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Tsunami and the Recent Eruption of Anak Krakatau Volcano, Sunda Strait, Indonesia

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Abstract

On December 22, 2018 tsunami hit the beaches of western Banten and South Lampung in Sunda Strait, Indonesia. The tsunami claimed lives of 359 persons dead and 60 others missing. Noiseless tsunami came ashore as high as 2 meters and inundated the beach about 200 meters run-up. There was no sign of earthquake and volcanic eruption. Those two precursors of tsunami generation did not occur, therefore no warning was issued. Based on the satellite image analysis it was revealed that the SW wedge of Anak Krakatau volcanic body slid down leaving the body broken. As many as 22.5 million cu meters of materials entered the sea and generated tsunami. The sliding might have taken place due to the steep slope exceeding 42.5^0 of the volcanic body and the unconsolidated clastic materials it composed. Additionally the long duration of volcanic trembling might have triggered the sliding. The slumping gave way to the uprising magma and finally on December 24 it burst out comparable to Saint Helens or Bandai-San types, though at a very small scale. The sea entered the orifice of the new crater and produced the Surtseyan type eruption. The proceeding activity on 26 December closed the crater from the open sea creating a crater lake. The present summit of Anak Krakatau decreased to about 250 meters from the initial elevation of about 450 meters. The new crater shifted about 5 meters NW along the weak line of Rakata-Danan-Perbuwatan.

Keywords: Tsunami, land sliding of Anak Krakatau, Saint Helens type, Surtseyan type, decrease of the summit

Introduction

Krakatau volcano is world widely known because of the devastating eruption-generated tsunami that killed more than 36,417 people. The Plinian type eruption took place in 1883 and blew out the entire volcanic body leaving a submarine caldera of 7 kilometers wide. The volcano is located in the middle of Sunda Strait between Java and Sumatra Islands (Figure 1).

Figure 1. The location of Anak Krakatau in Sunda Strait between Java and Sumatra, West of Jakarta

The tectonic position of the volcano was among others investigated by Nishimura et al. (1992) showing the weak zone of Sunda Strait in the direction of NE-SW. The zone was still opening due to the pull up of the clockwise rotating Sumatra Island. The volcano is located at the junction of Sumatra axis, Java axis and the Sunda Strait weak zone. This location in the triple adjoining lines might explain the gigantic eruption of the volcano in 1883.

Based on the tsunami deposits left in beaches, recently Iskandarsyah et al. (2016) described the inundated area in the upland of Ujung Kulon. It was revealed that beside the low lands in Banten and Lampung, tsunami also swept out the neck of Ujung Kulon peninsula where the sea water from Sunda Strait topple up to Indian Ocean. The elevation of the neck is about 20 meters above sea level. Four times of tsunami inundations were identified.

The relation between tsunami and the eruption remains debatable. Escher (1919) and others were in the opinion that the tsunami was generated by the eruption mechanism releasing energy and an estimated 18 cu km of volcanic mass. Self and Rampino (1981) believed that the pyroclactic flow might have been the most likely agent to generate tsunami.

Most of the volcanologists agreed that beside the submarine earthquake, volcanic eruption might also generate tsunami. Latter (1981) demonstrated the close correlation between tsunami and air wave recorded by gasogram in the 1883 Krakatau eruption. The outburst of gas and ashes in Krakatau eruption produced noise and high air pressure which traveled as air wave. In the paroxysmal stage the sound of Krakatau eruption reached Rodriguez island of about 5.000 kilometer distance.

Yokoyama (1981) on the other hand, put forward the geophysical evidence of the occurrence of earthquake at the initial phase of the eruption. Tsunami therefore, might have been generated by the earthquake. It is generally believed that the origin of tsunami is submarine earthquake based on a long experience of tsunami occurrence in Japan.

Yokoyama's opinion has received no positive respond. In the case of Krakatau, it was believed that the prime cause of the killing tsunami was the volcanic eruption. The tsunami warning system was therefore focused to the volcanic activity. The telemetric volcano monitoring continuously recorded the seismicity of the volcano and sent the signals to the observatory located at the West Coast of Banten.

Data and Method

On Saturday December 22, 2018 tsunami inundated the beaches of western Banten and South Lampung. The tsunami killed 359 persons and 60 others were missing, particularly those who stayed at the hotels for week end and long vacation of the year end. Most of the hotels are located along the beach. The tsunami came noiseless and no warning was issued. It came ashore as high as two meters and caused run-up about 200 meters inland.

The telemetric seismograph with detectors placed in the island recorded seismic swarms for about two weeks before tsunami. However there were no sign of magma up rising. The seismic swarms fluctuated within a range of normal condition, therefore no alert was issued.

Several international satellites continuously passed over Krakatau and took the recording of the volcano. There were no images made public because no particular activity of Anak Krakatau observed. However the record taken before the occurrence of tsunami was finally released (Figure 2).

Figure 2. The satellite image taken about two weeks before the tsunami (Source: internet)

Right after the occurrence of tsunami many satellite imageries were put into public disposal acquiring information about Anak Krakatau. The interpretation of the images revealed the topographic changes of the SW portion of the volcano. The development of volcano configuration can be observed based on the repeated acquisition of images. The comparison between before and after tsunami can be made.

Following the satellite image interpretation a reconnaissance from a light plane was carried out. Finally ten days after the tsunami a visit to the volcano was made to collect ground truths and to confirm the interpretation results.

Result and Discussion

Satellite image interpretation revealed the SW sector of Anak Krakatau volcano slid down to the sea. It was estimated about 22.5 million cu meters of volcanic materials entered the sea. This might be the prime cause of the noiseless tsunami without earthquake and volcanic eruption precursors. Therefore no warning was issued.

The unconsolidated volcano clastic materials consisting of breccia, lapilli and tuff are very prone to the mass movement. The slope instability became severe due to the steep topography of the volcano. It was estimated that the upper part of the slope exceeded 42.5^{o}.

It was also reported that the volcano had been trembling for about two weeks. Combined with the condition of the loose materials and the steep slope, the upper part of the cone began to slide down. A crown was formed and the slumping materials brought over the lower slope resulting in mass movement. The toe of the landslide entered the sea and generated sea wave which traveled mostly to SW to the direction of Labuan, a fisherman village at Banten's coast. This area and the surrounding beach suffered most and caused fatalities.

The land sliding released the pressure and changed the magma stability at the conduit. Immediately after the sliding, magma squeezed to the surface and an eruption occurred. It seemed that the eruption might have involved the upper part of the conduit as evidenced by the short period of eruption. Although it was in a very small scale, the eruption comparable to Saint Helens or Bandai-San type. The mechanism of the eruption supposed to be slightly different; the release of pressure due to the sliding however, was comparably the prime cause of the eruption.

The sliding had also torn the SW part of the slope. An amphitheater topography facing SW was formed as recognized from its remnant. Combined with the eruption, the sliding resulted in the collapse of SW sector forming a U-shape crater. At the same time the eruption continued demonstrating the typical Surtseyan eruption. The phenomena indicated the submarine eruption caused by the entering sea water to the U shape crater. The eruption lasted for a few days and finally the crater lake was formed (Figure 3).

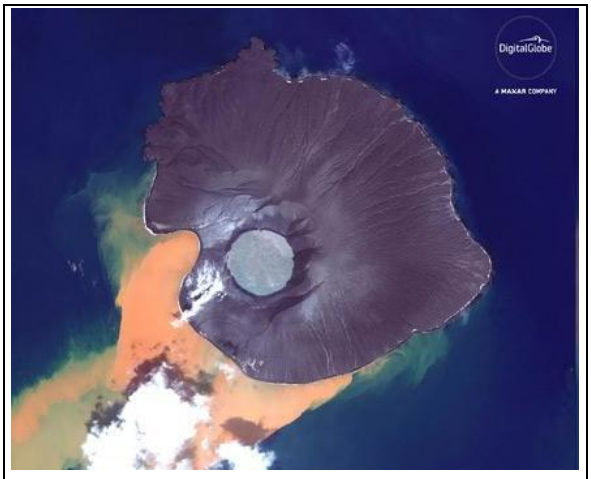

Figure 3. The crater lake was left after the eruption ceased. The brown sea water plume indicated the suspended debris of volcanic materials (Source: Digital Globe/internet)

The landslide decreased Anak Krakatau summit from the elevation of 450 meters to 250 meters. The position is lower than the crest of the Old Anak Krakatau which was previously higher.

The chronology of eruption and the generation of tsunami can be summarized as follows: First, for about two weeks seismicity had

caused Anak Krakatau to tremble. Then in early evening of December 24 the sliding of the unconsolidated volcanic materials occurred. Tsunami was generated and reached the coast at about 9:23 p.m. Finally the eruption took place immediately after the sliding (Figure 4).

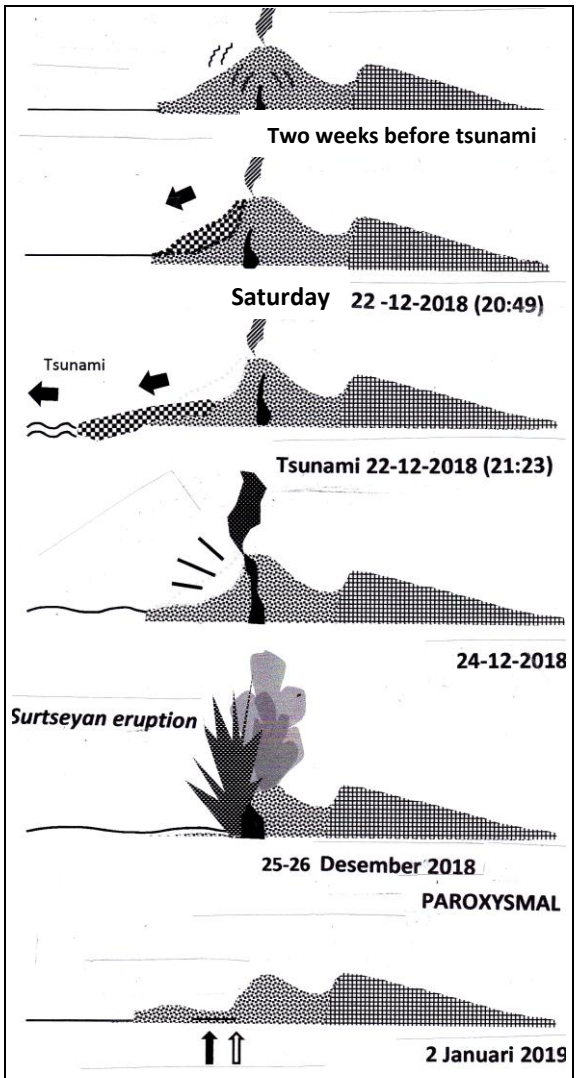

Figure 4. The illustration shows the chronology of the sliding, tsunami generation, eruption and final state of Anak Krakatau, where the diatrema shifted about 5 meters to SW (left, SW, right NE, Source: Sudradjat, 2019).

Anak Krakatau grew from the submarine caldera left by the Plinian eruption of Krakatau in 1883. After 44 years of quiescence period an activity recurred and gave birth to Anak Krakatau comparable to somma in Vesuvius.

The newly born volcano grew very vastly with the additional height about 4,25 meters a year. However sliding frequently occurred and kept the volcano less than 500 meter elevation. Sudradjat (1982) noted that the sliding has consistently shifted to SW direction. Anak Krakatau has moved about 400 meters since its birth in 1929. The present crater of Anak Krakatau shifted about 5 meters in SW direction (Figure 5).

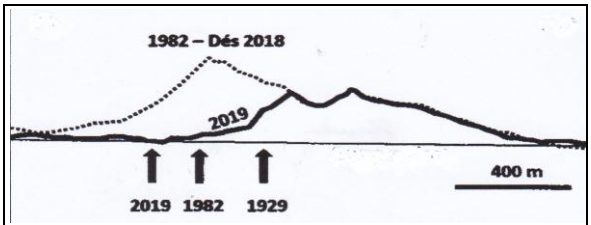

Figure 5. The development of Anak Krakatau after its birth in 1929 (Source: Sudradjat 1982)

It is anticipated that the newly formed volcano will also slide down in the future to SW direction. The noiseless tsunami will always be impending in addition to the danger caused by submarine earthquake and volcanic eruption.

Conclusions

1. The 2018 tsunami of Sunda Strait was generated by volcanic material slumping;
2. The seismic tremors had accelerated the sliding of the materials;
3. The sliding gave way to the magma at the upper part of the conduit to reach the surface;
4. In addition to the conventional origin of tsunami namely submarine earthquake and volcanic eruption, the mass movement might also be included;
5. It is strongly recommended widening early warning system of tsunami in Sunda Strait

to cover both conventional origins and the slumping.

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