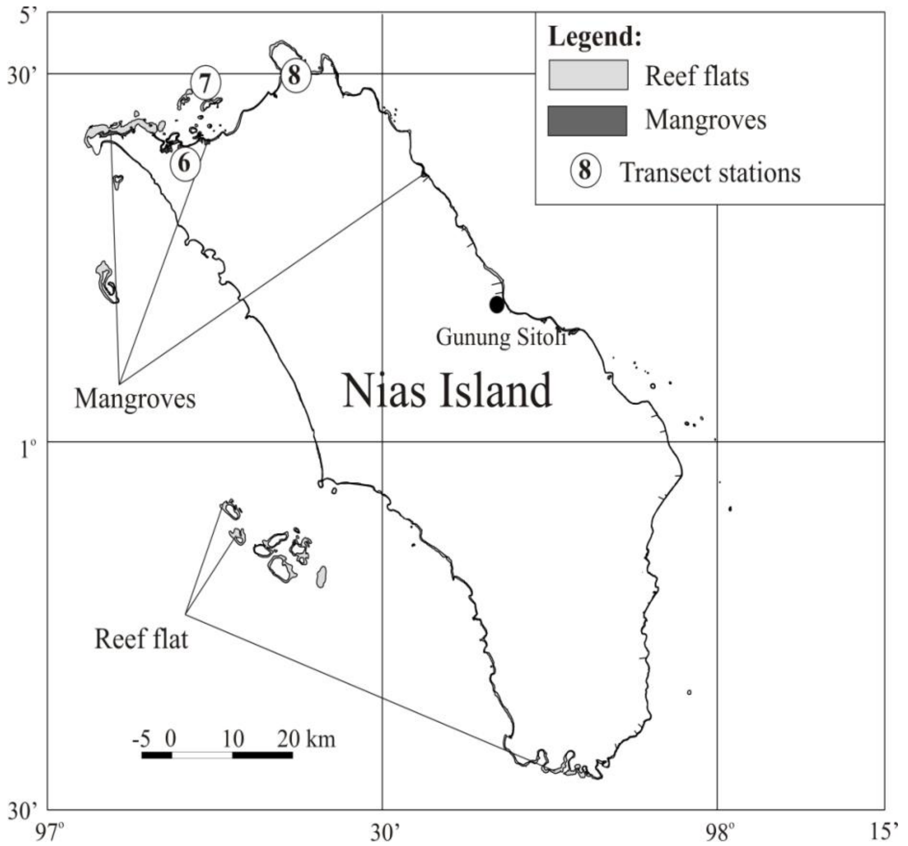

Fig. 6 Show coastal covers and transect stations at Nias Island based on Landsat imagery recorded December 2000.

Secondary data are information collected from the local people lives at Simeulue and Nias Islands. Simeulue Island people said that the island especially at the northwest part uplifted during the earthquake on December 2004 while people lives at Nias Island informed that the island was tilted after earthquake on March 2005. Based on these data viewed above suggested earthquake that occurred on December 2004 lifted the northwest part of Simeulue Island (1.55 meters up to 1.60 meters). Earthquake on March 2005 raised the southeast part of Simeulue Island (1.70 meters up to 2.70 meters) and the northwest part of Nias Island (2.60 meters to 2.70 meters).

The raised of shallow water reef flats at Simeulue Island (6407 hectares) and Nias Island (12073 hectares) had become new land and apart of previously shallowest reef slope become new reef flats. Mangroves condition at Simeulue Island (3164 hectares)

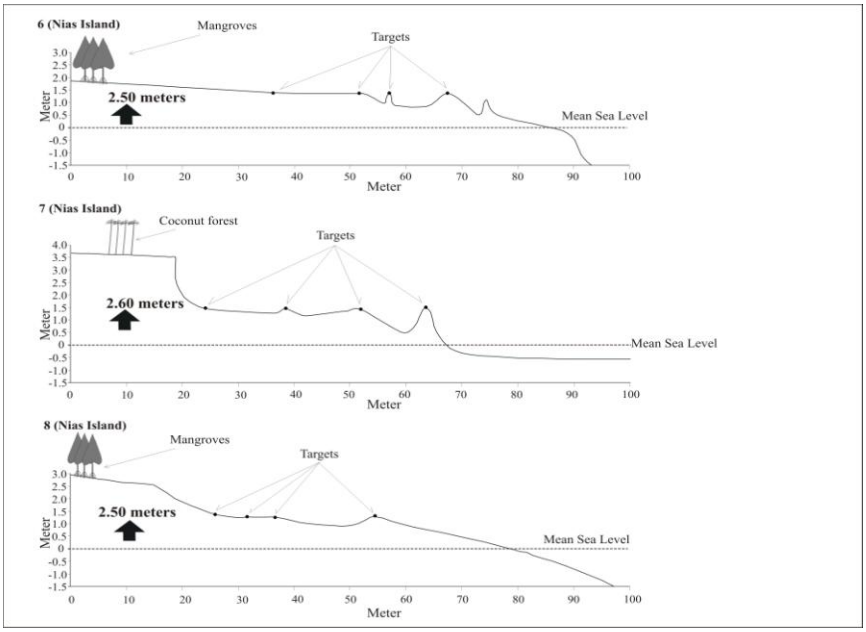

Fig. 7 Coastal profile collected at northwest part of Nias Island. The figures show the magnitude of land uplift range from 2.50 meters (lower) up to 2.60 meters (middle).

Fig. 8 Uplifted coral reefs near transect station 7 at Nias Island. Background in the photo is Baruna Jaya VII Research Vessel used in the research.

and Nias (1021 hectares) which previously growth at –0.70 meters up to + 1.25 metes to Mean Sea Level. After uplift the position of mangroves changes to 0.65 meters up to 3.85 meters at Simeulue Island and 1.80

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meters up to 3.85 meters above Mean Sea Level at Nias Island.

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