Seafloor Faulting and its Relation to Submarine Volcanic Activities Based on Sub Bottom Profiling (SBP) Analyses in Weh Island Waters and its Surrounding, Nangroe Aceh Darussalam Province

Pensesaran Dasar Laut dan Kaitannya dengan Aktifitas Gunungapi Bawah Laut Berdasarkan Analisis Profil Bawah Permukaan di Perairan Pulau Weh dan Sekitarnya, Provinsi Nanggroe Aceh Darussalam

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ABSTRACT: Sub bottom Profiling survey using strata box, a specially designed low penetration sub bottom Profiling (< 80 m) for coastal waters exploration, found out evidence of submarine volcanic activities in northern coastal waters of Weh Island, NanggroeAceh Darussalam Province. Gas bubbling could be observed at water columns of the digital sub bottom Profiling records as acoustic turbidity. There are at least 33 spots of volcanic gas bursts observed from the sub bottom Profiling. Examination of gas bursts at coastal area which show fumaroles and solfatara indicate reduce volcanic activity either at submarine or terrestrial. Identification of seafloor gas burst by diving team found out that center of such burst is occurred at a north – south opened lineation assumed as normal fault. It seems that the seafloor normal fault is the continuation of terrestrial fault of the same direction as observed from terrain earth google of Weh Island.

Key words: seafloor faulting, submarine volcanic activities, shallow sub bottom Profiling data, Weh Island Aceh

ABSTRAK: *Survei penampang bawah dasar laut (SBP) menggunakan strata box, suatu alat SBP penetrasi rendah yang didisain untuk eksplorasi perairan pantai, mendapatkan bukti-bukti aktivitas gunungapi bawah laut di perairan sebelah utara Pulau Weh, Provinsi Nanggroe Aceh Darussalam. Gelembung-gelembung gas dapat diamati pada kolom air rekaman digital penampang bawah dasar laut sebagai turbiditas akustik. Sedikitnya dijumpai 33 titik semburan gas volkanik yang teramati dari penampang bawah dasar laut tersebut. Pemeriksaan semburan-semburan gas pada wilayah pantai sebagai fumarola dan solfataramenunjukkan telah berkurangnya aktivitas volkanik apakah pada dasar laut maupun darat.*

Identifikasi semburan gas dasar laut oleh tim selam mendapatkan bahwa pusat semburan berada pada kelurusan berarah utara – selatan yang diduga sebagai sesar normal. Tampaknya adalah bahwa sesar normal dasar laut tersebut merupakan kelanjutan sesar darat yang berorientasi sama seperti teramati dari citra earthgoogle terrain Pulau Weh.

Kata kunci: *pensesaran dasar laut, aktivitas gunungapi bawah laut, data penampang bawah dasar laut, Pulau Weh Aceh*

INTRODUCTION

The area of interest, Weh Island coastal waters, is located at the northwesternmost of Great Sumatran strike-slip fault which is oriented northwest – southeast. This 1900-km-long and trench-parallel fault together with Mentawai fault offshore of west Sumatra (Diament et al., 1992) adapt an oblique convergence between the Eurasian and Indo-Australian plates through a significant amount of its right-lateral component. On the other hand, the Sumatran fault changes into spreading center of the Andaman Sea at its northwestern end (Curray et al., 1979); while in the Sunda Strait of its southeastern extremity, the fault bends to south direction to the deformation front (Diament et al., 1992).

Curray et al. (1979) also proposed that opening rate across the spreading centers of the Andaman Sea approximates about 37 mm/yr for the last 11 Myr, while the slip rate inferred for the Sumatran fault near its southern terminus appears to be 6 mm/yr. The latter data was obtained near the southern end of the fault from an offset channel incised into a dated Pleistocene tuff (Bellier et al., 1999).

Sieh and Natawidjaja (2000) found out that this Great Sumatran fault is highly segmented. They studied the fault using detailed topographic maps and stereographic aerial photographs along western coastal zone of Sumatra. At least 19 major subaerial segments had been identified with step overs cross-strike width between the segments usually many kilometers. Geomorphic offsets along the fault shows as high as 20 km represent the total offset across the fault which accommodates most of the dextral component of oblique convergence during the last few million years.

Sieh and Natawidjaja also found out that combined dextral slip on the Sumatran and Mentawai faults are no more than 100 km in the last few million years. This figure was based on their stretching analyses of the forearc region near the southern tip of Sumatra.Both authorspointed out that the geometry and character of the subducting Investigator fracture zone areaffecting the shape and evolution of the Sumatran fault system, especially within its central domain.

It seems that tectonic controlsthe submarine volcanism phenomenon in Weh Island waters – Aceh. On Sumatran land, the closest volcano SeulawahAgam, southeast of Weh Island, is located approximately at the same fault zone (Figure 1). According to Sieh and Natawidjaja (2000) the northern domain of Sumatran fault is characterized by a geometrically irregular fault above the 125 to 140 km subduction isobaths, a volcanic arc on and north of the Sumatra fault, a 1 to 2 km deep forearc basin, a very broad, structurally and bathymetrically complex outer-arc ridge, a homocline along its southernmost few hundred kilometers, and a very narrow inner trench slope.

The proximity of the Sumatran fault to the volcanic arc has been suggested by many authors (e.g. Fauzi et al., 1996; Tikoff, 1998; and Sieh and Natawidjaja, 2000). This due to the effect of magmatism on the lithosphere.

Faults such as the Sumatran fault that formed above the place of greatest strain gradient in the lower crust, according to Tikoff (1998), are occasioned by the magmatism of the volcanic arc. Current and ancient numerous small and large volcanic cones and calderas release step overs along the Sumatran fault (Bellier and Sebrier, 1994).

Relationships between Sumatran fault and young arc volcanoes are that : the average center line of the active arc is northeast of the Sumatran fault and the local center line of the young volcanic arc switches back and forth across the trace of the Sumatran fault along its 1650-km length of Sumatra (Figure 2). Mostly the volcanoes are located at 10 km separations and more from the fault, only two are more than 10 km southwest of the Sumatran fault. The average center line of the largest volcanic edifices is also situated approximately 10 km northeast of the Sumatran fault.

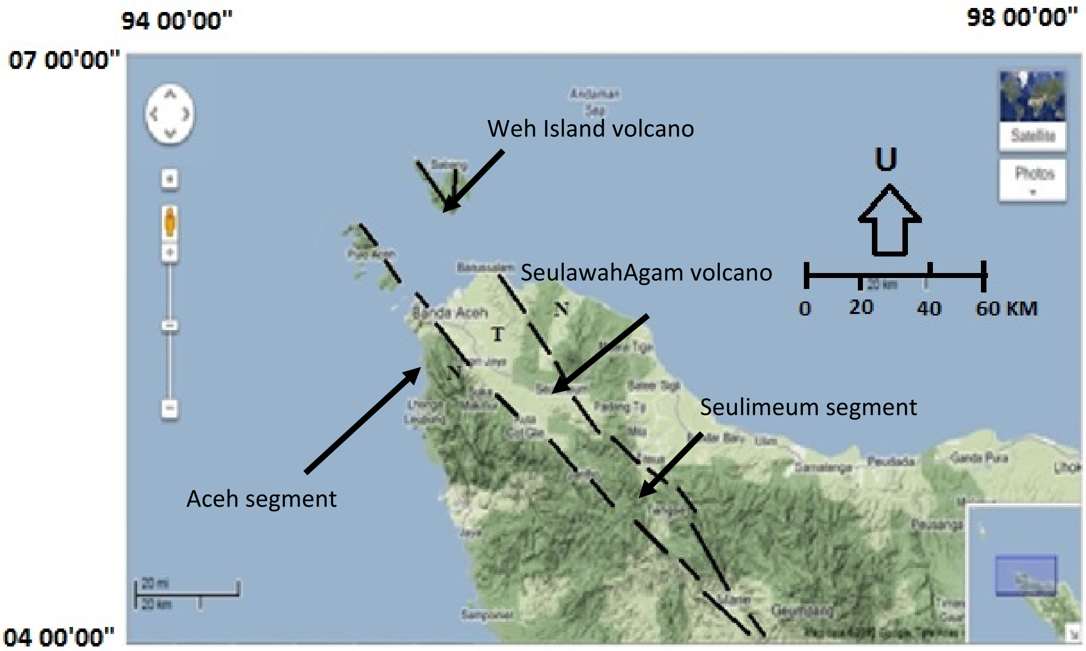


Figure 1. Regional fault zone of northern Sumatra traced from terrain earth google, which shows branching of Sumatran fault. Weh Island and SeulawahAgam volcanoes are located at approximately the same branching northwest fault of the Great Sumatran fault.Fault segments nomenclature, Seulimeum and Aceh, are derived from Sieh and Natawidjaja (2000) (Figure source: earth-google terrain).

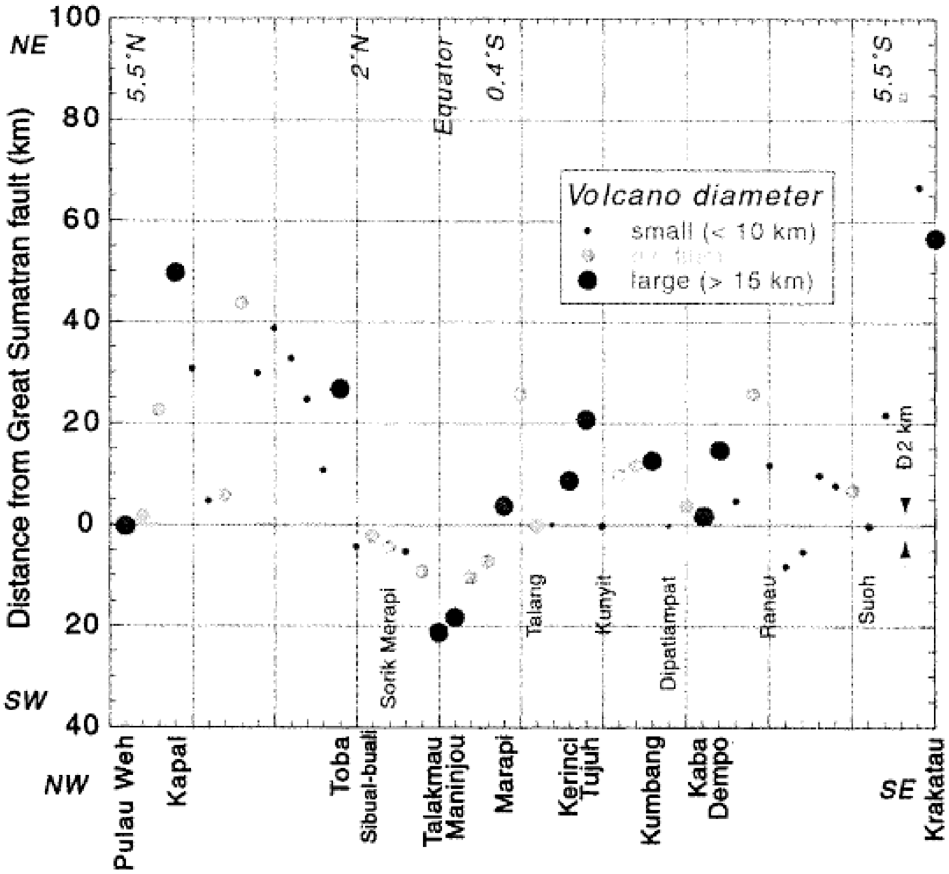


Figure 2. Volcanic centers plot from the Sumatran fault, which shows 9 of the 50 volcanic centers are less than2 km from the fault. Most of these 50 volcanic centers are associated with extensional right step overs of the fault (Source: Sieh and Natawidjaja, 2000).

The anomaly distribution of volcanoes relative to the Sumatran fault, according to our view is possibly influenced by existence of volcanic centers on tensional fault setting, not on compression state as supposed to main northwest-southeast Sumatran fault (Figure 3).

Bellier and Sebrier (1994) proposed that extensional pull aparts along the Sumatran fault have affected the location of the volcanoes. Only 9 of the young volcanic vents are located less than 2 km from the Sumatran fault, while from southeast to northwest: Kaba, Kunyit, Meleggok, Talang, Sibual-buali, SeulawahAgam and PulauWeh (7) are strato-volcanoes greater than 10 km in diameter. Mostly, the strato-volcanoes are located within dilatational stopovers.

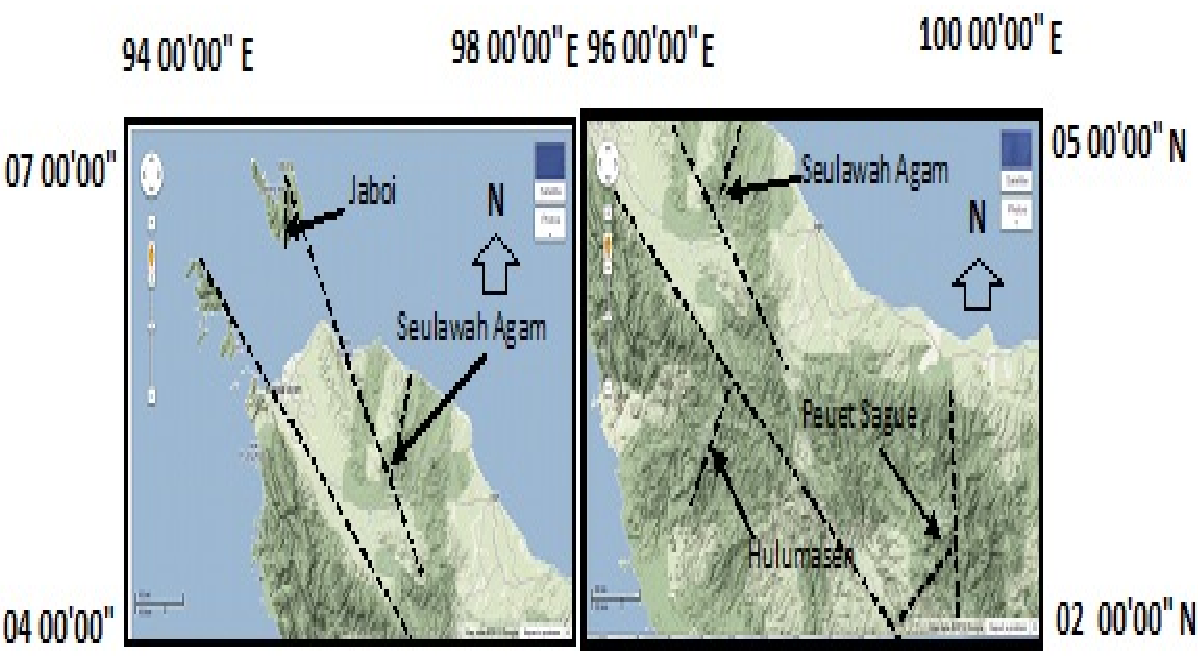
Sumatran fault on Aceh and Weh Island

Some authors suggest that Seulimeum segment of Sumatran fault (Figure 1) continues under water to Weh Island. Curray et al., (1979) and Curray (1999) support this view from bathymetric data; while other authors such as Peter et al (1966) and Weeks et al (1967) propose the continuation based on evidence of sub bottom Profiling reflection profiles. Geomorphic expression of faulting on Weh Island also back up the underwater continuation of Sumatran fault to the island (Sieh & Natawidjaja, 2000).

Masaaki et al (2013) in their study of Sumatran fault extension in Weh Island by measurement of gamma ray dose rate in theisland found out that there are two high radioactive level zones: one is in the east zone in accordance with structural lineation of Sumatran fault which is observed as valleys and erosion areas, and another is the central part of Weh Island. Masaaki et al was not sure of this another zone, even though geographically it looks like lineaments, nevertheless they noticed the existence of a fault line.

Volcanic arc and Sumatran fault

Fauzi et al (1996) and Tikoff (1998) noticed that the Sumatran fault has the proximity to the volcanic arc and suggested that the fault was formed because of the effect of magmatism on the lithosphere. We observed, mentioned above, that volcanic arc in Sumatra is in the tensional tectonic of the strike-slip fault; which take the



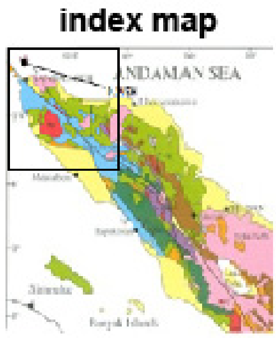


Figure 3. Main fault pattern of Aceh – Weh Island and its surrounding.Jaboias one of many volcanic centers at Weh Island is passed through by a north-south orientation fault. At Sumatra mainland, SeulawahAgam volcano is also passed by a rather northeast-southwest fault assumed as a normal fault (left), Hulumasenvolcano at the south of Sumatran fault occupies the same fault orientation, while PeuetSague volcano is at a junction between N-S and NE-SW faults (right) (Figure source: terrain earthgoogle).

form of normal faults of relatively north-south direction. The tectonic setting is possibly second order for this arc as their volcanism require ‘opening’ of the lithosphere for magma reached earth surface, while the strike-slip itself is the first order that accommodate oblique subduction of Indo-Australian Plate to the north, which also a habitat for compression tectonic.

Bellier and Sebrier (1994) have declared that many small and large volcanic cones and calderas along the Sumatran fault occur at both current and ancient releasing step overs, which is almost the same with our view mentioned above.

Sieh and Natawidjaja (2000) in their effort to test hypotheses of any relation between Sumatran fault and its volcanic arc, was using young volcanoes less than 100,000 years old; such as Toba caldera 73 ka (Chesner et al., 1991) and Maninjau caldera 60-90 ka (Nishimura, 1980). Utilizations of these young volcanoes are to overcome erosion problem especially for the old volcanoes that its morphology were not easily identified.

Sieh and Natawidjaja found out that: the average center line of the active arc is decidedly northeast of the Sumatran fault, and the local center line of the young volcanic arc switches back and forth across the trace of the Sumatran fault at its 1650 length (Figure 2). Mostly, the separations are 10 km and 25 km northeast from the Sumatran fault. Only two volcanoes are more than 10 km southwest of the Sumatran fault.

Sieh and Natawidjaja (2000) noticed that the southern part of Sumatran fault is located 100 to 135 km above the subduction interface, especially from about 6 S to the equator; while at about 3.5 N and 6.0 N (Weh Island included), the fault is situated 125 to 140 km above the subduction interface. The subduction interface was drawn on the top of the Wadati-Benioff zone, as defined by hypocentral locations in the International Seismilogical Center (ISC) catalog (Fauzi et al., 1996; Engdahl et al., 1998).

The segmentation of Sumatran fault according to Sieh and Natawidjaja (2000) appears to have influenced the rupture dimensions of historical large earthquakes and limited their magnitudes to 7.5.

Geology of Weh Island

According to Dirasutisna and Hasan (2007) Weh Island is a stratovolcano composed mainly of andesitic rocks. Field observation during MGI survey (Tim Sabang, 2012), Weh Island is mostly composed of andesitic and basaltic lava, and a few volcanoclastic rocks such as sandy tuff and laharicbreccias, and minor extent of coral reef, geothermally altered rocks and alluvium.

The geomorphology of Weh Island is mostly characterized by high reliefs of wavy mountain and steep hills formed by faults. The high reliefs are composed of andesitic lava, laharicbreccias and sandy tuff. While low relief morphology is spread at limited coastal areas, such as Sabang Harbor at the north, Gapang at northwest, and Balohanferry port at the south.

East side of Weh Island is observed an elongated mountain of southeast – northwest orientation, which is a morphology reflection of strike-slip fault belongs to Great Sumatran fault. Other morphology is north – south trend ridges which possibly represent normal faults.

Geothermal activities in Weh Island

Research on gravity anomaly for geothermal exploration in Jaboi – south of Weh Island by Suhanto et al (2005) found out that the geothermal activities due to the occurrence of fault. This result is the same with field observation during survey in 2012 by Marine Geological Institute (MGI). MGI team observed this phenomenon in coastal waters closed to Iboih north of Weh Island.

Agustanet al (2007) investigated the decrease of surface freshwater level on Aneuklaot lake after the great Indian Ocean earthquake and tsunami off the west coast of Sumatra in December 2004; they concluded that the decrease surface water level due faulting along the lake. Aneuklaotlake is located just north of Jaboi crater. Morphology observation of these two objects, they are located at the same north – south trending ridge assumed as normal fault (Kurnio et al., 2013).

METHODS

The method used for recognition of fault which assumed relates to submarine volcanic activities in the seafloor is firstly utilization of sub bottom Profiling data acquired during field survey in the second quarter of 2012. The sub bottom Profiling survey was using strata box, a specially designed low penetration sub bottom Profiling equipment *(lessthan 80 m sea depths)* for coastal waters exploration. Secondly, identification of volcanic bursts observed in the sub bottom Profiling records is also used as guidance for direction of faults. Thirdly, terrain fault pattern on Weh Island obtained from earthgoogle is also applied to direct offshore fault orientations, as the terrestrial faults have the tendency to continue seaward. Fault pattern analyses are also applied using strain ellipsoid (Anonim1, 2013); to find

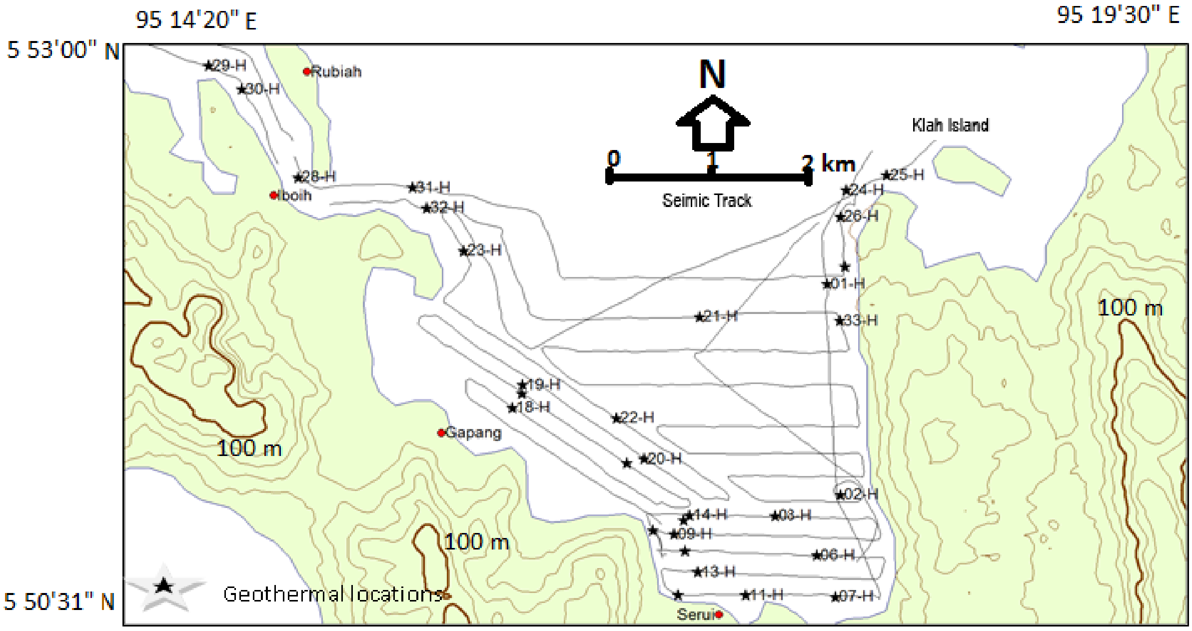


Figure 4. Geothermal locations identified from sub bottom Profiling records, at least 33 sites are recognized (Source: Tim Sabang, 2012).

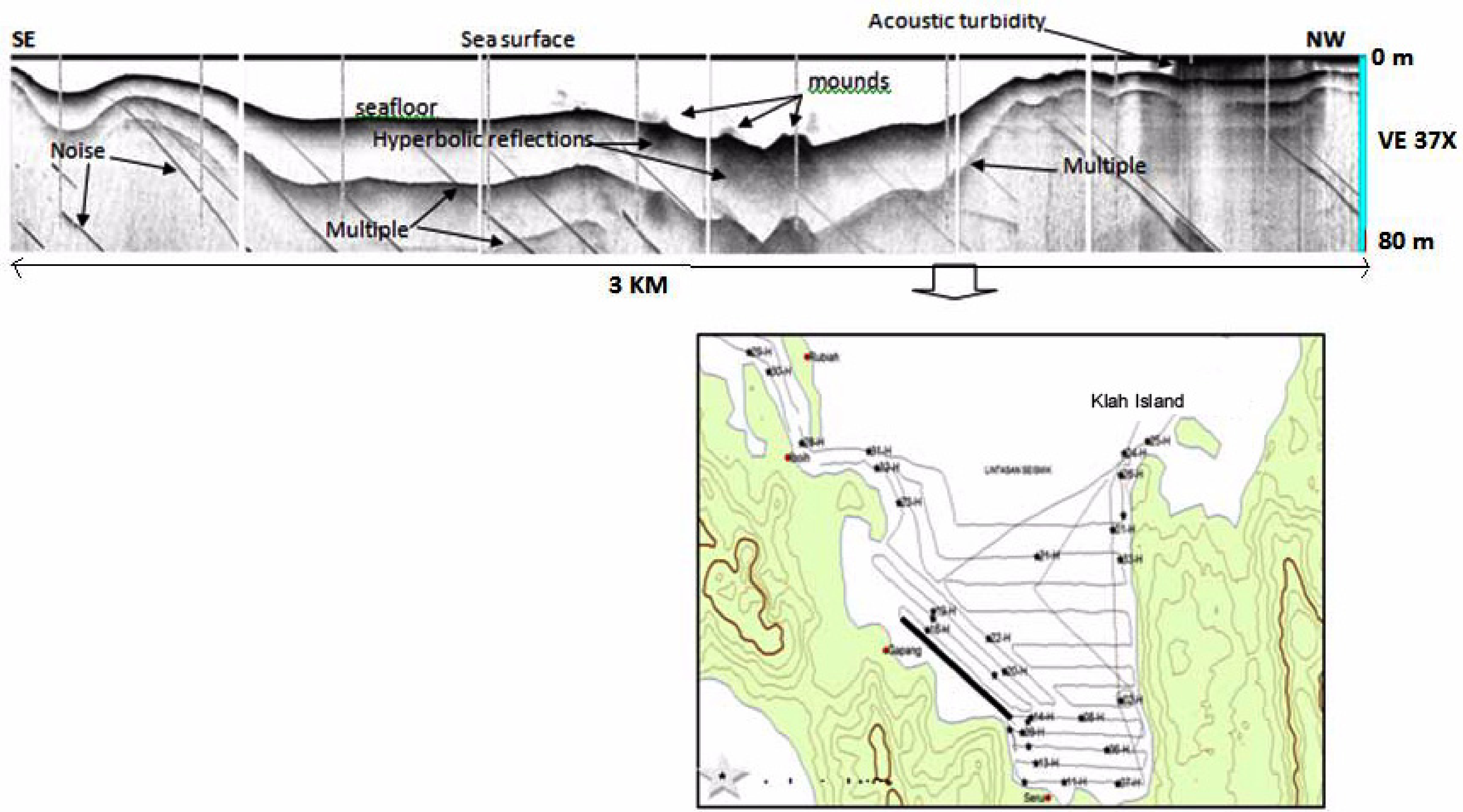


Figure 5. SBP record shows acoustic turbidity in sea water column (right) closed to Gapang due to intense submarine volcano activities. In the middle of the record is revealed three small mounds were just started to emit fumaroles. Hyperbolic reflections below seafloor mounds are indication of faults.

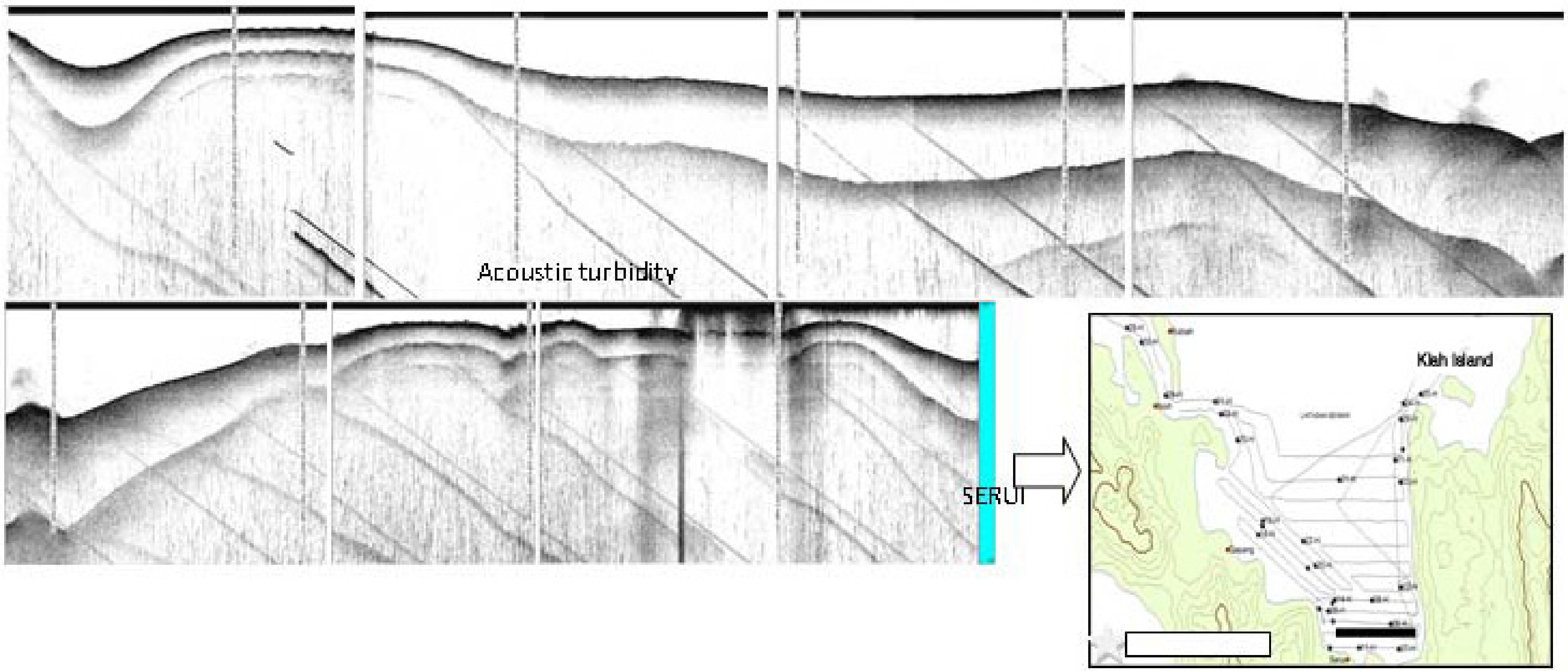


Figure 6. Another example of SBP record which shows intense acoustic turbidity in the water column. Location is in Serui shallow coastal water.

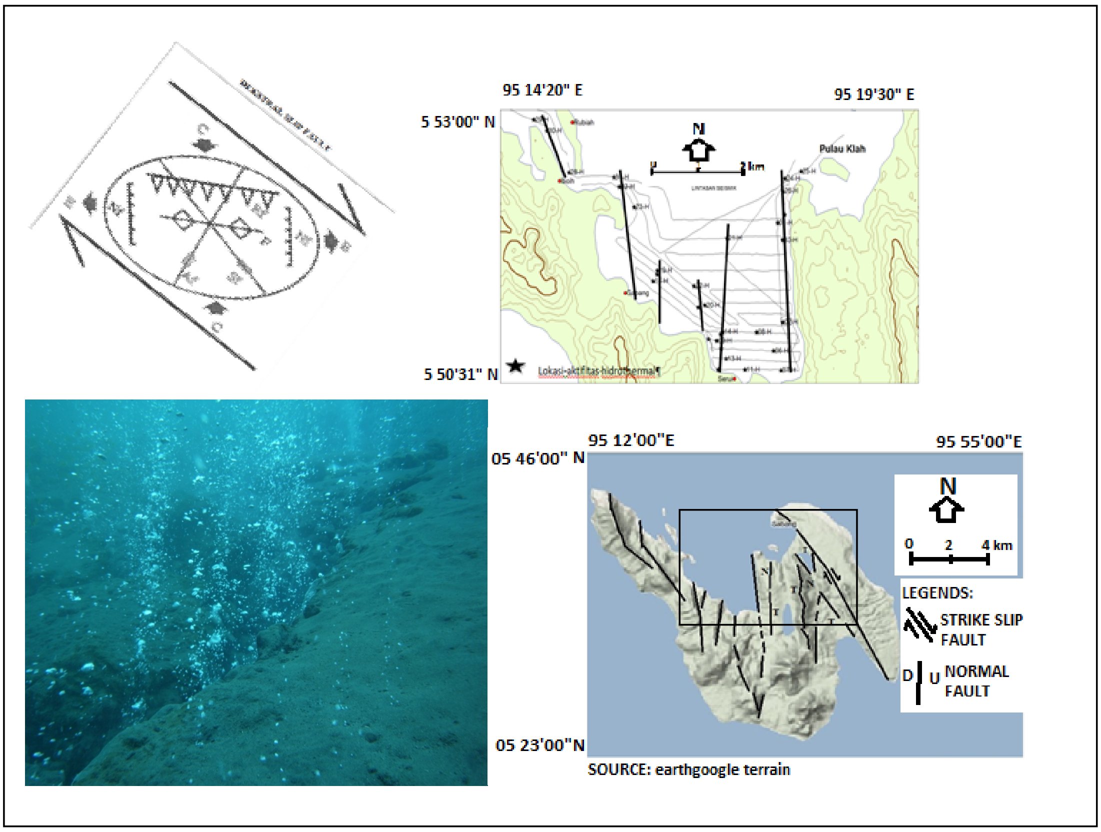


Figure 7. Analyses of faults in the investigation area.

out the scheme of each fault type and its orientation in the investigation area based on regional tectonic setting.

RESULTS

Analyses of sub bottom Profiling records had identified at least 33 sites of submarine volcano activities which generally influenced by faults (Figure 4). Mostly, the submarine volcano points are spread at coastal waters. The vast distribution of the points means that the eruption center is not concentrated in an area. The largest submarine eruption could be observed closed to Gapang (Figure 5). The identification of the volcano activities is through recognition of acoustic turbidity in the water column from digital sub bottom Profiling records (Figure 5). At Gapang coastal waters, the activity is so intensive that the water column was almost all blurred up by gas burst from the seafloor (Figure 5); and the sea depth in this site is approximately 10 m.

Upper left of Figure 7 above is the strain ellipsoid positioned to accommodate northward movement of Indo-Australia oceanic plate (C or compression stress);the strike slip (the opposite arrows) is parallel to and assumed as Sumatran fault; while normal faults are developed at either side of the ellipsoid (E) with direction north-south. Figure 7upper right shows fault pattern offshore drawn based on the occurrences of seafloor geothermal locations, directed by terrestrial fault mode (Figure 7 - right bottom) which shows north-south orientation. Left bottom of Figure 7is open seafloor lineation of north – south orientation assumed as normal fault which was observed by diver team. Normal fault interpretation was based on analyses as shown in the strain elipsoid above.

DISCUSSIONS

Faults that control the locations of seafloor geothermal are not the same orientation with the Great Sumatran Fault that directed to northwest – southeast which of a compressive state tectonic. The faults where seafloor fumaroles discharge gases tend to occur at tensional tectonic setting revealed as normal faults. These faults, based on analyses of strain ellipsoid as shown in Figure 7 upper left, tend to take place as north–south orientation fault. This opinion is supported by diver observation (Figure 7 bottom left) on the seafloor which demonstrated the orientation mentioned.

CONCLUSION

The study area is a submarine volcano of reduced magmatic activities. The reduced activities are through the occurrences of seafloor fumaroles which mostly distributed in the middle north shallow waters of Weh

Island. The fumaroles tend to develop at tensional tectonic setting characterized by normal faults.

Sub bottom profiling data used for recognition of submarine volcanic activities found out 33 gas bubbling spots derived from seafloor. The gas bubbling could be observed at water columns of the sub bottom profiling records as acoustic turbidity. The gas burst take place as fumaroles and solfatar, which indicate reduce volcanic activities.

Diving team observation on seafloor revealed that the gas burst takes place at north – south opening assumed as normal fault. The seafloor fault seems as the continuation of terrestrial fault from terrain earthgoogle.

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