Potential Eruption and Current Activity of Anak Krakatau Volcano, Indonesia

Kristianto1, N Indrastuti1, A Basuki1, H D Purnamasari1, S Adi1, C Patria1 and N Haerani1

1 Center for Volcanology and Geological Hazard Mitigation (CVGHM), Jl. Diponegoro 57, Bandung 40122, Indonesia

kris0432@yahoo.com

Abstract. Anak Krakatau Volcano is located in the Sunda Strait known for its paroxysmal eruption in 1883. During the January - November 2019 period, seismicity was dominated by types of quakes which indicated the occurrence of magma supply (VA and VB), near-surface volcanic activity (LF, Hybrid, Harmonic Tremors), and volcanic activity above the volcanic surface (eruptions, emission, and continuous tremors). In the period December 2019 - July 2020, there was an increase in the types of quakes near the surface (LF, Hybrid) and the types of quakes on the surface (emission and continuous tremors). Volcanic deformation monitors changes in tilt over the 2019-2020 period associated with pressure releases before, during and after the eruption. The results of GPS data modeling, the shallow pressure source is at a depth of 0.22 km below sea level. Volcanic activity until July 2020 was dominated by activity near and above the volcanic surface associated with the growth of lava domes. The volcanic system of Anak Krakatau is currently an open system, with the potential for eruptions. Strengthening the early warning system for the eruption of Anak Krakatau is important in mitigating efforts and understanding its eruption potential.

1. Introduction
Anak Krakatau volcano is one of the most active volcanoes in Indonesia which is located in the Sunda Strait. The last big eruption of Krakatau in 1883 was one of the well known in the world, an awesome volcanic eruption at the sea and followed by a tsunami that affected the people death in the tens of thousands.

Since its appearance on 11 June 1927 up to 2011, Anak Krakatau volcano has experienced more than 100 eruptions, both explosive and effusive, with repose periods ranging from 1 - 6 years (Data Dasar Gunungapi Indonesia, 2011) (Figure 1). There were several eruptions during the 2012-2013 time period, resulting in a ash column reaching 1000 meters high, followed by a strombolian eruption and ending with lava flows to the southeast and southwest. Since 2016, Anak Krakatau volcano has erupted every year. In 2016 the eruption occurred on 20 June 2016, while in 2017 the eruption occurred on 19 March 2017 in the form of a strombolian eruption (Kristianto, et al., 2019).

In 2018, it erupted again since June 29, 2018 in the form of a strombolian eruption. During the period from July to December 2018 there were eruptions of ash, strombolian, and lava flows. This eruption material fall and flowed around Anak Krakatau volcano. On 22 - 28 December 2018, the activity of G. Anak Krakatau increased with the recording of continuous volcanic tremors associated with continuous eruptions. This eruption resulted in the avalanche of the flank of Anak Krakatau from...
the west to the southwest, as well as a tsunami that inundate the area around the Sunda Strait. The eruption caused the volcanic monitoring system on Anak Krakatau to be totally damaged, so seismic monitoring can only be done from SRTG Station located on Sertung Island (Kushendratno, 2019).

During the period of 2019, monitoring equipment was installed with 2 seismic stations, deformation (2 tiltmeters, 1 GPS permanent, and 2 GPS temporary), 3 infrasound, and 2 CCTV. The equipment installation aims to replace equipment damaged by the 2018 eruption, continuously monitor volcanic activity, and strengthen the eruption early warning system of Anak Krakatau volcano.

![Figure 1](image)

**Figure 1.** Graph of eruption history, eruption index, and peak elevation of Anak Krakatau. Explosive eruptions and tephra eruptions are drawn in red, lava flows in green, and peak elevations in dashed lines.

### 2. Potential of geological hazard in the Sunda Strait

The tectonic setting of the area around the Sunda Strait is an active area of tectonic activity. The Sunda Strait area is strongly influenced by tectonic activity in the form of collisions between the Eurasian Continental Plate moving southeast at a speed of about 0.4 cm / year and the Indo-Australian Ocean Plate moving north at a speed of about 7 cm / year (Minster and Jordan, 1978 in Yeats, et al., 1997). In the Sunda Strait area, it is interpreted to have an open zone (extension zone) controlled by the Sumatra horizontal fault system and grabens in the western region of Banten (Pramumijoyo and Sabrier, 1991). The Sunda Strait area is also an opening zone with the appearance of a structure in the form of normal faults (Malod, et al., 1995; Susilohadi, et al., 2009. While Handayani and Harjono (2008) state that the zone of openings that occurs from south of the Sunda Strait to southern Java is caused by the accommodation of the impact force in the subduction zone, the Sumatra Fault and the Mentawai Fault.

The Krakatau complex is located right at the junction of two northeast-southwest and northwest-southeast directions (Verbeek, 1885). The Krakatau volcanic complex is controlled by tectonic movements associated with the South Sumatra Fault System (Effendi, et al., 1986). In the Sunda Strait area, it is interpreted to have an open zone (extension zone) controlled by the Sumatra and graben horizontal fault system in the western region of Banten (Pramumijoyo and Sabrier, 1991).

### 3. Monitoring system

After the 2018 eruption, the monitoring systems that are still functioning due to the eruption material are one seismic station on Sertung Island and one Pulosari seismic station in the southwestern part of the Pasauran Observatory. Some permanent monitoring equipment was then installed, in February 2019 1 seismometer L4C was installed at the Tanjung Seismic Station in the eastern part of Anak Krakatau (Kushendratno, et al., 2019), on March 2019 1 Biaxial Tiltmeter Jewel type 701-2 sensor and 1 CCTV around the summit of Anak Krakatau were installed (Rosadi, et al., 2019), on March 26-27, 2019 1 Biaxial Tiltmeter Jewel type 701-2 sensor was installed on the eastern slope of Anak Krakatau (Triastuti, et al., 2019), in November 2019 1 3-component broadband digital seismometer (Radian) was installed unit - Guralp), and 1 Chaparal Physics Model 25 infrasonic sensor at a location in the northern part of Anak Krakatau Island (Lava-93 Station), 1 Chaparal Physics Model 25 infrasonic
sensor at Kalianda Observatory, and 1 Chaparal Physics Model 25 infrasonic sensor at Pasauran Observatory (Kuswandarto, et al., 2019), as well as the addition of 1 permanent GPS sensor at the Lava-93 station and 2 temporary GPS stations (KRA1 Station and KRA2 Station) (Patria, et al., 2019). In March 2020, 1 CCTV was added to the Lava-93 Station (Patria, et al., 2020) (Figure 2), because the CCTV around the summit was damaged due to bursts of volcanic material.

![Figure 2. Map of the monitoring network of Anak Krakatau activities using seismic equipment, GPS, Tiltmeter, CCTV, and infrasound (Patria, et al. 2019).](image)

4. Data and methods
The methods used in this paper are: visual observation, seismic observation (seismic classification and analysis of RSAM, SSAM), and deformation observation (GNSS method and tiltmeter method).

The seismic data used in this paper is continuous seismic data from 1 January 2019 to 30 September 2020, to calculate the release of seismic energy Real-time Seismic Amplitude Measurement (RSAM), (Endo and Murray, 1991), Seismic Spectral Amplitude Measurement (SSAM) (Rogers and Stephens, 1995) which is spectral data (frequency content) from earthquake records within a certain time interval, classification, and number of quakes. RSAM data is related to earthquake energy while SSAM data is related to the dominant earthquake mechanism. RSAM and SSAM data are used in evaluating seismic energy and interpreting the phenomena that occur (Basuki, et al., 2019).

The classification of earthquakes records at Anak Krakatau volcano consists of Eruption, Emission, Tremor, Shallow Volcanic (VB), Deep Volcanic (VA), Low Frequency (LF), Local Tectonic (TL), and Far Tectonic (TJ). The Eruption quake has a low dominant frequency content, which is around 1.3 s.d. 2.4 Hz, strong earthquake onset and duration of 15 - 255 seconds. The Emission quake is also characterized by a low dominant frequency content, which is around 1.3 s.d. 3.0 Hz, quake onset is ...
generally emergent, lasting about 9 - 180 seconds. Low Frequency quakes have a bandlimited frequency spectrum between 1 and 8 Hz. Hybrid quakes contain a dominant frequency of 2 - 3 Hz. Tremor quakes generally contain a frequency of about 1 - 2.4 Hz with a duration of about 14 - 101 seconds. VB quakes and VA quakes are Volcano Tectonic / VTs quakes characterized by a broader band and have a higher frequency content, VTs band quakes ranging from 1 to 20 Hz, generally having a dominant frequency peak of 8 - 15 Hz. Local Tectonic quakes are high frequency quakes and have an S-P greater than 4 seconds.

The 10-minute RSAM data and SSAM data are calculated automatically using the earthworm data acquisition system (http://www.earthwormcentral.org/), from 10 minutes of data a daily average is calculated to be compared with the total daily quakes. RSAM provides information on the relative total of seismic energy release. Seismic classification is carried out based on direct analysis of the frequency content and waveforms.

Deformation data used in this paper is GNSS data with dual frequency L1 (1575.42 MHz) and L2 (1277.60 MHz) for the period of November and December 2019. Monitoring the ground deformation of Anak Krakatau uses the GNSS (Global Navigation Satellite System) method. conducted in the period November - December 2019. GNSS data is processed automatically in the Webobs application using the GipsyX / JPL software (Beauducel, et al., 2020). The results of GNSS data processing yield the speed and depth of the source of deformation.

The tiltmeter data is used from the recordings at Tanjung Station for the period January - April 2020. Deformation monitoring with the tiltmeter uses the tilting method on each of its axes (X and Y axes), the X (tangential) axis is located 90 ° from the Y (radial) axis. With this Tiltmeter device, it can be used to determine the leverage pattern caused by changes in pressure on the volcanic ground and can calculate the volume of magma injection (Nishi, et al., 2007).

5. **Visual monitoring**

Visual monitoring of Anak Krakatau’s activities is carried out using CCTV (Closed Circuit Television) cameras and direct monitoring in the field. The equipment used to support visual monitoring consists of 2 CCTV cameras installed at the G. Anak Krakatau Observation Post in Pasauran and on Anak Krakatau Island. The CCTV equipment located on Anak Krakatau Island (Lava-93 Station) has been operating since March 11, 2020 until it was damaged at the end of April 2020 due to being hit by the eruption material, it can resume operation after being repaired on September 7, 2020. Visual monitoring via CCTV can also be shared via the web: www.vsi.esdm.go.id, so that it can be accessed by anyone who needs a visual image (Photo 1b).

Visual monitoring was also carried out by conducting direct checks to locations around Anak Krakatau (Photo 1a). A visit to this location is very important to find out the current condition of the Anak Krakatau Crater after the 2018 eruption. In December 2019, the crater visuals often observed surtseyan eruptions in the central and northern parts of the crater lake (Patria, et al., 2019) (Photo 2a). The last monitoring towards the crater was carried out on March 11, 2020 (Kuswandarto, et al., 2020) (Photo 2b), and photo donation from Samsul as a tour guide who had passed Anak Krakatau volcano in the southwestern part of April 17, 2020 (Photo 3a). When compared to the results of monitoring March 2020 with September 2020, there are very significant changes in the conditions around the crater. On March 11, 2020, it was observed that the crater had begun to fill with volcanic material in the middle, and the crater lake was divided into two parts. In the photo on April 17, 2020, the condition of the crater is covered in volcanic material and lava flows, the crater lake water is no longer visible. On monitoring on September 8, 2020, the crater conditions were increasingly changing, especially at the height of the lava flow which was getting higher and evenly distributed to the west-southwest. The height of the lava dome is still below the current highest peak (157 m), estimated to be about 100 meters above sea level (Photo 3b).
Photo 1. Visual Crater of Anak Krakatau from the north-eastern crater rim on September 7, 2020, observed activity of gas emission from the center and southeast side of the lava dome. While the lava flow leads to the west-southwest (a), and from the CCTV at Lava-93 Station on September 8, 2020 (b), it is observed gas emission with a height of 25 - 50 meters from the summit.

Continuously gas emission (Constant degassing) was observed predominantly from the central location of the lava dome and around the crater, with a height of up to 500 meters. On September 7, it was observed that the dominant gas emission came from the center of the lava dome and the eastern part of the crater, with a height of 25 - 50 meters from the peak of the lava dome and occasionally observed exceeding the peak of Anak Krakatau as high as 50 meters (Photo 1b).

Photo 2. Visual crater in December 2019, often observed surtseyan eruptions in the central and northern parts of the crater lake (a). Visually around the crater on March 11, 2020, the crater lake has started to fill with volcanic material in the middle, and the crater lake is divided into two parts, Constant degassing is observed in the eastern crater (photo: Jumono, March 11, 2020) (b).
Photo 3. Visual Crater of G. Anak Krakatau from the northwest using a speedboat, observed activity of gas emission from the center and around the lava dome. While the lava flow leads to the west - southwest part (Photo: Samsul, 17 April 2020) (a). Visually on September 8, 2020, activity of gas emission was observed from the center of the lava dome of Anak Krakatau as high as 25 - 50 meters from the top of the lava dome (b).

Photo 4. Volcanic rock falls resulting from the eruption of 10-11 April 2020, around Lava-93 Station with a diameter of about 10-30 cm (a), around the crater rim generally measuring 30-100 cm in diameter (b).

The distribution of the eruption material from 10-11 April 2020 in the form of gravel was observed to be scattered to the northeast - north - west - south from the active crater. Volcanic material falls with a diameter of 30-100 cm are found around the crater rim and a small portion of about 10-30 cm in diameter can be found around the Lava-93 station (Photo 4).

6. Seismic monitoring (2019-2020)
Seismicity records during 2019 were marked by continuous surtseyan eruption quakes and there was no clear precursor before the eruption occurred in the period February to October and December 2019. The increase in VA quakes in January - February was followed by an increase in VB, LF, Eruption, emission, and continuous tremors quakes starting March 2019. The eruption on February 14, 2019 was preceded by the recording of the VA quake swarm the day before. The VA Earthquake shows a new intrusion, building up pressure and causing surface quakes (gas events) to be recorded, that are VB quake, emission quake, and Harmonic Tremor quake. Continuous tremors correlate with constant degassing or constant magma in contact with water (which produces steam) - heat (Kristianto, et al. 2020).

During the period from January to September 2020, the seismicity was characterized by non-continuous eruption quakes until April 17, and increased Emission, Continuous Tremors, LF, Hybrid, VB, TL, and TJ quakes (Figure 3). Changes in the release of seismic energy calculated using RSAM
(Figure 4) are associated with an increase in the amplitude of continuous tremors, corresponding to the SSAM pattern (Figure 5) dominated by a dominant frequency of 0.5 - 4 Hz related to the mechanism of Eruptions, Emission, and Continuous Tremors quakes. The dominant amplitude occurs with a maximum between 3 - 40 mm.

**Figure 3.** Daily quakes at Tanjung Station for the period January 2019 to September 2020, from top to bottom Eruption (Let), Emission (Hemb), Harmonic Tremor (TH), Continuous Tremors, Hybrid, Low Frequency (LF), Shallow Volcanic (VB), Deep Volcanic (VA), Local Tectonic (TL), and Far Tectonic (TJ).

**Figure 4.** Graph of the value of RSAM Tanjung Station for the period February 2019 to September 2020, during the period 28 July - 6 September 2020 there was no data because the equipment was damaged.
Figure 5. Graph of the SSAM value of Tanjung Station for the period January 2019 to September 2020, during the period 29 July - 6 September 2020 there was no data because the equipment was damaged.

7. Deformation monitoring (2019-2020)
Deformation monitoring of Anak Krakatau using GNSS data at 3 GNSS stations, that are KRA1, KRA2 and KRA3 produces velocity and depth of the source of deformation. Webobs uses a depth-varying point source solution (Williams & Wadge, 1998) for a topographic correction approach in deformation, with isotropic point model type, 3-D probability map, volume variation and probability deflation - inflation model (Beauducel, et al., 2014) shown in Figure 6.

Figure 6. Velocity Vector of GPS (a) and Source Modeling GPS (b) for the period November 13 - December 5, 2019 at KRA1, KRA2 and KRA3 stations.
The tiltmeter data of Tanjung Station for the period January 1 - April 30, 2020 which is correlated with the eruption quake that occurred at Anak Krakatau is shown in Figure 7, and the tilting pattern after the eruption on April 10 and before the eruption on April 11 2020 is shown in Figure 8. Changes in the average magma injection (Nishi, et al., 2007) that occur at the tiltmeter after calculating the average magma injection of Anak Krakatau is 37-54 m$^3$ / minute at a depth of 4-5 km below the surface of the activity center. This is greater than the magma injection for the period October - December 2019 of 15 - 34 m$^3$ / minute (Kristianto, et al., 2020).

![Figure 7. Tanjung station tiltmeter (X axis and Y axis) correlated with the eruptive quake that occurred during the period January 1 - April 30, 2020.](image1)

![Figure 8. Y axis (a) and X (b) axis on the Tiltmeter showing the tilting pattern at Tanjung Station after the eruption on April 10, 2020 and before the eruption on April 11, 2020.](image2)

8. Discussion
The potential for flank landslides that can produce tsunami waves in the near future is still very small, because at this time a large enough cone has not been formed. Cones that are built through eruptive activity (explosive or effusive). Explosive eruption material is deposited around the crater and lava flows out to the west - southwest become an effective system in building new cones, currently reaching a height of around 100 meters above sea level. By comparing the visuals of the crater on March 11, April 17, and September 7, 2020, a significant change occurred in the March - April 2020
period marked by changes in the height of the lava dome and lava flows towards the west-southwest. This can be seen also in the seismic recordings in that period which are dominated by types of emission quakes are directly associated with the occurrence of passive gas emission, LF quakes associated with increased pressure in shallow areas under volcanic craters, Harmonic Tremors and Continuous Tremors associated with volcanic or strombolian eruption activity on 10-11 April 2020 which produces ash plume, steam, and ballistic trajectory rocks around the crater and the northern part of the crater.

In the period January - March, mid-April, and September 2020 there is a corresponding pattern of increasing data for RSAM, SSAM, eruption quakes, emission quakes, and continuous tremors. RSAM data shows the relative value of the total high seismic energy release, SSAM data is dominated by a dominant frequency of 0.5 - 4 Hz related to the mechanism of eruptions quakes, emission quakes, associated with the release of volcanic material to the surface in the form of eruptions (volcanic and strombolian), emission gas, and lava flows.

Seismicity during the period January 2020 to mid-September 2020 is indicated by an increase in LF, Emission, Hybrid, and continuous tremors quakes. The seismicity of the VA and the VB quakes was insignificant, on average less than 1 event per day, but there were several times the increase in VB quakes in April, June and July 2020. This shows that magma intrusion still occurred in this period. The seismicity of LF, Emission, and Hybrid quakes was quite significant, indicating the occurrence of gas movements, as well as the release of volcanic material in the form of lava and gas flows to the surface. Continuous tremor quakes were recorded significantly in this period, which correlates with the constant degassing process.

The strombolian or surtseyan eruptions that occurred on February 6 -11, 2020 were not preceded by changes in the seismicity that could be identified significantly (Kristianto, et al., 2020), this event was similar as the eruption that occurred on 10-11 April 2020 not preceded by changes in the VA and VB quakes significantly, some quakes that increase in the 5 days before the eruption are the Emission, LF, and continuous tremor quakes. The volcanic system of Anak Krakatau is currently open, so volcanic or strombolian eruptions can occur without a significant change in seismicity that can be identified. During the eruption period the seismicity was dominated by Continuous Tremors, Harmonic Tremors, Emission, LF, and Eruptions. Continuous tremors correlate with constant degassing or constant magma in contact with water (producing steam) - heat and gas (McNutt and Roman, 2015; White and McCausland, 2019).

The tectonic activity around Anak Krakatau volcano has an effect on its volcanic activity, the Krakatau volcanic complex is controlled by tectonic movements associated with the South Sumatra Fault System (Effendi, et al., 1986). Faults in the Sunda Strait region are controlled by a horizontal fault system in Sumatra and grabens in the western region of Banten (Pramumijoyo and Sabrier, 1991), seen in an increase in Local and Far Tectonic quakes from 29-30 June 2020, which triggered an increase in Emission, LF, and Hybrid quakes. This shows that tectonic activity can affect the stability of magma that is already at a shallow depth to near the surface.

The results of GNSS data observations show that the velocity vector that points to the source of the crater activity is interpreted as deflation. In the monitoring period from November to December 2019, seismic activity was dominated by emission, so that observations of deformation that showed deflation had an effect on the release of energy that occurred in the body of Anak Krakatau. The tilting pattern showed stability before and after the eruption on April 10, 2020, but after that the tilting on the X axis and Y axis increased for about 8 hours before finally stabilizing and one hour 45 minutes later the eruption returned to be precise at 09.45 WIB, this indicates the occurrence of magma migration from shallow pockets to the surface.

9. Conclusion
The results of visual, seismicity and deformation data analysis of Anak Krakatau volcano show that the potential hazard from the current activity is vulcanian and strombolian eruptions which can be accompanied by ballistic trajectory rocks, lava flows and heavy ash fall around the crater within a
radius of 2 km from the active crater. The volcanic system of Anak Krakatau volcano is currently open, so that volcanic or strombolian eruptions can occur without significant changes in volcanic phenomenon.

The current volcanic activity of Anak Krakatau is in the form of the release of volcanic material to the surface in the form of lava flows and constant degassing or constant magma in contact with water (which produces steam) - heat and gas. In order to face the potential hazard of Anak Krakatau eruption, strengthening the early warning system is important in mitigating efforts and understanding its eruption potential.

Acknowledgements
The author would like to thank the Head of the Center for Volcanology and Geological Hazard Mitigation, Kasbani, and the Head of Volcanic Mitigation, Hendra Gunawan, who gave the team the opportunity to repair the monitoring equipment of Anak Krakatau volcano and study its volcanic activity. We would like to thank Samsul from the tour guide who has donated his photos for use in this paper.

References
[1] Basuki A, Kristianto, Mathovanie A 2019 Sistem pemantauan gunung Anak Krakatau Dinamika Geologi Selat Sunda Dalam Pembangunan Berkelanjutan, Badan Geologi, Kesdm
[2] Beauducel F, Nurmaning A, Iguchi M, Fahmi A, Nandaka M, Sumarti S, et al. 2014 Real-time source deformation modeling through GNSS permanent stations at Merapi volcano (Indonesia) in AGU Fall Meeting Abstracts (San Francisco, CA)
[3] Data Dasar Gunungapi Indonesia, 2011. Badan Geologi Kementerian Energi Dan Sumber Daya Mineral.
[4] Effendi AC, Bronto S and Sukhyar R, 1986 Geological map of Krakatau Volcanic Complex. Volcanological Survey of Indonesia.
[5] Endo ET and Murray T 1991 Real-time seismic amplitude measurement (RSAM): a volcano monitoring and prediction tool Bulletin of Volcanology, 53(7), pp.533-545.
[6] Handayani, L., dan Harjono, H., 2008, Perkembangan tektonik daerah busur muka Selat Sunda dan hubungannya dengan zona sesar Sumatera, Jurnal Riset Geologi dan Pertambangan Jilid 18 No.2, pp. 31-40.
[7] Kristianto, Triastuty, H, Mulyana I, Rosadi U, Basuki A, 2019, Revitalization of early warning systems of the Anak Krakatau volcano eruption post-eruption 2018. The 6 th Annual Scientific Meeting on Disaster Research 2019 International Conference on Disaster Management Proceeding Book Vol. 4, Indonesia Defense University, Bogor 18 – 19 June 2019.
[8] Kristianto, Patria C, Indrastuti N, Basuki A, Heruningtyas, Adi A, Mardiono D, Kuswandarto, H, Yoga A and Haerani N, 2020 Kajian seismik gunung Anak Krakatau pasca erupsi tahun 2018, Prosiding Kolokium Kajian Kegunungapian 2019 Pusat Vulkanologi Dan Mitigasi Bencana Geologi Hal. 35-44.
[9] Kushendratno 2019 Laporan tanggap darurat letusan gunungapi Anak Krakatau, Banten 14 – 23 Februari 2019. Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi, Badan Geologi KESDM.
[10] Kuswandarto H, Mulyana I, Setiono S and Rahmanto, 2019. Laporan instalasi peralatan pemantauan G. Anak Krakatau, Lampung 11-24 November 2019 Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi Badan Geologi KESDM.
[11] Malod JA, Karta K, Beslier MO and Zen MT 1995 From normal to oblique subduction : Tectonic relationships between Java and Sumatera, , Journal of Southeast Asian Earth Sciences, Vol. 12, No.1 2, pp. 85 – 93.
[12] McNutt SR and Roman DC 2015 Volcanic seismicity. In The Encyclopedia of Volcanoes (pp. 1011-1034). Academic Press.
[13] Nishi K, Hendrasto M, Mulyana M, Rosadi U and Purba winata MA 2007 Micro-tiltchanges preceding summit explosions at Semeru volcano, Indonesia Earth Planets Space 59, 151-156

[14] Patria C, Kristianto, Adi S and Basuki A 2019 Laporan kajian Anak Krakatau tahap pertama 8–14 November 2019 Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi Badan Geologi KESDM.

[15] Patria C, Mulyana I, Setiono S, Hidayat D A and Yosa Putra D E 2020 Laporan tanggap darurat letusan gunungapi Anak Krakatau, Banten Maret 2020. Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi Badan Geologi KESDM.

[16] Pramunijoyo S and Sebrier M 1991 Neogene and Quaternary fault kinematics around the Sunda Strait area, Indonesia, Journal of Southeast Asian Earth Sciences, Vol. 6, No. 2, pp. 137 – 145.

[17] Rogers JA dan Stephens CD 1995 SSAM: real-time seismic spectral amplitude measurement on a PC and its application to volcano Monitoring Bulletin of the Seismological Society of America Vol. 85 No.2, pp.632 - 639.

[18] Rosadi U 2019 Laporan singkat survey gunung Anak Krakatau tanggal 7-8 Maret 2019 Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi, Badan Geologi KESDM.

[19] Susilohadi, Gaedicke C dan Dja jadidhardja Y 2009 Structures and sedimentary deposition in the Sunda Strait, Indonesia Journal of Tectonophysics 467, pp. 55-71.

[20] Triastuty H 2019 Laporan tanggap darurat letusan gunungapi Anak Krakatau Banten 26 – 27 Maret 2019 Arsip Pusat Vulkanologi dan Mitigasi Bencana Geologi Badan Geologi KESDM.

[21] Verbeek RDM, 1885 Krakatau. In: Simkin T and Fiske R S (Editors), Krakatau 1883 : the volcanic eruption and its effects. Smithsonian Inst. Press, Washington, D.C.

[22] White, R.A. and McCausland, W.A 2019. A process-based model of pre-eruption seismicity patterns and its use for eruption forecasting at dormant stratovolcanoes. Journal of Volcanology and Geothermal Research, 382, pp.267-297.

[23] Williams C and Wedge G 1998 The effects of topography on magma chamber deformation models: Application to Mt. Etna and radar interferometry, Geophys. Res. Lett., 25, No.10, 1549-1552.

[24] Yeats RS, Sieh K and Allen CR 1997 The geology of earthquakes Oxford university press: 567.