Morphotectono-volcanic of Tertiary volcanic rock in Kulon Progo mountains area, Yogyakarta-Indonesia

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Abstract. Kulon Progo Mountains have very distinctive shapes, where they have form of circular structures of volcano that are still intact and the other is not been intact. This morphology is the morphology of the remaining volcanoes formed by tectonics and certain volcanism. The study was conducted through a series of interpretations of volcanic body distribution, alignment interpretation on satellite imagery and field work. The formation of Kulon Progo Mountain morphology is strongly influenced by tectonic and volcanic processes. The process of tectonics which produces strike-slip fault structures, normal faults, and uplifts have formed the lineaments of the valleys and hills with various pattern directions. The volcanism that has occurred forms the structure of volcanic remains. Distribution of volcanic rocks form a circular or semicircle structures because of the normal fault structures that have occurred.

Keywords: morphology, tectonic, volcanic, uplift, fault.

1. Introduction
Kulon Progo Mountain is located in the southern part of Java Island, Central Java-Indonesia. Volcano-tectonically, the Kulon Progo Mountain is part of the Sunda-Banda Arc, which is a Tertiary (Ancient volcanic arc) up to the Quarternary volcanic arc (recent volcanic arc). These volcanic arcs are formed as a result of subduction of oceanic plate in the south of Java Island. This is a normal subduction of the Indian Ocean Plate northward under the Eurasian Continental Plate. The location of the study area is shown in Figure 1.

The position of subduction in southern Java Island progressed closer and further away from the mainland of Java, but the location of the arc was relatively constant [1]. This results in the occurrence of superimposed volcanic activities from time to time in the Kulon Progo Mountain. Previous researches by [2, 3], conclude that the unique morphological expression of the Kulon Progo Mountain is caused by the general trend of tectonics that has occurred in Java since Eocene time. This research gives some explanations related to the morphological and tectonic relation in forming the recent morphological of the area.

2. Regional Geology
The stratigraphy of Kulon Progo area is included in the Old Volcanic Area, composed by sedimentary rock formations of Nanggulan and volcanic rocks of Kebo Butak Formations. The Nanggulan and Kebo Butak formations are intruded by andesite and dacite which have generally been altered.
Research resulted by [4, 5, 6], state this volcanic groups are covered by the shallow sea of limestone sediments of Jonggrangan and Sentolo Formations.

Figure 1. Research area location.

Nanggulan Formation can be found in the area of Nanggulan, Girimulyo and Kalibawang (east of Kulon Progo Mountain). Locally, this formation is also found in the Sermo Dam-Kokap sub-district region in the form of lenses or xenolite blocks in andesite rocks. The old research by [7], explains that this formation is the oldest rock in Kulon Progo Mountain. Its lithology consists of sandstones with lignite [8,9,10], sandstone, limonite, marl and limestones, sandstones, tufs rich in foraminifera and molluscs, estimated thickness 350 meters. Based on the study of planktonic foraminifera, the Nanggulan Formation has an age range between the Middle Eocene to the Oligocene [7,8,11,12,13,14]. This formation is formed in a shallow marine environment to transition [15].

The Old Andesite Formation [7] formed unconformitycally above the Nanggulan Formation. Lithologically, this formation consist of volcanic breccia with andesite fragments [16], andesite intrusive rocks [4, 5, 6, 16, 17], dasite intrusion [4, 5, 6], basal intrusion [16], lapilli tuff [16], tuff [16], lapilli breccia, andesite lava flow [16], agglomerates, and volcanic sandstones exposed in many locations in the Kulon Progo region. The formation is exposed both in the central, northern, and southwestern regions of the Kulon Progo Mountain, forming a moderate to steep ridge of morphology. The thickness of this formation is approximately 600 meters. The age of this volcanic formation is Upper Oligocene [1, 18, 19, 20, 21], up to Miocene [21, 22].

Above the Old Andesite Formation deposited limestone rock of Jonggrangan Formation, unconformitycally at the volcanic heights [23, 24]. Generally, this formation at the bottom consists of conglomerates, tuffaceous marl, and sandstone with molluscs and claystone with lignite. At the top, the composition of this formation is bedded limestone and coraline limestone [25]. The thickness of the constituent rocks is 200-500 meters [7] and its age is the Early to Middle Miocene. This formation, at the bottom is inter-fingered with the bottom part of the Sentolo Formation. This formation formed the mountains and conical hills and spread in the middle of Kulon Progo Mountain [7]. Sentolo Formation consists of limestones, marls and calcareous sandstones. According [26], the age of this formation is the early Miocene to Pliocene.

Normal faults, thrust faults and strike-slip faults [27] control the distribution of rocks in the Kulon Progo Mountains. Joints, folds and faults [28] can be found in the Kulon Progo Mountains. Shear fracture, tension fracture, normal fault, thrust faults, strike slip fault, syncline and anticline [29] formed in Kulon Progo Mountains. The fault formed in the Kulon Progo region is generated by the compressional and extensional tectonic phases [30]. Fault lineaments are common in the inner part volcanic rocks of Gajah volcano [31]. In Kulon Progo Mountains, the steep slopes tend to form in lava rock and andesite breccia in areas with a lot of geological lineament [31]. Previous research by [32] states that the alignment of geological structures in the Kulon Progo Mountain is more intensive when compared with the Southern Mountain of Java on the eastern side of Yogyakarta Province.
3. Method
The method used in this research is through a series of morphological analysis work, tectonic and volcanic body in Kulon Progo Mountain. Morphological analysis includes the interpretation of volcanic body distribution and the making of morphological cross-section of each volcanic body. Tectonic analysis includes alignment interpretations on satellite imagery, drawing of rosette diagrams, and field geology studies resulting in the distribution of geological structures on the Geological Map. The results of previous research by some researchers are used in supporting the analysis and synthesis of this study.

4. Volcanism in Kulon Progo Mountain

4.1. Eocene Volcanism
Based on previous researchs, there have been mentioned 3 volcanoes in Kulon Progo Mountain [6, 20]. These volcanoes are Gajah, Ijo and Menoreh volcanoes. However, based on other researchers studies mentioned the existence of older rocks. The presence of Eocene volcanic rocks is determined by [33]. These rocks are located in the central part to the north of the body of Ijo volcano (Figure 2). Distribution of this Eocene-based rock, stretching from the area of Nanggulan Formation found at the edge of the Sermo Dam to the northwest. These rocks form the morphology of mountain slopes up to hills. Based on the results of field observations (Figure 3) and previous research studies, revealed that the type of rocks are andesite and basaltic lava. The results of determining the absolute age [33], indicate the presence of rocks aged 47.42 + 3.19 or Middle Eocene. Based on the morphological texture of the image, we can describe the rocks that have the same character (Figure 2). This Eocene volcanic rock is within the circle of Ijo volcano's body, as the bedrock of Ijo volcano's body. This rock is above the Nanggulan Formation in the southeast.

The volcanic material found in Nanggulan Formation rocks is from this Eocene volcano. Tuffaceous materials and andesite / basaltic rock fragments in quartz sandstone are present at the bottom of the Nanggulan Formation. Mixing between claystone (Nanggulan Formation) and andesite (Eocene volcanic) rocks found at the top of the Nanggulan Formation (sedimentary melange-Figure 3 part a).
4.2. Oligocene Volcanism

Gajah volcano is a volcano located in the middle of Kulon Progo Mountains and some researcher state to be the oldest volcano in this area (Figure 4.). This volcanic product is centered on the western part and stretches east, north and slightly westward. The western and southern sides of this volcano have been broken and missing covered by younger volcanic materials or sediments. Central part or central facies of Gajah volcano which is the place of magma from the earth to the surface located in the west part or in the Kaligesing-Purworejo Regency. This part is characterized by lava rock associations and a variety of semi-volcanic intrusions such as volcanic necks and dykes. [6] states this central facies region as the body of Pencu Mountain. He mentioned that the rocks of this region in the form of andesite intrusion, lava and breccia of Mount Pencu.

In the southern part, there is a circular pattern that is still intact from Ijo volcano. This intact circular pattern covers Gajah volcano in the middle part of Kulon Progo Mountain. Ijo volcano more shows a circular pattern (circular features) and still intact, while Gajah volcano no longer shows this structure. This happens because Gajah volcano is covered by the presence of rock from Ijo Mountain. This cross-cutting relationship shows that Gajah volcano comes first and then Ijo volcano comes to close part of Gajah volcano's body. Almost the entire body of Gajah volcano covering the proximal, medial and distal facies on the south side has been collapsed and covered by the material of Ijo volcano.

4.3. Late Miocene Volcanism

At the northern part of the Kulon Progo Mountain, there is a half-circular pattern of Menoreh volcanic body. This Tertiary volcanic body has been cut and only half of it. The rest of this volcano opens to the north. The foot of this volcano is located on the body of Gajah volcano in the northeast. By added Jonggrangan Formation at image analysis, indicating that Menoreh volcanic body is above the Jonggrangan Formation. By image analysis can be determined that Menoreh volcano is younger than Gajah volcano, Ijo volcano and Jonggrangan Formation.
Figure 4. The body of Gajah and Ijo volcanoes which have Oligocene age and Menoreh which has Late Miocene age.

Menoreh volcano is a volcano located in the northern part of Kulon Progo Mountain as the youngest volcano. Menoreh volcano is separated from Gajah volcano and Ijo by a long period of time covering the post-Ijo erosional period, the settling period of Jonggrangan and the post-Jonggrangan erosion period. This semi-circular structure of the volcano can still be seen clearly (Figure 4.). An absolute age analysis by K-Ar method of a rock taken from the volcanic centre near Borobudur Temple (north side of Kulon Progo Mountains) has been done by [22]. This dating by hornblende age analysis showed age of 12.4 ± 0.7 Million years ago or Late Miocene.

5. Volcanic Residual Morphology

Proximal facies rocks such as lava and pyroclastic breccia of Gajah volcano develop in the east, west and north of the central facies. This area is dominated by lava flows and pyroclastic breccia, which are highly resistant, thus forming a pile or height influenced by the northwest-southeast (NW-SE) trending normal faults. Intrusion of dyke andesite is found in the southern part of Gajah volcano directed northwest-southeast (NW-SE) cut off andesite lava rock. Its position is adjacent to the hydrothermal Gajah volcano, causing the area to undergo hydrothermal alteration. This results in changes of some minerals to clay minerals in rocks. The flow of the river develops following the structure and the argilic alteration zones where clay minerals develop intensively. This leads to these close facies, lower in elevation than in the central Gajah volcano and the intermediate facies of Gajah volcano area (Fig. 5 Section 1 and 2).
Figure 5. East-West and North-South morphological cross-section of Gajah volcano.

Medial facies rock such as laharic breccia of Gajah volcano, develops in the east and north side of proximal facies. There is a thin of lava because of more far away from the volcanic source. Laharic breccia and tuff are start to dominant. Generally, laharic breccia has angular to sub-rounded form. Conglomerate with rounded-sub rounded form, sandstone, siltstone and claystone presents at this area. The rocks of this area are not affected by hydrothermal alteration, so they are still resisten. As the position is more high, these area then to be the place of growing corall as the source of Jonggrangan Formation in the east side of Gajah volcano (Figure 5 Section 3). In the eastern part of Gajah volcano, andesite breccia, conglomerate, sandstone, siltstone, thin limestone are develop at the distal facies. East-west faults form some river and morphology at figure 5 section 4. Morphologically, this area controlled by east-west normal fault and northeast-southwest thrust fault which bring Nanggulan Formation to expose.

Proximal facies of Ijo volcanic rocks such as lava and pyroclastic breccia develop around the central facies (Figure 4). A small part of this rock group is very resistant, so some form hills, hills of intrusion and lava surrounding the central facies. Most of these lava bodies have undergone alteration and mineralization, thus forming a low relief surrounding the height of the volcanic centre (Figure 6 Section 1). Medial facies rocks such as andesite breccia and lava develop around the proximal facies on the slopes of Ijo volcano, both on the western, southern, northern and eastern sides. This area is dominated by breccia tuff, andesite breccia and tuff. The process of alteration and mineralization does not develop intensively in all parts of this facies, thus the resistance of the rock to the facies is still maintained. Generally these facies form a high altitude morphology (Figures 6 Section 2, 3 and 4) surrounding the proximal facies of Ijo volcano. The circular or circular pattern of Ijo volcano body can be easily recognized through the image and topographical map through the delineation of this medial facies. In the upper Girimulyo and Kokap areas, this rock becomes the site of the growth of coral reefs forming the Jonggrangan limestone formation (Figure 6 Section 3).
Distal facies rocks do not develop intensively on the slopes of Ijo volcano either on the south west, north and east. Locally these distal facies are found in the eastern part of Ijo volcano (Figure 4). This is likely due to a fault that cuts out the distribution of this facies or because it is covered by the Sentolo carbonate sediment formation.

Morphology of the Menoreh volcano shows a semi-circular shape facing northeast (NE). This morphology is highly controlled by normal faults and hydrothermal alterations in the middle part. The loss of half of this mountain is due to a normal fault of the east-west trending in the north side (cut in Figure 7 Section 4). The circular pattern is seen to be more controlled by the erosion of the argillic alteration zone which is rich in the hydrothermal clay of the andesite lava rocks. Meanwhile, in the un-altered medial facial breccia, there is no strong erosion (Fig. 7 Section 2 and 3).

6. Tectonism
Interpretation of the lineaments are done by drawing lines on the image, where in the field can be a pattern flow channel, a row of hills that form straightness, straightness scrap, straightness of the valley and straightness due to similar rock types. The types of straightness can’t be directly determined from the line drawing on the image, therefore, to the structure of the structure of the results of image interpretation, conducted field review to ensure the results of interpretation. Fieldwork is also needed to find geological structural data and field measurements. The results of the image interpretation and fieldwork will be related to the distribution of rocks on the geological map, resulting in a relationship between geological structures with the distribution of rock formations in the Kulon Progo Mountain.
Gajah volcano as the oldest volcanic rock in the Kulon Progo Mountain shows the highest lineaments of 430 pieces or 41.99% of all the data. The number of lineaments is the largest compared to other rock groups in Kulon Progo Mountain. As the oldest volcanic rocks, some of the structures formed on the volcano's body are also the recording of the structure to the youngest rocks (Menoreh volcano). Ijo volcano as the second volcanic rock present in Kulon Progo Mountains, shows the presence of 345 data or 34.69% of the alignment of all the straightness in the study area. Menoreh volcano as the youngest volcanic rocks present in Kulon Progo Mountains, shows the presence of 249 lineaments or as many as 24.31% of the overall straightness.

**Figure 8.** Lineaments interpretation and rose diagram of lineaments in Kulon Progo mountain area.

In the map of the geological structure (Figure 9) above, it is illustrated the faults in the west part of Gajah volcano. This fault is the oldest fault in the Kulon Progo area because it develops in the oldest rock and causes the collapse of Gajah volcano on the south side with the same direction that is northwest-southeast (NW-SE). Stereographic analysis of shear fracture and brecciation data resulted in a normal fault. Referring to the age of Ijo volcano which was born in Oligocene age, then the age of this fault is also still Oligocene.

**Figure 9.** Geological structures and stereographic analysis of the structures.
There is a long fault that cuts Kulon Progo Mountain from south to north, cutting Gajah, Ijo and Menoreh volcano. Because of this fault cut Menoreh volcano, as the youngest rock, the fault is active last time at post-Menoreh (post Late Miocene). The fault is an old fault that existed since the late Oligocene [13, 33, 34, 35]. The possibility of this old fault is activated and is an active fault, since there is a river alignment in the same direction in the quarterly rocks in the northern Kulon Progo Mountain. Based on stereographic analysis of shear fracture data, brecciation and tension fracture in lava of Gajah volcanic rock, this type of fault is a sinistral fault or left lateral strike slip fault. This sinistral Kulon Progo fault extends to Mount Muria in the north of Java Island as the Progo-Muria Fault [13, 33, 34, 35].

On the northern side of the Kulon Progo Mountains, Menoreh volcano is cut off by a west-east (E-W) trending structure. This trending fault is intensively formed in this section and less developed in other parts of Kulon Progo Mountain. Based on stereographic analysis of striation data, this normal fault is formed by a north-south trending extension. On the eastern side of Gajah volcano there is an Eocene rock. This phenomenon is controlled by the existence of a thrust fault that lifts it from the depth so it is exposed on the surface.

7. Discussion
The morphology of Kulon Progo Mountain is composed of Gajah, Ijo and Menoreh volcano. This row of mountains have a relatively north-northeasterly direction (NNE). These Tertiary volcanoes and Progo-Muria fault line described by [13]. Research by [34] also describes this straightness as the boundary of Archean continental plate in the Southern Mountains of Java. Publication by [33] also describes the Progo-Muria straightness originally derived from the transform fault that accommodates East Java’s microcontinent shifts. By delineation of the fault line, it can be obtained pattern of fault is left stepping left lateral fault.

Model by [36] illustrates the emergence of volcanoes in extensional and contractional tectonic regions (Figure 10). In this proposed model, in the tectonic extension zone, the polygenetic volcano develops extending perpendicular to the extension force. In the contractional tectonic zone, the polygenetic volcano develops relatively in the direction of the compression force. Kulon Progo Mountain is a zone of polygenetic volcano formed on two volcanic arcs in Java. Eocene volcanic rocks, Gajah volcano and Ijo volcano are on the Late Eocene-Early Miocene volcanic arc. While Menoreh volcano is on the Late Miose-Pliocene volcanic arc in the north.

![Figure 10. Emergence volcanic according to [36] model (A) Extensional tectonic stress field, (B) Contractional tectonic stress field and (C) emergence volcanic in Kulon Progo mountain model.](image_url)

These three volcanoes form the north-northeast straightness (NNE), which is controlled by the sinistral Kulon Progo fault, which forms a left stepping sinistral fault pattern. The directions of the fault lineament are forming an angle of about 30° from the direction of main compression (Figure 10.
section c). Kulon Progo fault or Progo-Muria fault is indicated as an old and active fault since before Oligocene time. The left stepping pattern of sinistral fault is one of the fault patterns that allow the formation of tension zones due to normal faults that develop. This zone makes it possible to rise of magma to the surface forming a volcano. The presence of Eocene volcanic rock, Oligocene volcano and the late Miocene volcano show this fault is very old and continues to be activated.

A complex of volcanism according to [37] allowed to develop on the base of sedimentary rock basins with particular tectonic controls. The sedimentary basin can evolve, from sedimentation of sedimentary material which is decreased to be buried by volcanism. The result of this change is the formation of sediment and volcanic body which is higher than the surrounding rocks. In Kulon Progo, Eocene volcanic rocks grow on Eocene sediments, Oligocene volcanics grow over sedimentary and volcanic of Eocene rocks, Late Miocene volcanism grows above the Jonggrangan Formation.

8. Conclusions
Tectonic effect in volcanic morphological formation and morphology of volcanic residue in Kulon Progo Mountains since Eocene time until now. N-S compression that produces left stepping left lateral fault, allowing the Tertiary volcano in Kulon Progo Mountains to be in one direction of NNE-SSW straightness. Compression from the southeast forms thrust fault and normal faults on the east side of Gajah volcano, resulting in the emergence of Nanggulan Formation. Morphology of the southern and western sides Gajah volcano has been collapsed by normal faults in the Oligocene Age. North side Menoreh volcano has been collapsed by normal west-east faults at Pleiocene time.

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