The Influence of Rock Resistance for Geomorphology of Krakatau Islands, South Lampung District, Lampung Province

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Abstract. Krakatoa Islands is one of the results of high activity volcanic islands located in the Sunda Strait, Indonesia. Volcanic activity of the research area is highly influential on the typical morphological conditions. Rocks produced from this volcano activity a role in the formation of geomorphology that is typical of areas with high volcanic activity. Rocks in the study area were the result of volcanic activity such as lava, pyroclastic alluvial. Geomorphology analysis was conducted by analyzing river flow pattern, slope criteria analysis and shoreline analysis since 1984. East Anak Krakatoa island which is dominated by lava, in contrast to the krakatoa west of which the rock formers are dominantly pyroclastic fall. Unconsolidated rocks form west Sertung island, east Panjang island and south Rakata island which the rock formers are dominantly pyroclastic flow. Evidence of 1883 catastrophic eruption is highly visible on the north Rakata island, east Sertung island and west Panjang island shown by vertical high cliff which is indicated as a caldera structure. The results of the geomorphological analysis are poured into geomorphological maps. Geomorphology unit in research area consist of 9 (nine) geomorphology units of Krakatoa Islands. Krakatoa Islands in this geomorphological case, is still controlled by climate change, erosional of sea water wave, 1883 catastrophic eruption which produces rock in the form of lava and pyroclastic and volcanic activity still continues to this day.

Keyword. Geomorphology; Sunda Strait; Krakatoa Islands; Indonesia.

1. Introduction
Administratively the research area is located in Nature Preserve and Marine Preserve Krakatoa islands, South Lampung District, Lampung Province (Figure 1). Geographically the research area is located at 105° 21’ 25” – 105° 28’ 00” S dan 06° 04’ 15” – 06° 10’ 15” E. Research area has a wide area of 138.1 km² which includes two areas, namely is marine with an area of 112,4 km² and land territory which is divided into several islands, namely is Sertung island with an area of 7.8 km², Anak Krakatoa island
with an area $2.8 \text{ km}^2$, Panjang island with an area of $2.7 \text{ km}^2$, Rakata island with an area of $12.4 \text{ km}^2$ with total land of area of $25.7 \text{ km}^2$.

Krakatoa Islands now have an active volcano that is Anak Krakatoa volcano which is one of 129 active volcanoes in Indonesia. Krakatoa Islands consists of four islands, namely is Rakata, Sertung, Panjang, and Anak Krakatoa island. The first three islands are the remains of the ancient Krakatoa volcano, whereas Rakata Island is a volcano that has grown at the same time with Danan volcano and Parbuwatan volcano before plinian erupted in 1883 AD.

![Figure 1. Location map of Krakatoa islands.](image)

Old Krakatoa is known in history at the time of the great eruption in 416, which led to formed of the first caldera [1-3]. In the formation of the caldera and the evolution of the Krakatoa Volcano has occurred three times (Figure 2) [1-7].
According to [1], the formed of caldera occurs due to the collapse of volcanoes by the emptying of magma and gas, formed of the caldera that causes the occurrence of tsunami. Tsunami occurred due to the eruption of 18 km$^3$ material eruption that depressed the sea water and this collapse that caused the tsunami that swept western coast of Java and southern coast of Sumatra [8]. The plinian erupted of volcano Krakatoa in August 1883 AD has killed 36,417 peoples [2].

Morphologically, Krakatoa islands has a very significant change, due to the volcanic activity that continues to work in the research area. The last eruption in 1883, it was the eruption that made the geomorphology of Krakatoa islands now. After the eruption of 1883 AD, in 1927 has appeared of new volcanic activity below sea level on the Krakatoa islands was shown by the burst of volcanic ash 40 meters [9]. The volcanism activity has now become an island, called Anak Krakatoa Island. Anak Krakatoa is one of the active volcanoes in Indonesia. The Krakatoa Islands now consist of 4 islands, with the morphology as the result of volcanic activity.

2. Data and Method
In this study, geomorphological analyzes were performed using topographic maps of the Krakatoa islands (Figure 3), DEM (Digital Elevation Model), shoreline digitization from 1984 to 2018 (Figure 4) and direct field observations. Data is processed to determine the geomorphology of the research area.
Geomorphology unit of the research area refers to the classification of geomorphology by [10]. of Geomorphology unit boundaries in the research area has drawn based on the observed contour patterns using topographic maps, surface textures that can be seen from DEM (Digital Elevation Model), and slope criteria referred to the slope classification by [11] (Figure 5).
Figure 5. Slope map of Krakatoa islands.

River flow/valley pattern is easily recognized from topographic or aerial maps, especially on a large scale, while on a medium scale will show an overall pattern as a reflection of rock types as well as geologic structures. Determination of river flow pattern in this study refers to the classification of river flow patterns by Howard, 1967 [see 11]. Based on observations from topographic maps with a scale of 1: 20,000, that rivers in the research area have a pattern is radial and semi radial (Figure 6).

Figure 6. Valley pattern map of Krakatoa islands.

3. Result and Discussion
Geomorphology of Krakatoa islands is controlled by erupted materials and level of rock resistance. Volcanic activity in the form of explosive and effusive eruption acts as an early stage of topographical expression of research area, then influence of erosion process resulted in the erosion of older rocks. The level of rock resistance to the geomorphic process results in topographic expression with a tightly contour pattern and can be divided into 9 geomorphological units (Figure 7). Geomorphology unit of the research area refers to [10].
Figure 7. Geomorphological map of Krakatoa islands.

The first geomorphological unit is the unit of Anak Krakatoa volcano crater (Figure 8). This unit is located at the top of the Anak Krakatoa volcano, with extensive is 0.08% of Anak Krakatoa island area and 0.009% of the lands area of the study area. This unit has a slope of 16 ° to 35 ° in height ranging from 315 to 325 meters above the surface of the sea. This unit is the center of volcano eruption Anak Krakatoa by showing the structure of the crater with the volcanism activity shown. The height of the volcano Anak Krakatoa will continue to increase as eruption volcano Anak Krakatoa which in 1 year can happen 1 to 6 times eruption with rest period of 1 to 8 years [9]. This unit is generally formed by igneous rocks with high resistance levels.

The second geomorphological unit is the volcano cone Anak Krakatoa unit (Figure 9). This unit is located on Anak Krakatoa island with extensive area of 18.55% of Anak Krakatoa island area and 2.02% of the land area of the research area, characterized by a tight contour pattern. This unit has a slope of 25° to 40° with a height of 50 to 325 meters above sea level. This geomorphological unit is an active volcano cone until now formed in the middle of the volcano crater Anak Krakatoa which is now a ridge of the remaining volcano Anak Krakatoa in 1983 highly about 200 meters above sea level and the eruption that occurred on the volcano Anak Krakatoa continues to perform its activities, the growth of the new Anak Krakatoa volcano cone becomes larger and exceeds the height of the ridge of the remaining volcano Anak Krakatoa. In 2000, the volcano cone of Anak Krakatoa reached a height of about 300 meters above sea level and in 1999 the ridge of the remaining volcanoes of Anak Krakatoa and the new volcano of Anak Krakatoa cone formed a large volcanic cone [12]. This geomorphological unit is composed of fall deposit and is dominated by resistant lava.
The third geomorphological unit is the ridge of the remaining volcano Anak Krakatoa unit (Figure 10). This unit is located on Anak Krakatoa Island with an area of 9.47% of Anak Krakatoa Island area and 1.03% of the land area of the research area, characterized by a relatively tight contour pattern. This unit has a slope of 25° to 35° with an height of 60 to 150 meters above sea level. The ridge of the remaining volcano Anak Krakatoa is not showing the actual cone because the top of the volcano Anak Krakatoa has disappeared and left the ridge with a crater structure that has not shown volcanism activities with a height of about 150 meters above sea level. This unit shows the remaining crater structures shown by the bedding on the crater wall with formed by pyroclastic deposit.
The fourth geomorphological unit is the ridge of the lava flow of Anak Krakatoa volcano (Figure 11). This unit is located on Anak Krakatoa Island with an area of 54.85% of Anak Krakatoa Island and 6.1% of the land area of the research area, characterized by a relatively loose contour pattern. This unit has a slope of 4° to 16° with an altitude ranging from 0.1 to 140 meters above sea level. These geomorphological units are generally formed by lava flows. In this unit can be seen aa’ lava in every lava flow of volcano Anak Krakatoa. Lava flow in this unit has a special morphology that is formed almost in all directions. These geomorphological units generally exhibit a form with a rough surface reflecting from the aa lava structure and generally exhibiting flow patterns and forming a ridge extending from the source of the eruption to the coast. See figure 4, there is not so intensive change in the shoreline of this unit because the constituent rocks in this morphology are igneous rocks that the level of resistance to erosion is high enough.

The fifth geomorphological unit is the pyroclastic plains of Anak Krakatoa volcano (Figure 12). This unit is located on Anak Krakatoa Island with an area of 14.74% of Anak Krakatoa Island and 1.61% of the land area of the research area, characterized by a loose contour pattern. This unit has a slope of 0° to 16° with a height ranging from 0.1 to 60 meters above sea level including flat to steep slopes. Lithology of the unit in the form of pyroclastic deposit. Generally, the unit is covered by dense vegetation with abrasion process on the beach. Abrasion of the beach on the southern part of this unit is quite a contrast, at least several times has reduced by abrasion. Looking at figure 4, from 1983 to present the shoreline...
of this unit has land-degradation in both the southern and the eastern parts of this unit. This reduction of land is controlled by the constituent rocks of this unit is a unconsolidated pyroclastic deposit.

![Image of pyroclastic plains of Anak Krakatoa volcano.](image1)

**Figure 12.** Pyroclastic plains of Anak Krakatoa volcano.

The sixth geomorphological unit is the rest ridge of the Rakata volcano unit (Figure 13). This unit is located on Rakata island with an area of 28.51% of Rakata island and 13.82% of the land area of the research area, characterized by a contoured pattern. This unit has a slope of 25° to 45° with an height ranging from 110 to 750 meters above sea level. This unit is the remnant of Krakatoa island which was originally an island with 3 volcano cone namely is Rakata, Danan volcano and Parbuwatan volcano. In 1883, there was a big eruption on the three cones so as to the formation of the second caldera that had previously occurred in 416 AD. Krakatoa eruption in 1883 AD leaves only half-cone morphology which is the Rakata island now.

![Image of rest ridge of Rakata volcano.](image2)

**Figure 13.** Rest ridge of Rakata volcano.

The seventh geomorphological unit is the ridge of the pyroclastic flow of Krakatoa volcano (Figure 14). This unit is located on Sertung island, Panjang island and Rakata island, with an area of 63.86% of the land area of the research area and is characterized by a loose contour pattern. This unit has a slope of 10° to 25° with a height ranging from 0.1 to 220 meters above sea level. This unit is evidence of the deposit of Krakatoa eruption in 1883. This unit is deposited in almost all islands located in the Krakatoa
islands and almost covered 50% of land on each island. Seeing from figure 4, this unit saw many shoreline changes, especially on the northern part of Sertung island from 1983 until now, in contrast to the difference and when viewed from the constituent rocks in the area that is the product of Krakatoa 1883 eruption that unconsolidated properly. The units on this part of Rakata island are slightly different from the shoreline changes in parts of Sertung island, because the products of the 1883 Krakatoa eruption have been quite consolidated compared to the parts of Sertung island. In this geomorphological unit is still often occur shoreline changes both the addition of land and land reduction due to the constituent rocks are rocks that have not been consolidated enough so well that abrasion or caused by the decrease of sea level.

![Figure 14. Ridge of pyroclastic flow of Krakatoa volcano.](image)

The eighth geomorphological unit is the wall of Krakatoa caldera unit (Figure 15). This unit is located on Sertung island, Panjang island and Rakata island, with an area of 11.82% of the land area of the research area, characterized by tight contour patterns until very close. This unit has a slope of 40° to more than 55° with a height ranging from 0.1 to 790 meters above sea level. This unit is evidence of the remaining caldera formation resulted from the 1883 Krakatoa eruption. This geomorphological unit also shows the succession of constituent rock of Rakata island. Geomorphology locus lithology consists of pyroclastic flows from Krakatoa 416 at the bottom, pyroclastic fall deposit, andesite lava and basalt lava and pyroclastic fall at the top of Rakata. Exogenous processes that affect these units are weathering and vertical erosion.
The ninth geomorphological unit is the Krakatoa coastal plains (Figure 16). This unit is located on the Sertung island and Anak Krakatoa island with an area of 0.51% of the land area of the research area with characterized by a very loose contour pattern. This unit has a slope of 3° to 7° with an altitude ranging from 0.1 to 18 meters above sea level. This geomorphological unit occupies the northeast and south of Sertung Island, east of Anak Krakatoa, north, Panjang island and east of Rakata. This unit is composed pyroclastic and sand of loose material. Looking at figure 4, these units often shoreline changes due to changes in wind direction resulting in frequent occurrence of land increase and land decrease.

4. Conclusions
- Generally, geomorphology of the research area is controlled by volcanic activity. Geomorphology unit in the research area is divided into 9 geomorphology units, namely is crater of Anak Krakatoa volcano, volcano cone of Anak Krakatoa, rest ridge of volcano Anak Krakatoa, ridge of lava flow of Anak Krakatoa volcano, pyroclastic plains of Anak Krakatoa volcano, rest ridge of Rakata volcano, pyroclastic flow ridge of Krakatoa, wall of Krakatoa caldera and Krakatoa coastal plains.
- Geomorphology of the Krakatoa islands is controlled by rock resistance, other than that by abrasion resulted in coastline changes. From 1983 to present, shoreline in the Krakatoa island can
still continuous. Rocks with high resistance are long enough to experience shoreline changes whereas in rocks that have unconsolidated or rocks with low rock resistance are very rapidly changing shoreline.

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