

Review of Submarine Landslides in the Eastern Indonesia Region

Tinjauan Longsor Bawah Laut di Wilayah Timur Indonesia

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ABSTRACT: This paper reviews submarine landslide potential in the eastern Indonesia by analyzing published and recently acquired bathymetric data and interpreting seismic reflection data. This review aims to study and invent hazards that might affect seafloor infrastructure construction such as optic cables, especially in the eastern Indonesia Region. The hazards were also recognized as source of tsunamis such as Palu Bay 2018 and Babi Island north of Flores Island in 1992. On the other hand, submarine landslide is a common process of basin fill sedimentation in the region. As blessed with many active volcanoes, it has 130 of total the world 400, Indonesia should aware of tsunami induced by volcanoes especially the ones closed to the sea. There are five active volcanoes frequently produce tsunami in historical times: Anak Krakatau, Sunda Strait; Makian, Maluku Province; Sangihe, Sulawesi; Teon and Nila, Banda Sea; and Iliwerung, Lembata Island, east Lesser Sunda Islands.

Key words: submarine landslide, volcanic tsunami, seafloor infrastructure, eastern Indonesia

ABSTRAK: Makalah ini menelaah potensi longoran dasar laut di wilayah Timur Indonesia melalui analisis publikasi dan data batimetri yang baru diambil serta penafsiran data seismic refleksi. Tinjauan longoran dasar laut dimaksudkan untuk mempelajari dan menginventarisasi bencana yang mungkin bisa mempengaruhi pembangunan infrastruktur dasar laut seperti halnya kabel optic, terutama di wilayah Timur Indonesia. Bencana tersebut telah dikenal sebagai sumber beberapa tsunami seperti Tehuk Palu 2018 dan Pulau Babi utara Lombok di tahun 1992. Sebaliknya, longoran dasar laut merupakan proses sedimentasi pengisian cekungan yang biasa terjadi di wilayah tersebut. Dikarunia akan gunungapi terbanyak di dunia, sebab memiliki 130 dari 400 dunia, Indonesia harus menyadari bahaya tsunami ditimbulkan oleh aktivitas gunungapi terutama yang dekat laut. Terdapat lima gunungapi aktif yang sering menghasilkan tsunami dalam sejarah: Anak Krakatau, Selat Sunda; Makian, Provinsi Maluku; Sangihe, Sulawesi; Teon dan Nila, Laut Banda; dan Iliwerung, Pulau Lembata, Nusa Tenggara Timur.

Kata kunci: longoran dasar laut, tsunami gunungapi, infrastruktur dasar laut, Wilayah Indonesia Timur

INTRODUCTION

Eastern Indonesia is a very dynamic region on its geologic setting. It consists of many islands separated mostly by deep seas and influenced by interaction of three mega-plates of Indo-Australia, Eurasia and Pacific. The seas among the islands in historical times have experience geological hazards such as submarine volcano eruptions, tsunami and landslides (Yeh *et al*, 1993; Tsuji *et al*, 1995; Pelinevsky *et al*, 1997; Rynn, 2002; Brune *et al*, 2010; Lovholt *et al*, 2012; Yudhicara *et al*, 2015; Heidarzadeh *et al*, 2018; Paloksung *et al*, 2019 and Mutaqin *et al*, 2019).

As a country with 130 active volcanoes from the world total 400 (Mutaqin *et al*, 2019), Indonesia posed volcanic tsunami threat. In historical times, there are five active volcanoes that produce volcanic tsunamis: Anak Krakatau, Sunda Strait; Makian, Maluku Province; Sangihe, Sulawesi; Teon and Nila, Banda

Sea; and Iliwerung, Lembata Island, east Lesser Sunda Islands (Paris *et al*, 2014). Volcanic tsunami is another form of submarine landslide. This article tries to discuss submarine landslide and its possibility to destroy seafloor infrastructures such as cable optic.

Submarine landslide

Submarine landslides on open continental slopes are important processes for global sediment fluxes which also can generate very damaging tsunamis (Mason *et al*, 2006). Furthermore, Mason *et al* define that submarine landslides are sediment transport across the continental shelf into the deep ocean and these could take place on continental margins, many varieties of geological conditions and water depths.

Submarine landslide is initiated when the downwards gravity and other factors stress overcome the resisting stress of the seafloor slope material which

generating movements along concave to planar surfaces (Mason *et al*, 2006). It also can occur at planes as low as 1 and cause significant damage to life and property. Much greater uncertainty on preconditioning factors and triggers occur in submarine landslides due to difficulty in monitoring the events. Submarine landslides that take place in very low gradients is representing involvement of high pore pressures (Talling *et al*, 2014).

Harbitz *et al* (2014) found out that defining areas prone to submarine landslide is easier than predicting individual hazardous locations, dimensions and evolution. There are variety of processes and dynamics which include release mechanism and disintegration, mixing with water; depend on the triggering and the moving behavior (rheology) of the masses involved.

Violent earthquakes provoke smaller landslides rather than large landslides (Volker *et al*, 2011). Mostly, submarine landslides occur on the lowest slopes, due to larger sediment accumulation before its release. Volker *et al* (2011) compared bathymetric datasets before and after mega earthquake Mw 8.8 Maule 27 February 2010 offshore Central Chile and found out that no giant landslide occurred. From gravity core data, they observed that a pre-existing slide features took place until 700 to 1000 years ago which occurred as retrogressive failures at the slide wall. The smaller slides were triggered by aftershocks. Volker *et al* (2011) pointed out that frequent violent earthquakes at convergent margins do not create landslide that generate tsunami due to its small scale. According to Masson *et al* (2006) landslide head wall mostly take place on the mid-slope with its peak located between 1,000 to 1,300 m water depth; rather than on the upper slope.

Areas where fine-grained sediments prevail, submarine landslide frequently occur (Masson *et al*, 2006). The sediments are created by chemical weathering processes at tropical regions and their accumulations on continental slope promote landslide formation. Other subjects of landslides are submarine deltas and fans of large rivers especially deltas formed where rivers discharge sediment onto steep submarine walls.

The dynamic processes and flow regimes of a submarine landslide are depend on the mobilized sediment composition where clay to sand ratio is the key control parameter (Elverhoi *et al*, 2010; De Blasio *et al*, 2006). Clay-rich material remain compact and achieve very long run-out distances and high velocities on gentle slopes in the ocean, while increased sand content makes the flow less cohesive leading to internal particle segregation (Elverhoi *et al*, 2010). The finer clay and silt form an upper low-density layer, while the coarser material forms a lower sandy granular high-

density layer. Submarine landslide could also cause destructive effect, such as evidence in the 1998 PNG tsunami – Indonesia neighbor country in the east (Tappin *et al*, 2008).

Shigihara *et al* (2006) carried out hydraulic experiment in the laboratory how a landslide on a uniform slope causes the generation of a tsunami. They noticed that interaction between material and water is significant generating tsunami, while the continuous material flow makes tsunami wave period short. The experiments were numerically simulated using two-layer model of shear stress on the bottom and interface, and compared its results.

Akgun (2011) investigated landslide-induced wave in dam reservoir lake. Parameters used for the landslide material are internal friction angle and unit weight. Using these data, wave characteristics were calculated using empirical relationship. The wave characteristics include height, run-up and velocity. The obtained wave properties were used for a potential hazard assessment in vulnerable areas such as the highway in front of dam location. On the other hand, the dam itself is safe due to the distance from the landslide area.

Fine *et al* (2005) investigated a 7.2 M earthquake November 18, 1929 that triggered a large submarine landslide involving 200 km³ material in the Atlantic coast of Canada. The landslide was transformed into a tsunami consisted of turbidity current of mud and sand moving 1000 km eastward, breaking 12 telegraph cables and killed 28 Canadian people. The tsunami was also observed in the United States and Portugal – eastern part of the Atlantic with amplitudes 3 to 8 m and runup until 13 m along the coast. Simulation using a shallow-water numerical model results in reasonable agreement between computed and observed tsunami arrival times. Parsons *et al* (2014) also studied the source and progression of a submarine landslide and tsunami generated by the 1964 great Alaska earthquake at Valdez.

DATA AND METHODS

Bathymetric data was acquired along 2049 km ship tracks using Research Vessel Geomarin 3 owned and operated By Marine Geological Institute of Indonesia (MGI). It was conducted at 2018 in the program of systematic marine geological and geophysical mapping around Kai Archipelago Maluku Province. Equipment used was *Echosounder SyQuest Bathy 2010* frequency 3.5 kHz. Bathymetric resolution is 10 m on 1 : 250,000 map scale.

Multichannel seismic data directly was stored in SEG-D format during acquisition. Seismic data processing used IBM workstation software O/S Linux RedHet and ProMAX 2D 2003 version after field

survey finished. The seismic was applied Airgun supported by three compressors as acoustic source and streamer to receive signal reflected from subseafloor geological features. Seismic data acquired was the same length with bathymetry along 2049 km ship tracks while seismic penetration deep was 3.2 seconds.

Seafloor sediment was sampled using gravity corer (length 4.2 m and weight section 350 kg) operated at the back deck of Geomarin 3. Positioning was done when the corer touch seafloor. Total 25 seafloor sediments were already taken. All the samples were megascopic described and analysed grain size using sieving method.

On the other hand, study was also carried out through many relevant scientific publications and information gained via on line. Identification of current submarine landslide was recognized through multi-channel seismic records on its seafloor features such as blocky slump and slump deposits. The landslide was also identified through sediment core observation obtained during the cruise. On the other hand, paleo submarine landslide was identified through older sediment sequences.

RESULTS

Submarine landslides at Eastern Indonesia based on data acquired by MGI

Study on submarine landslides in the eastern Indonesia region is started with data acquired by Marine Geological Institute (MGI) itself using research vessel Geomarin 3. The data was acquired in 2018 surrounding Kei Archipelago East Maluku Province. The methods used are marine geology through sampling of seafloor sediments using gravity corer and geophysics applying multi-channel seismic, gravity and geo-magnetic method. Geological data discusses sediment especially relate to indications of landslide seafloor material, while geophysical data used to look for submarine landslide features is seismic.

Bathymetry of Kei Archipelago Waters geologically are controlled by karst high of shallow sea depth amongst Kei Islands in the middle, West Arafuru Basin in the east which is consisted of shallow platform with thick sediments and East Banda Sea in the west (Weber Deep) (Figure 1).

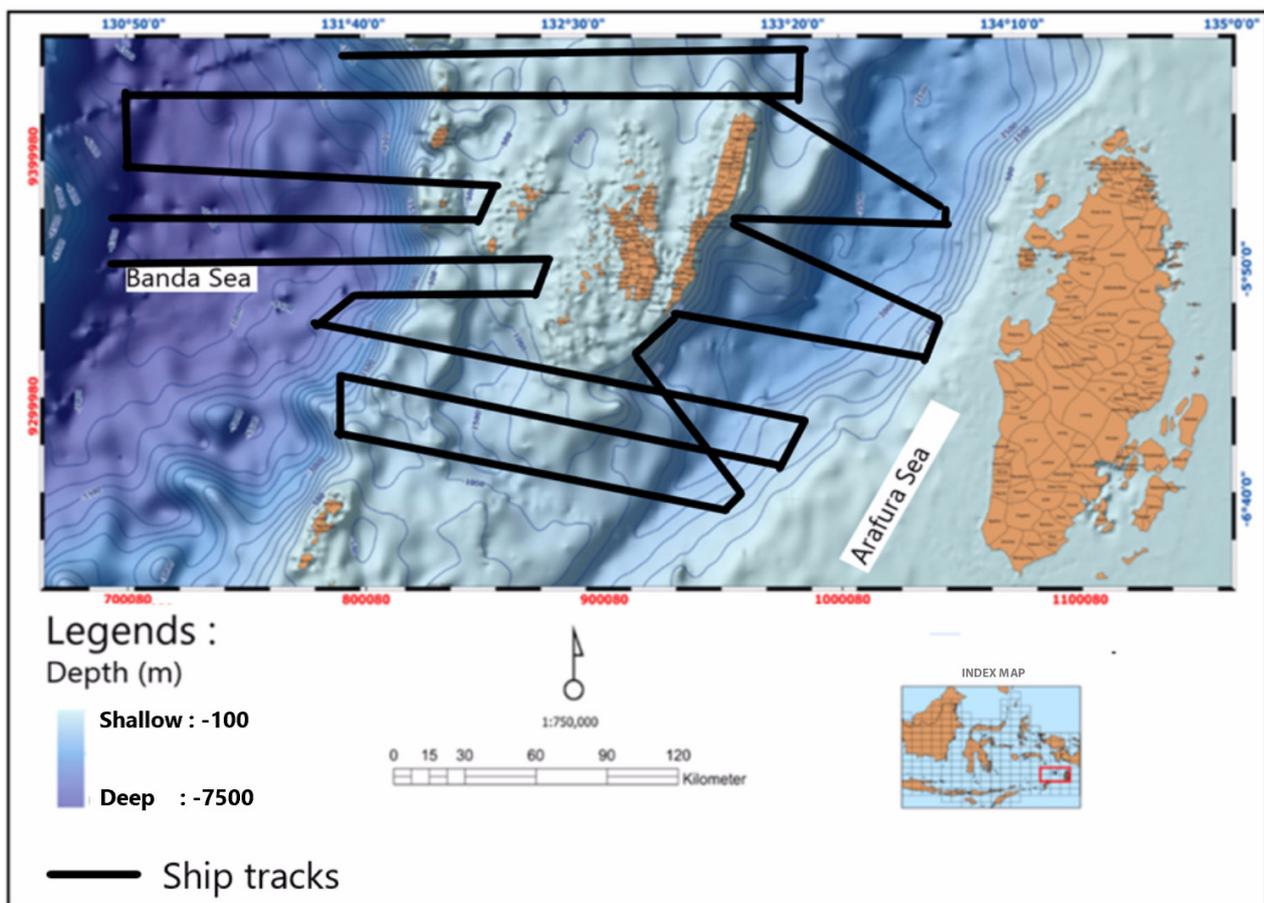


Figure 1. Bathymetric map of Kei Archipelago Waters from RV Geomarin 3 cruise. Ship tracks are shown. Data sources are: Marine Geological Institute of Indonesia (MGI), Agency for Geospatial Information, Center for Geological Survey and TOPEX 2018.

Figure 2 shows sea floor slope map in Banda Sea and Arafura Sea. The steep slopes are in accordance with steep morphology shown in seismic records (Figure 4) where some submarine landslides might occur. Steep slopes ($>50^\circ$) immediately west of the islands (Kei Archipelago in the middle and Aru Archipelago in the east) revealed geological control on its formation (Hartadi *et al*, 2015). The area is located at northwestern margin of the Australia Craton (Audley-Charles, 2004). The predicted landslide sediments on the steep slopes taken during field survey (Figure 2) are composed of mixed sizes from clay to gravel and distributed sporadically in the east and west of Kei

analyses 10 cm top sediment were sampled from the cores. Based on megascopic descriptions, sediments of Kei Archipelago Waters are consisted of dark grey sand, fine to coarse sizes, loose, rounded to angular grain shapes, moderate sortation, composed of quartz, rock fragments, mafic, mollusk shells and shells fractures; and dark grey silt, soft, composed of quartz, mafic, and rock fragments. Sediment classifications are based on Folk (1965).

Appearance of west Arafuru Basin in seismic records (Figure 4, small red square right side in the middle figure) shows thick sediment at fault scarp. According to Audley-Charles (2004) and Aldha and Ho

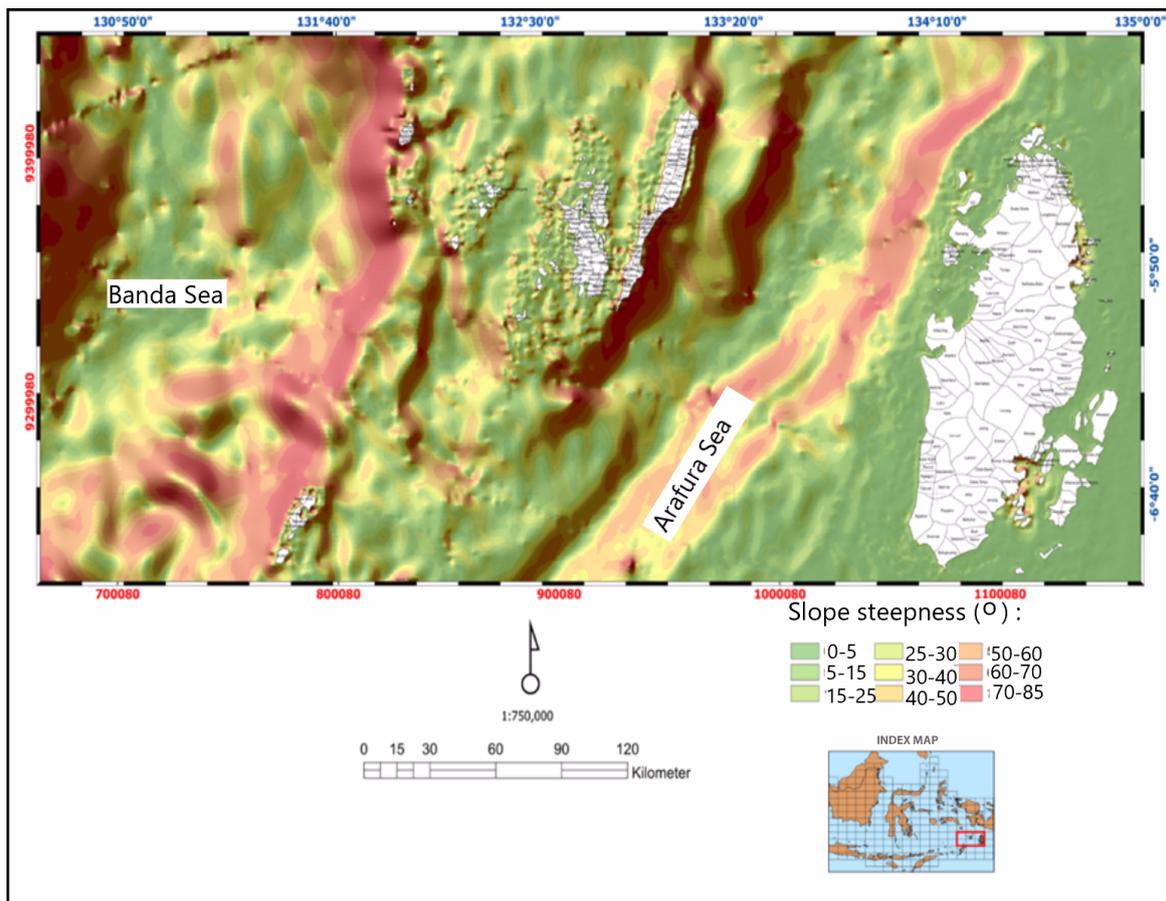


Figure 2. Sea floor slope map in the vicinity of Kei Archipelago shows steep morphology immediately west of the Archipelago and west of Aru Island in the east.

Archipelago (Figure 3), of sea depth between 234 to 668 meters and of slope seafloor morphology mostly 60-70°. They are consisted of gravel (5.91 – 15.85 %), sand (60.01 – 72.68 %), silt (9.42 – 22.4 %) and clay (4.06 – 8.97 %).

During field survey 25 seafloor sediment samples were taken using gravity corer which locations as shown in Figure 3. The sediment obtained has length from 22 cm to 343 cm in the cores and all had been megascopic described. For the purpose of grain size

(2008) this sediment is landslide materials occurred at post-rift phase in the south part of the basin. On the other hand, steep slopes were also observed in some seismic records west of Kei Archipelago (Figure 4, large red square in the middle). Slope angle of these scarps are mostly less than 30° . The blow up image from the eastern area represents East Banda Sea shown as depression bounded by Kai high in the east and southeast. Sea depth of this part approximately 3,000 meters.

Table 1. Grain size analysis of predicted landslide sediments.

| No | Sample No. (GM3-2018) | Percentage (%) | | | | Sediment Textures (Folk, 1965) | Sea Depths (meter) |
|----|--------------------------|----------------|-------|-------|-------|-----------------------------------|-----------------------|
| | | Gravel | Sand | Silt | Clay | | |
| 1 | KAI-01 | 10.48 | 65.49 | 18.40 | 05.63 | gravely muddy Sand (gmS) | 461 |
| 2 | KAI-13 | 15.85 | 65.75 | 09.42 | 08.97 | gravely muddy Sand (gmS) | 668 |
| 3 | KAI-17 | 05.91 | 72.68 | 14.77 | 06.64 | gravely muddy Sand (gmS) | 464 |
| 4 | KAI-20 | 13.53 | 60.01 | 22.40 | 04.06 | silty Sand (zS) | 234 |

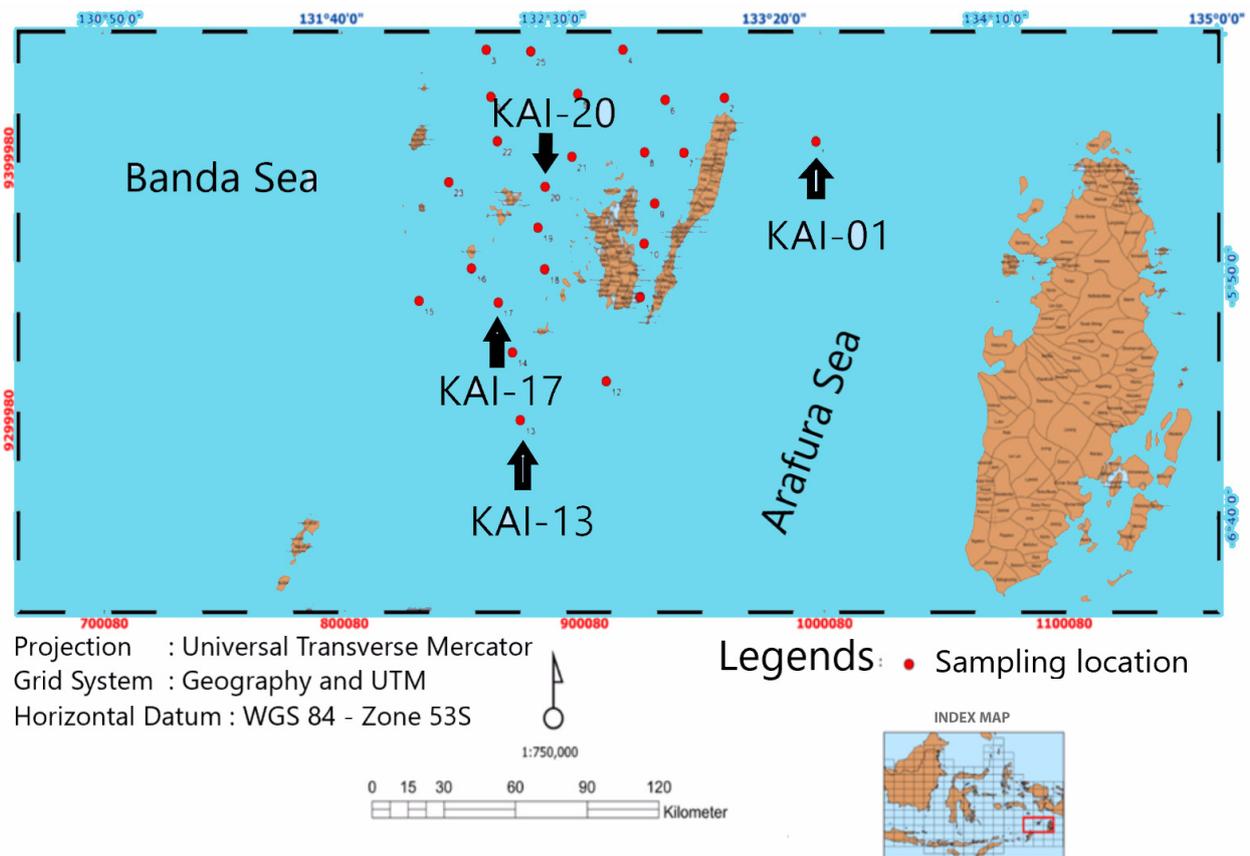
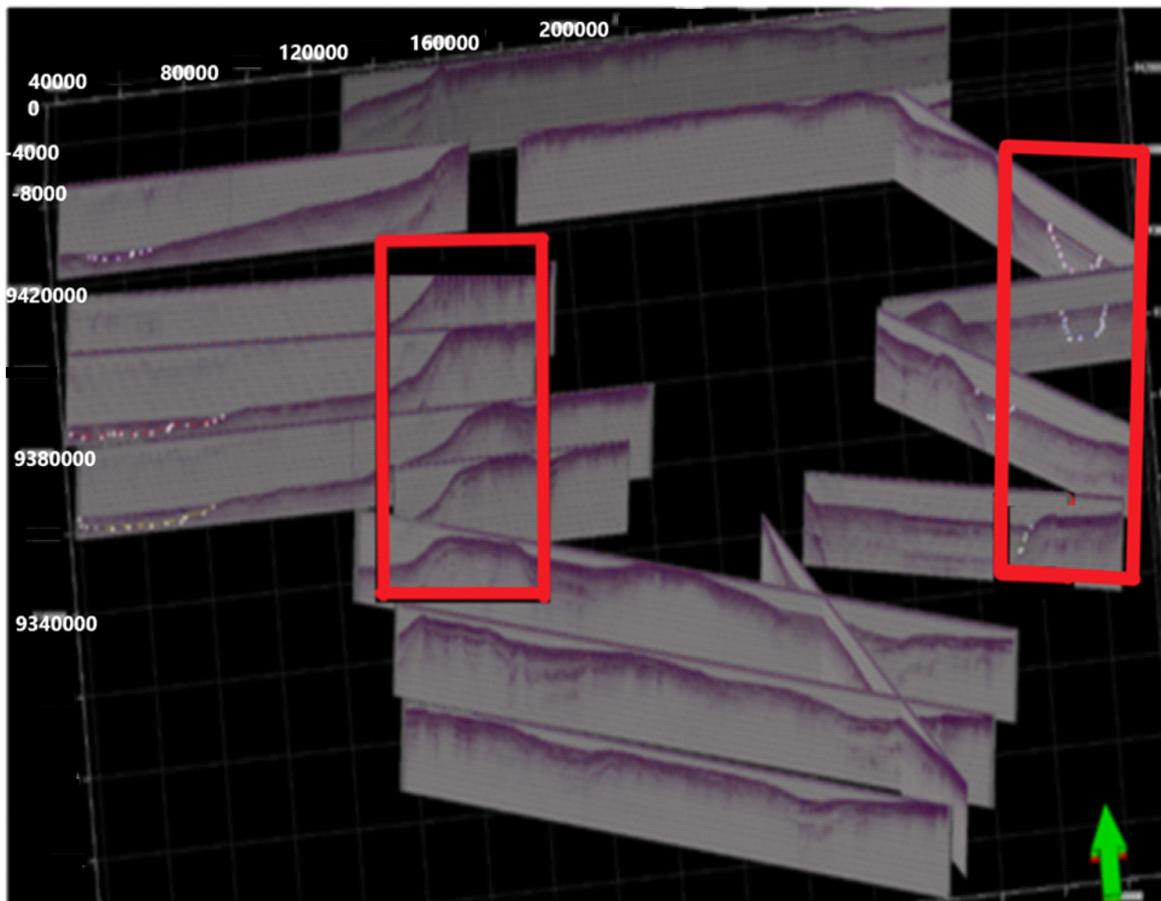
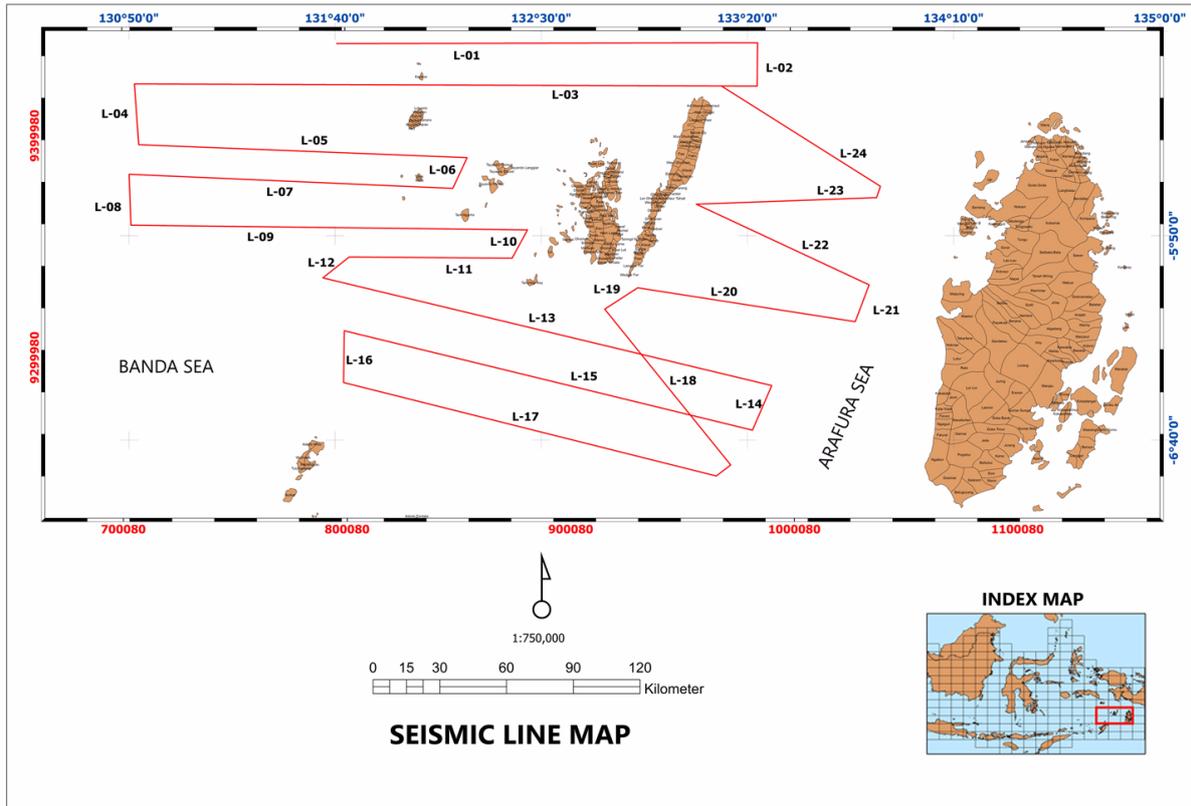


Figure 3. Seafloor sediment sampling locations in Kei Archipelago Waters and samples interpreted as landslide sediments (black arrows).



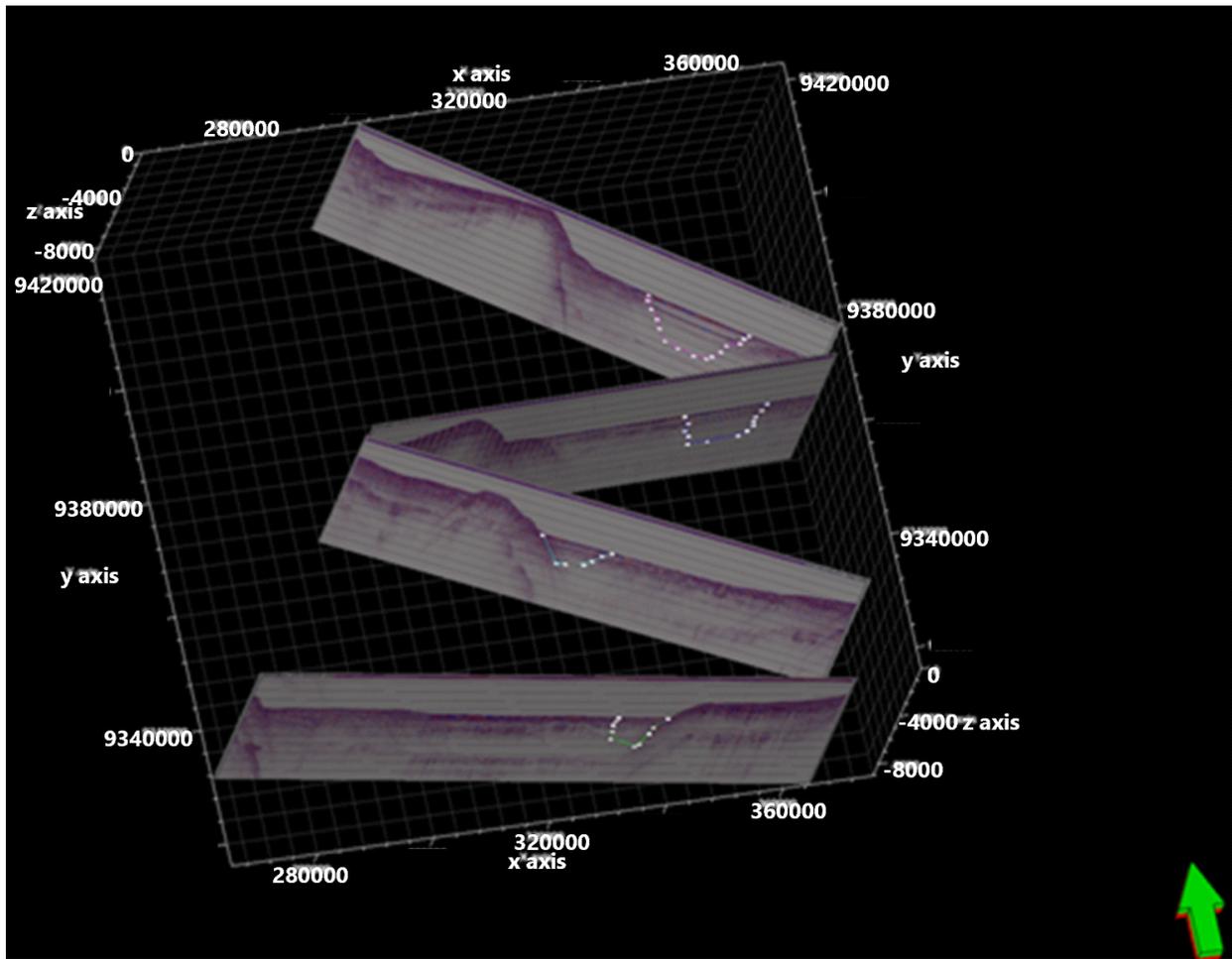


Figure 4. Seismic line map (above), seismic records acquired by Marine Geological Institute Research Vessel Geomar 3 in 2018 surround Kei Archipelago (middle) which shows steep morphology in the west as well in the east (red squares). and seismic blow up image represent the eastern area (below).

Another study of sedimentation was based on multi-channel seismic records obtained by Research Vessel Geomar 3 cruise in Aru Basin – west of Aru islands and south of Papua. In this study is found that the youngest sediment sequence, especially in the middle of the basin, is consisted of deep sea landslide debris and turbidite deposits at its lower slope. Seafloor sample observations on microscope of this debris show shell fragments, foraminiferas, mafic minerals and lignite (Kusnida *et al*, 2018).

In the past, between lower part Middle Pliocene until upper part Late Pliocene, as also observed from multichannel seismic records; the depositional framework of the sediment sequences show repetition of progradation typical of basin slope mass flow (Kusnida *et al*, 2018). According to Vail *et al* (1977) the landslide sediments were deposited at transgression phase as revealed from its seismic characteristics alternation of low to medium amplitude, continuous and wavy reflectors.

Northwest of Kai Islands and south of Bird's Head Papua, seismic reflection data interpretation was noticed sedimentation process at Seram Trough (Figure 5). The process took place as slumps and sediment fill. The slumps could take the forms of blocky slide and slump deposits. Blocky slide is a certain area of seafloor with blocky topography lay downslope from the head of landslides. According to Normark *et al* (1993) this feature has the possibility of giant landslide. Sediment core acquired shows gravitational movement deposit at the slope base triggered possibly by earthquake while at the central floor of Ceram Trough was deposited significant turbidites masses. The 210 length core was obtained from water depth 2320 meters and consisted of dark greenish grey soft sandy clay. Bioclastic clasts part of debris was found at core depths between 79 and 95 cm and it consists of carbonaceous materials, mafic minerals and stiff clay (Kusnida *et al*, 2016).

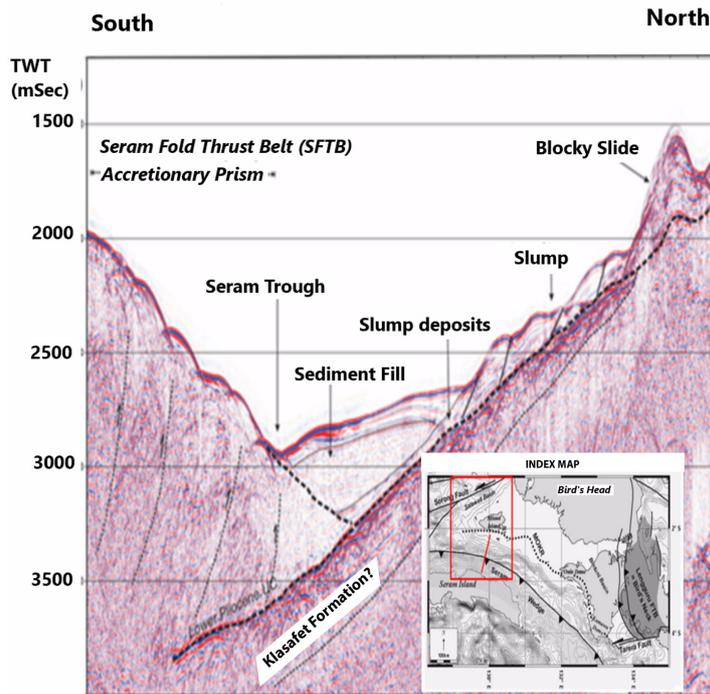


Figure 5. Seismic record south of Bird's Head Papua shows submarine landslides occurred as slumps in slope and sediment fill in the base of basin (Naibaho, 2013).

Submarine landslides at Eastern Indonesia based on published studies

On the other hand, based on literature study; tsunamigenic slope failures in Indonesian history have been observed many times. Moderate earthquakes

could trigger submarine mass failures that generate locally catastrophic tsunamis especially in the eastern region. Submarine landslides that generate tsunami in this area have been recorded by Brune *et al* (2010) and Lovholt *et al* (2012) as shown in Figure 6 and Table 2.

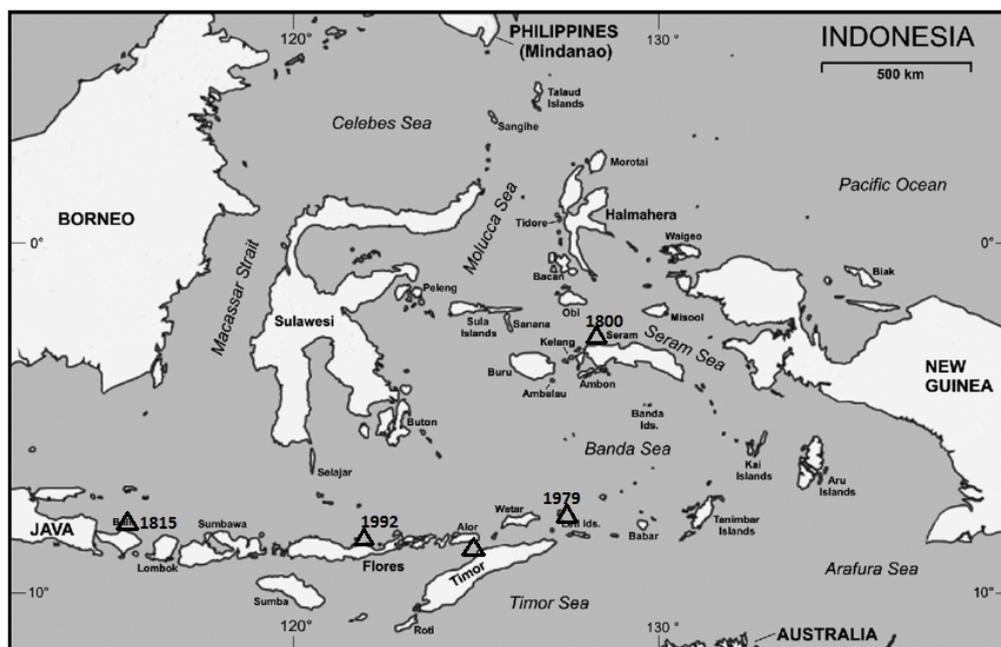


Figure 6. Locations of recorded historical tsunamis in Eastern Indonesia generated by submarine landslide (Lovholt *et al*, 2012).

Table 2. Historical tsunami in Eastern Indonesia generated by submarine landslide (Lovholt *et al*, 2012).

| YEAR | SOURCE | REGION | VICTIMS |
|------|-----------------------------------|-------------|---------|
| 1899 | Landslides | Banda Sea | 3730 |
| 1992 | Landslides and M7.8 Earthquake | Flores Sea | 2200 |
| 1815 | Landslide and M7.5 Earthquake | Bali Sea | 1200 |
| 1979 | Landslide | Flores Sea | 539 |
| 1871 | Volcano, Earthquake and Landslide | Celebes Sea | 400 |
| 1928 | Volcano and Landslide | Flores Sea | 128 |

Unfortunately, not all tsunamigenic submarine landslides are documented well.

The following Table 2 invents submarine landslides in Eastern Indonesia triggered by many factors such as excessive sedimentation, earthquake and volcano (Lovholt *et al*, 2012); while this paper tries to discuss the seafloor phenomenon based on literature study and interpretation of own data acquired during surveys using Research Vessel Geomarin 3 operated by Marine Geological Institute of Indonesia (MGI). MGI survey results especially interpretation from seismic records show that some areas potential produce submarine landslide that may generate tsunami, such as shown in Seram Sea – south of Bird’s Head Papua (Figure 4). In 1989 Large subaerial landslides have been observed in Seram Island. It was triggered by a magnitude of $M_s=7.8$ earthquake that generated a local tsunami (Brune *et al*, 2010).

Southwest of Seram Island, in northern coast of Flores an earthquake struck in December 1992 that killed over 1000 people in the island as well as 1000 due to the generated tsunami. Run-ups until 6m were measured in the coastal areas of Flores and Babi Island (Tsuji *et al*, 1995). Large run-ups found in east Flores (11-26 m) washed away house foundations. Brune *et al* (2010) explained that all tsunami waves were generated by rupture on two seismic faults, even though the largest run-ups could not be justifiable with such tectonic source model. Yeh *et al* (1993) pointed out that large landslides were produced by the earthquake. Their views on landslide tsunami hypothesis were supported by numerical modelling where the resulted wave heights similar to the measured values. Tsunami largest run-up behavior was also studied on the backward side at nearly conical Babi Island. Experiments either numerical or analog showed that these could be ascribed to tsunami wave splitting around each side of the island and collided at the back side directing to large run-up.

At first, a disastrous coastal mountain landslide was generated by a $M_S=7.0$ earthquake north of Bali in 1815. Then, It was followed by a tsunami when it reach

the shore that flooded and killing more than 1000 people at the surrounding area (Rym, 2002).

In Lembata east of Flores Island, previously named as Lomblen, tsunami was occurred without earthquake in 1979. Landslide was generated strong tsunami of 7 to 9 m heights and inundated up to 1500 m on shore. It was reported that it began with first negative wave followed by second large positive wave that killed 530 people and 700 missing from four villages (Soloviev *et al*, 1992; Yudhicara *et al*, 2015). Landslide mechanism was studied by Yudhicara *et al* based on study of origin soil, landslide material and hot spring water samples around the site. The original soil has much more coarser grain sizes than the landslide material (80.5% to 11.8%) and it is interpreted that the soil become finer and softer before being landslide material. On the other hand, high content of SO (99.48%) in hot spring water is interpreted that magmatism processes involved in making the soil become acidic and fragile; furthermore, X-ray diffraction analysis show that the landslide material demonstrates hydrothermal minerals such as quartz, saponite, chabazite, silicon oxide and coesite. These results reveal that the area was influenced by an active geothermal system as also the main source of landslide mechanism.

In Eastern Indonesia, some submarine landslides that generate tsunami were also occurred in combination with earthquakes such as in Bali and Flores region (Lovholt *et al*, 2012). In this region, the obvious tectonic features are Java trench and Flores Thrust (Figure 7). Flores thrust seismically more active than the subduction, eight large earthquakes north of Bali based on analyze source mechanisms were mostly thrust.

Submarine landslide generating tsunami was investigated in Palu Bay during the September 28th 2018 earthquake (Pakoksung *et al*, 2019). The landslide took place in the strike-slip Palu-Koro fault zone on Sulawesi Island, Indonesia. The landslide was generated by horizontal displacement of the fault which triggered tsunamis that creating wave hazards along coastal area of Palu City. In the past there were three events of tsunami in this area (heights 15, 3 and 10 m) generated by 1927 (M 6.3), 1938 (M 7.6) and 1968 (M 7.8) with sources are unclear (Gomez-Gesteira *et al*, 2010 and Pelinovsky *et al*, 1997).

Heiderzadeh *et al* (2018) noticed that horizontal movement was not significant in the Palu-Koro strike slip to generate tsunami, instead they used fault slip information provided by USGS for modelled tsunami propagation of Palu event. They also concluded that horizontal movement was not generate tsunami based

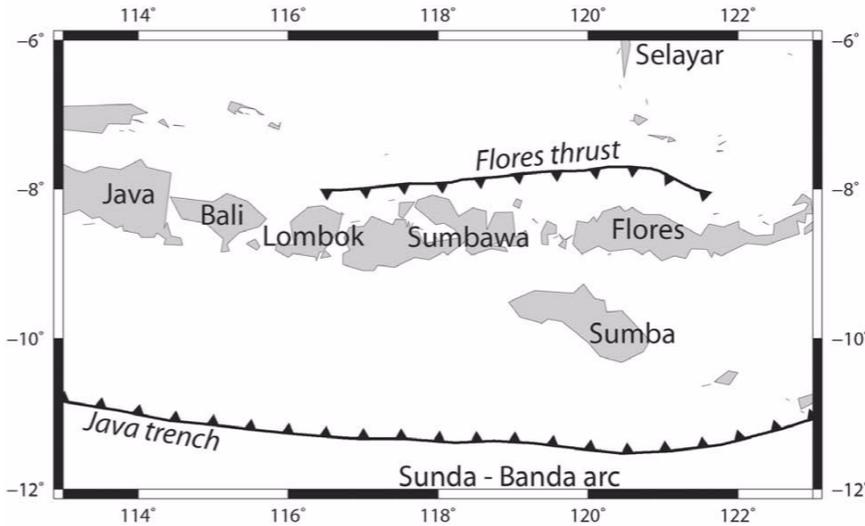


Figure 7. Tectonic overview of Bali and Flores region based on Lovholt *et al.*, (2012).

on observations from tide gauges. Submarine landslide mechanism has been proposed for tsunami generation in Palu Bay.

According to Pakoksung *et al* (2019) submarine landslides tend to generate large localized waves tsunami compared to the longwave system tsunami resulted from submarine earthquake. Compared to earthquake-

generated tsunamis models that well developed and widely used, numerical models for landslide-generated tsunamis are inadequate (Heinrich *et al*, 2001; Shigihara *et al*, 2006).

DISCUSSION

Vulnerable with many geological hazards, Indonesia should be aware with these hazards especially relate to construction of seafloor infrastructures such as optic cables, gas and oil pipes, and electricity cables. Indonesian telecommunication company PT Telkom Tbk gradually built Information Communication Technology infrastructure (ICT) based on optical network platform

which was named Nusantara Super Highway (<https://inet.detik.com/telecommunication/d-1620709/nusantara-super-highway-rampung-di-2015>) (Figure 8). NSH is the vision of the company to unite Indonesia which was started since 2001 using satellite based technology. NSH construction is divided into six rings

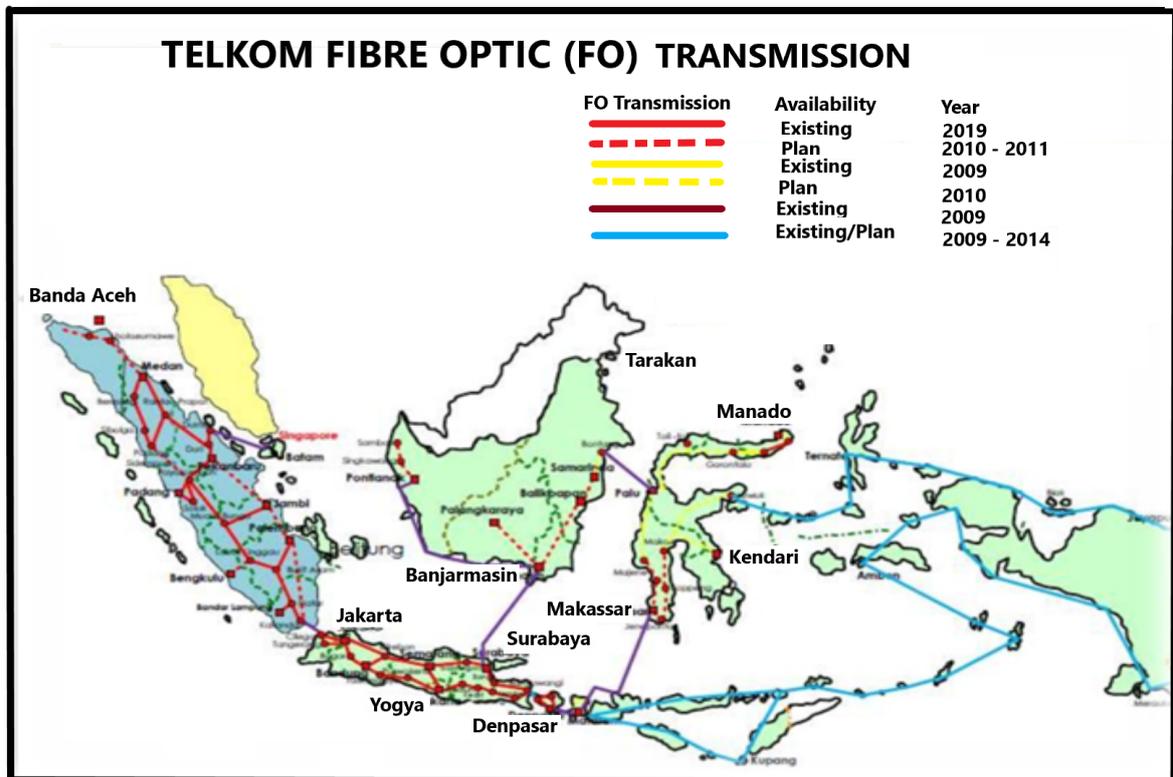


Figure 8. Seafloor fibre optic network existing and plan to built by PT Telkom Tbk some are passing through area of potential submarine landslide hazard (Source: <https://www.slideshare.net/mulimuljati/indonesia-domestic-fibre-optic>)

to connect Indonesian islands in accordance with six economic corridors developed by Indonesian Government. The six rings are : Sumatra (9,981 km), Java (11,524 km), Kalimantan (6,664 km), Sulawesi and North Molucca (7,233 km), Bali and Nusa Tenggara (3,444 km) and Molucca and Papua (8,254 km). The last ring is connected Ambon – the capital city of Molucca Province; FakFak, Sorong, Manokwari, Jayapura and Merauke – West Papua and Papua Provinces (Figure 8). The projects are funded by PT Telkom Tbk itself and prioritize on eastern Indonesia due to western Indonesia has been completed. The total length of NSH is 47,099 km spread from Sumatra to Papua which covered 421 cities and regencies. The network is meant to support TIME – Telecommunication, Information, Media and Edutainment; business platform based on information technology in the era of digital economy network. The NSH has been completely built in 2015, but monitoring of its seafloor cables should be continuously carried out especially at the areas of submarine geological hazards.

Marine Geological Institute of Indonesia (MGI) has provided data on marine geological hazards such as submarine volcanoes, submarine landslide and faults for PT Telkom Tbk. The data was used for precaution existing seafloor fiber optic cables in Papua, West Papua, Saumlaki and Ambon of Molucca Province which all are in Eastern Indonesia and Padang–Mentawai Western Indonesia.

Submarine landslides triggered by volcanic collapse were not documented well in the eastern Indonesia. This view reveals after Krakatau volcano collapse in Sunda Strait that generated tsunami in the coastal area especially in Java side. Beside volcanic collapse, there are other tsunami related volcanic activities : underwater explosion, air wave generated by the blast, and pyroclastic flows that entered to the sea (Mutaqin *et al.*, 2019). National Geophysical Data Center (NGDC) – NOAA has catalogue global historical tsunami database triggered by volcanic activity since 2100 BC. At least 139 tsunamis recorded where the most catastrophic occurred in Thera Island, Greece in 1610 BC and Hokkaido Island Japan on 29 August 1741 BC. Both reached 90 meter maximum run-up.

In the world death caused by volcanic tsunamis reached more than 54,000 persons, which is equal to 25% volcanism total victims (Mutaqin *et al.*, 2019). Although tsunami related to volcanic eruption rarely happen, some events had major impacts such as the 1792 CE of dome collapse of the Mayuyama volcano in Kyushu (15,030 death tolls), the 1741 CE eruption of Oshima-Oshima Volcano in the Japan Sea (1,607 death tolls), and the Krakatoa tsunami, Indonesia in 1883 CE (36,000 death tolls) (Lockridge, 1988).

Indonesia should aware of the volcanic eruption-induced tsunami because it is known as a volcano-rich country, with more than 130 active volcanoes from a total 400 volcanoes in the world.

Recent activity of marine volcano Krakatau in Sunda Strait was reported by Center for Volcanology and Geological Hazard Mitigation (CVGHM) occurred on 22 September 2018. Small amount of volcanic materials fell into the sea, especially on the south – southeast flank. Thus, it is still categorized as a tsunami hazard; especially for the coastal area along Sunda Strait. Relate to this, knowledge and preparedness of the communities should be improved as well as other stakeholders such as scientists, journalists, local governments and polices. Other potency for tsunami hazards are Agung Volcano in Bali, Soputan Volcano and Gamalama Volcano in North Maluku.

CONCLUSIONS

The study found out that blocky slide and slump deposits were observed in Seram Sea - south of Bird's Head Papua based on interpretation of seismic records. Blocky slide has the possibility of giant landslide that might affect seafloor infrastructure such as cable optic and trigger tsunami. On the other hand, submarine landslide that trigger tsunami was occurred in north of Flores Island in 1992 and Palu Bay in 2018; while submarine landslides are common processes for basin fill sedimentation in Eastern Indonesia.

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