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RESEARCH ARTICLE

Morphotectono-Volcanic of Menoreh-Gajah-Ijo Volcanic Rock In Western Side of Yogyakarta-Indonesia

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Abstract

Menoreh-Gajah-Ijo have a very distinctive shape, where there are form of circular structure of volcano that is still intact and the other has not been intact. These morphologies are the morphology of the remaining volcanoes formed by tectonics and certain volcanisms. This study was conducted through a series of interpretations of volcanic body distribution, constructing a Slope Map, constructing a Slope Direction Map, constructing an alignment interpretation on satellite imagery and field mapping work. The formation of Menoreh-Gajah-Ijo morphologies are strongly influenced by tectonics and volcanic processes. The process of tectonism that produces the strike-slip fault structures, the normal faults, and the uplift have formed the lineaments of the valleys and hills with various directions patterns. The Menoreh-Gajah-Ijo volcanisms that have occurred form the structure of volcanic remains. Distribution of Menoreh-Gajah-Ijo volcanic rocks form some semicircle structures because of the normal fault structure that has occurred.

Keywords: Tectonic, Volcanic, Morphology, Alignment, Fault.

1. Introduction

Menoreh-Gajah-Ijo volcanics are located in the southern part of Java Island, Central Java-Indonesia. Volcano-tectonically, the Menoreh-Gajah-Ijo Mountains are part of the Sunda-Banda Arc, which is a Tertiary (Ancient volcanic arc) up to the Quarternary volcanic arc (recent volcanic arc). This volcanic arc is formed as a result of subduction of oceanic plate in the south of Java Island. This is the normal subduction of the Indian Ocean Plate northward under the Eurasian Continental Plate. The location of the Menoreh-Gajah-Ijo areas are shown in Figure 1 below.

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 (Soeria-Atmadja, et al., 1994). This results in the occurrence of superimposed volcanic activity from time to time in the Menoreh-Gajah-Ijo Mountains. Budiadi (2009) and Sudradjat, et al. (2010), concludes that the unique morphological expression of the Menoreh-Gajah-Ijo Mountains is caused by the general trend of tectonics that has occurred in Java since Eocene.

2. Regional Geology of Menoreh-Gajah-Ijo

The stratigraphy of Menoreh-Gajah-Ijo areas are included in the Old Volcanic Area, composed by sedimentary rock formations of Nanggulan and volcanic rocks of Kebo Butak Formation.

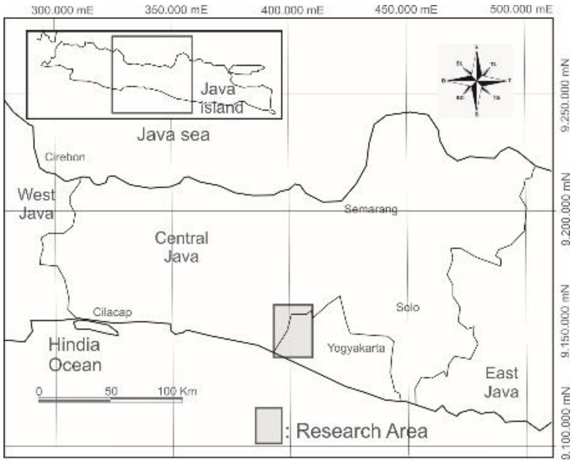

Figure 1. The Menoreh-Gajah-Ijo Tertiary volcanics location

The Nanggulan and Kebo Butak formations are intruded by shallow intrusive rocks in the form of microdiorite, andesite and dacite which have generally been altered. Rahardjo, et al. (1995), Rahardjo, et al. (2012) and Harjanto (2011) state these volcanics group are covered unconformitically by the shallow sea sediments of the Jonggrangan Formation and Sentolo Formation.

Van Bemmelen (1949), explains that Nanggulan Formation is the oldest rock in western of Yogyakarta area. Its lithology consists of sandstones with lignite (Harley and Morley, 1995, Rahmad et al., 2008, Ansori et al., 2015), sandstone, limonite, marl and limestones, sandstones, tufs rich in foraminifera and molluscs, estimated thickness 350 m. Based on the study of planktonic foraminifera, the Nanggulan Formation has an age range between the Middle Eocene to the Oligocene (Van Bemmelen, 1949, Bolliger and De Ruiter, 1975, Premonowati, 1994, Harley and Morley, 1995, Smyth et al., 2005, Saputra and Akmaludin, et al, 2015). This formation is formed in a shallow marine environment to transition (Prasetyadi, 2008).

The volcanic rock of Old Andesite Formation (Van Bemmelen, 1949) formed unformitycally above the Nanggulan Formation. Lithologycally, this formation consist of volcanic breccia with andesite fragments, andesite intrusive rocks (Suroso et al. 1987, Rahardjo, et al. 1995, Harjanto, 2011, Hartono and Pambudi, 2015, Rahardjo, et al. 2012), dasit intrusion (Rahardjo et al. (1995), Harjanto, 2011, Rahardjo, et al. (2012), basal intrusion (Suroso, et al. 1987), lapilli tuff, tuff, lapili breccia, andesite lava flow, agglomerates, and volcanic sandstones exposed in many locations in the Menoreh-Gajah-Ijo regions.

Satyana and Purwaningsih (2003) and Satyana (2005) state that above the Old Andesite Formation deposited Jonggrangan Formation, unconformitically at the volcanic heights. Generally, this formation at the bottom consists of conglomerates, tuffaceous marl, and sandstone with molluscs and claystone with lignite. Sulistyoningrum and Rahardjo, et al. (2010) states that at the top, the composition of this formation is bedded limestone and coralline limestone. The thickness of the constituent rocks is 200-500 meters (van Bemmelen, 1949) 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 Menoreh-Gajah-Ijo Mountains.

Sentolo Formation is also deposited above the Old Andesite Formation, in addition to the Jonggrangan Formation. The relationship between the Sentolo Formation and Jonggrangan Formation is inter-fingered. It consists of limestones and marl calcareous sandstone. It lower part consists of a conglomerate piled by tuffaceous marl with tuff. These rocks upward gradually transform into a nice layered coffin rich in foraminifera. The thickness of this formation is about 950 m. According Riandari and Wiyono (2013), the age of this formation is the early Miocene to Pliocene.

3. Research Method

The method used in this Menoreh-Gajah-Ijo research is through a series of morphological analysis work, tectonic and volcanic body in Menoreh-Gajah-Ijo Mountains. Morphological analysis includes the interpretation of Menoreh-Gajah-Ijo volcanics body distribution and making the morphological cross-sections of each volcanic body. Interpretation of Menoreh-Gajah-Ijo volcanics body distributions are done by Terrasar-x satellite image. Tectonic analysis includes alignment interpretations on satellite imagery, drawing of rosete 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 Menoreh-Gajah-Ijo Mountains Area

4.1 Gajah Volcanism

Gajah volcano is a volcano located in the middle of Menoreh-Gajah-Ijo Mountains and some researcher state to be the oldest volcano in this area (Fig. 2). This volcanic product is centered on the western part and stretches east, north and slightly westward. The western and southern sides of this mountain have been broken and missing covered by younger volcanic materials or sediments.

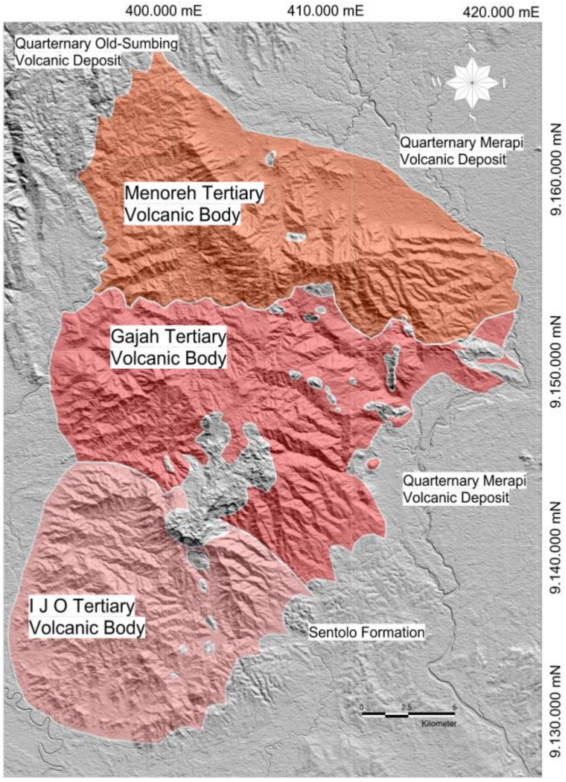

Figure 2. The body of Gajah and Ijo volcano which have Oligocene age and Menoreh which has Late Miocene age.

Central facies of Gajah volcanic body which is the place of magma from the earth to the surface located in the west part or in the Purworejo region. This part is Characterized by lava rock associations and a variety of semi-volcanic intrusions such as volcanic necks and dykes. Harjanto (2011) states this central facies region as the body of Pencu Mountain. He mentioned that the rocks of this region in the form of andesit intrusion, lava and breccia of Mount Pencu.

4.2 Ijo Volcanism

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 the 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.

The center of this volcano is the location of hydrothermal activity that affects the surrounding facies, resulting in the formation of altered rocks and even mineralization in surrounding facies such as in Kokap and surrounding areas (Purnamawati and Tapilatu, 2012). Setiabudi (2005) proposed in the Sangon area which is a proximal facies, found gold mineralization in quartz veins. It effected to the erosional proces and finally to the geomorphological features.

4.3 Menoreh Volcanism

In the northern part of the mountains there is a half-circular pattern of Menoreh volcanoes. This volcano 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 north. Image analysis added Jonggrangan Formantion, indicating that Menoreh volcano is above the Jonggrangan Formation. Thus Menoreh volcano is younger than Gajah volcano, Ijo volcano and Jonggrangan Formation.

Menoreh volcano is a volcano located in the northern part of the lineaments of Menoreh-Gajah-Ijo mountains 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.). Akmaludin et al. (2005) conducted an absolute age analysis by K-Ar method of a taken from the volcanic center near Borobudur Temple (north side of the mountain). Hornblende age analysis showed age of 12.4 ± 0.7 Million years ago or Late Miocene. On regional geological appearance, Menoreh volcanic rocks are above Nanggulan and Jonggrangan Formation. Menoreh volcano is also above the medial and distal faces of the north side of Gajah volcano.

The central facies of Menoreh volcano as a place where magma came out appears in the middle of the semicircle structure. This area characterized by igneous rock associations such as lava, volcanic neck and dyke (Idrus, et al., 2013; Idrus, et al., 2014; Rahardjo, et al., 1995; Rahardjo, et al., 2012). This area is the site of the formation of hydrothermal fluid, which affects the surrounding area. Therefore, it resulted in the formation of rocks alteration or mineralizations in the surrounding area in proximal facies.

The proximal facies of Menoreh volcano is outward from the central facies. This area is dominated by lava flows and pyroclastic breccia. This area has undergone a very intensive rock alteration so that the soil layer formed is very thick. This area is a site highly affected by hydrothermal fluid, thereby resulting in the formation of alteration rocks or even mineralization in the surrounding area such as Mount Gupit in Salaman and Borobudur Subdistrict, Magelang Regency (Idrus, et al., 2013) and in Kalisat area-Magelang (Idrus, et al., 2014).

Medial facies Menoreh volcano develops to the east, south and west of the volcanic body. In this area, as it is further away from the location of the volcanic source, lava flows and agglomerates have been reduced. In this area breccia andesite and tuff are very dominant. Laharic breccia has already begun in this area but lava Menoreh still reaches this part, showing the very dilute nature of lava. This rock group is very resistant, thus forming the height of Suroloyo and its surroundings.

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. 3 Section 1 and 2).

Medial facies rock such as laharic breccia of Gajah volcano, develops in the east and north side of proximal facies. There is a litle 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. Conggomerate with rounded-sub rounded form, sandstone, siltstone and claystone presents at this area. The rocks of this area are not affected by hydrotermal 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 (Fig. 3 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 Fig. 3 section 4. Morphologically, this area controlled by east-west normal fault and northeast-southwest thrust fault which bring Nanggulan Formation to exspose.

Proximal facies of Ijo volcanic rocks such as lava and pyroclastic breccia develop around the central facies (Fig. 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 center (Fig. 4 Section 1).

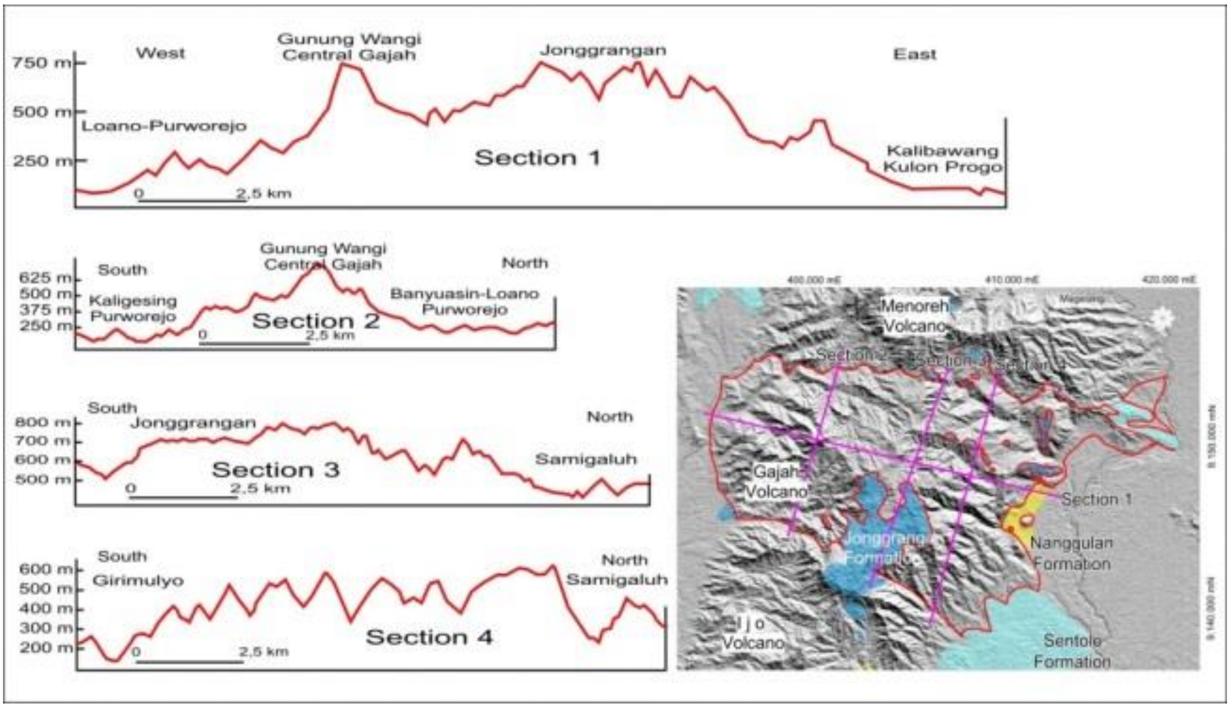

Figure 3. East-West and North-South morphological cross-section of Gajah volcano

Medial facies rocks such as andesite breccias 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 (Fig. 4 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 (Fig. 4 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 (Fig. 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 Fig. 5 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 unaltered medial facial breccia, there is no strong erosion (Fig. 5 Section 2 and 3).

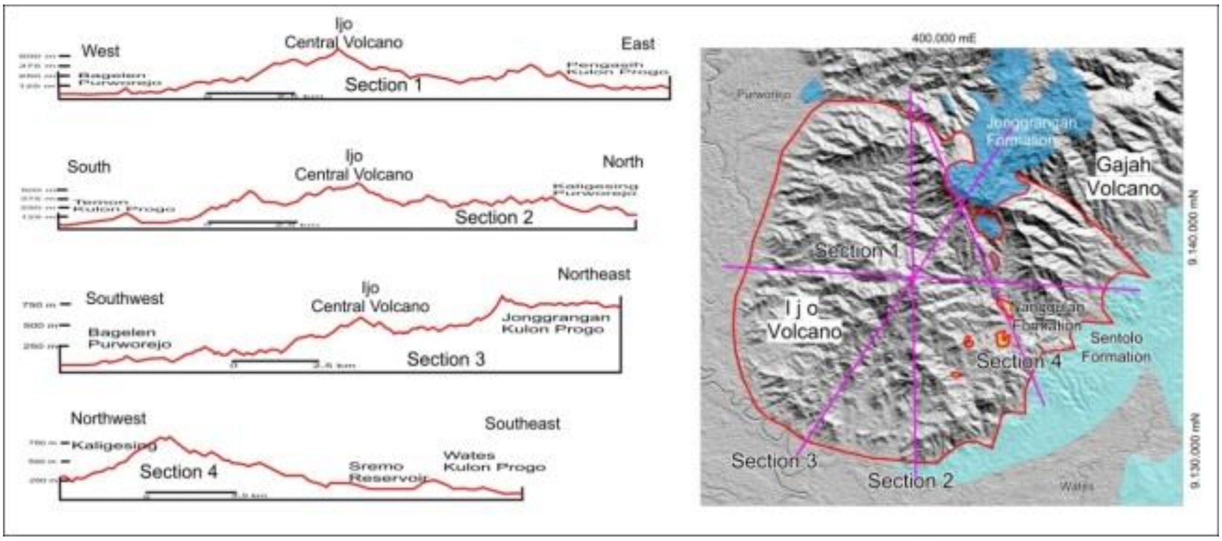

Figure 4. The cross-sectional view of Ijo volcano.

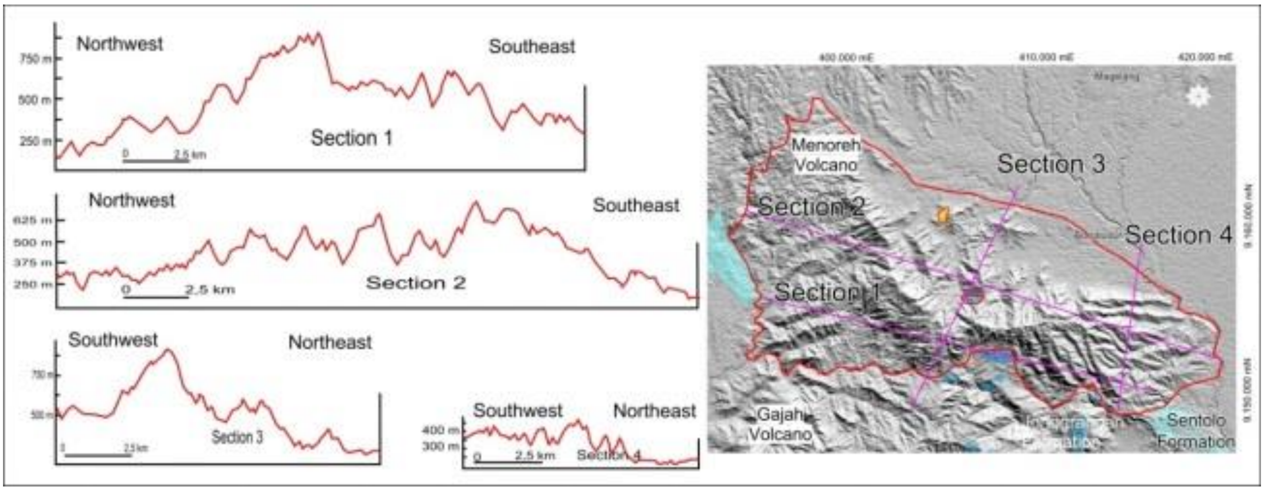

Figure 5. Cross-sectional of Menoreh Mountain morphology.

6. Tectonism

Reviews of Menoreh-Gajah-Ijo Mountains tectonism include interpretation and analysis of geological structure alignment, as well as an overview of geological structures on the geological map generated from this study. The alignment according to Sabins (1996) is a phenomenon on the surface of the earth that shows the characteristics of a straight appearance or an arch associated with a fault or a weak zone. The flow pattern is a common geomorphological expression of straightness. The different types of rocks also allow a contrasting appearance in remote sensing imagery observations.

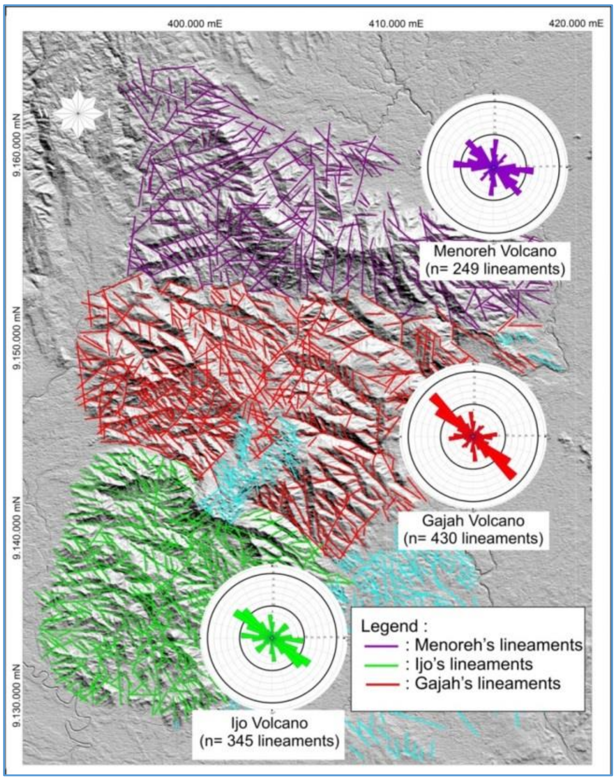

Figure 6. Lineaments interpretation and rose diagram of lineaments in Menoreh-Gajah-Ijo mountains area

Interpretation of the lineaments are done by drawing lines on the image (Fig. 6), 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 not 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 Menoreh-Gajah-Ijo Mountains.

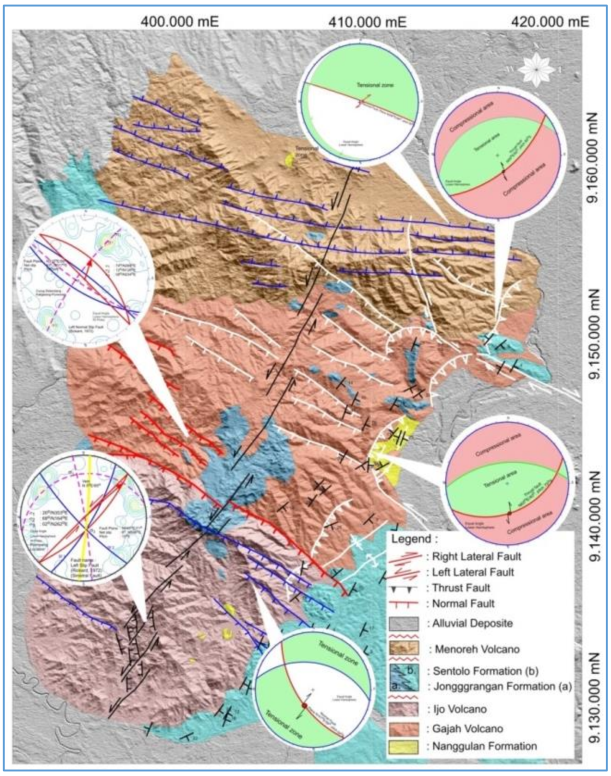

Figure 7. Geological structures and stereographic analysis of the structures

Gajah volcano as the oldest volcanic rock in the Menoreh-Gajah-Ijo Mountains 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 Menoreh-Gajah-Ijo Mountains. 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 Menoreh-Gajah-Ijo 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 Menoreh-Gajah-Ijo Mountains, shows the presence of 249 lineaments or as many as 24.31% of the overall straightness.

In the following Geological Map, we can see the distribution of three units of Tertiary rocks namely Gajah volcano, Ijo volcano and Menoreh volcano. These rocks are unconformity above the Nanggulan Formation exposed on the eastern side of Gajah volcano and the central part of Ijo volcano. The Sentolo Formation is found on the eastern side of Menoreh-Gajah-Ijo Mountains. Jonggrangan formation is found in the height in the middle of the mountains.

In the map of the geological structure (Fig. 7) above, it is illustrated the faults in the west part of Gajah volcano. This fault is the oldest fault in the Menoreh-Gajah-Ijo areas 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.

There is a long fault that cuts Menoreh-Gajah-Ijo Mountains from south to north. Because of this fault cut Menoreh volcano, as the youngest rock, the fault is active last time at post-Menoreh (post Late Miocene). However, if we refers to Smyth et. all, 2005, Hall et al, 2007, Smyth et al, 2008 and Husein and Nukman 2015 then this fault is an old fault that existed since the late Oligocene. 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 Progo fault extends to Mount Muria in the north of Java Island. Smyth et al, 2005, Hall et al, 2007, Smyth et al, 2008 and Husein and Nukman 2015 refer to it as the Progo-Muria Fault.

Normal faults in Ijo volcano develop in the northern part of Ijo volcano. This fault cuts the northern part of Ijo volcano, cuts Jonggrangan limestone rock formation and also crosses the sinistral Progo fault. Based on the stereographic analysis of the striation data in the fault plane, the tension-forming direction of this fault is southwest-northeast (SW-NE). This tectonic extension produces some normal faults on the north side of Ijo volcano.

On the northern side of the Menoreh-Gajah-Ijo 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 the Menoreh-Gajah-Ijo Mountains. 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 outcrop, which is very rare inJava island. This phenomenon is controlled by the existence of a thrust fault that lifts it from the depth so it is exposed on the surface. Based on stereographic analysis of striation data, it is generated that the movement of thrust fault is caused by the compression force from the southeast direction. This compression force also led to the exposure of sedimentary rocks of the Sentolo Formation, extensively on the east side of Ijo volcano, and not at all on the western side. This is supported by the presence of folds in the Naggulan Formation and Sentolo Formation which have the axis of the northeast-southwest (NE-SW) trending fold. The presence of this style is also supported by the dominance dipping layers of the Sentolo Formation rocks, which are tilted to the southeast.

6. Discussion

The morphology of the Menoreh-Gajah-Ijo Mountains is composed of Gajah, Ijo and Menoreh volcanic bodies. This row of mountains has a relatively north-easterly direction (NNE). Smyth et al. 2005 describes this Tertiary volcano and Progo-Muria fault line. Hall et al. 2007 also describes this straightness as the boundary of Archean continental plate in the Southern Mountains of Java. Husein and Nukman 2015 also describe the Progo-Muria straightness originally derived from the transform fault that accommodates East Java's microcontinent shifts. Based on field data analysis such as brecciation, shear fractures and tension fractures and striation along this fault line, it can be concluded that this fault is a horizontal fault or sinistral fault. By delineation of the fault line can be obtained pattern of fault is left stepping left lateral fault.

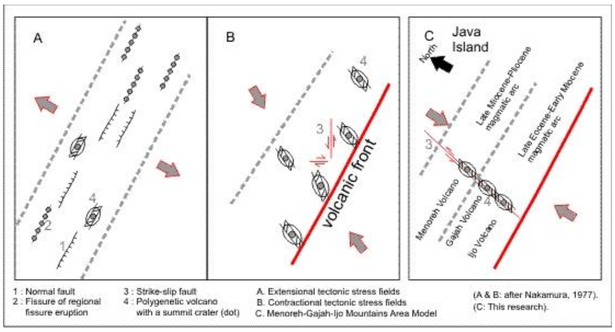

Figure 8. Emergence volcanic according to Nakamura (1977) model and emergence volcanic in the Menoreh-Gajah-Ijo mountains model

Nakamura (1977), illustrates the emergence of volcanoes in extensional and contractional tectonic regions (Fig. 8). In the 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. In this second model, he describes the presence of the geological structure of the fault of sinistral and dexstral, but no alignment of the polygenetic volcano follows both directions of the structure. The Menoreh-Gajah-Ijo Mountains are zones of polygenetic volcanoes formed on two volcanic arcs in Java. Gajah volcano and Ijo volcano are on the Late Eocene-Early Miocene arc volcano. While Menoreh volcano is on the Late Miosen-Pliocene volcano arc in the north.

These three volcanoes form the north-northeast straightness (NNE), which is controlled by the left horizontal fault (the sinistral 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 (Fig. 8 section c). Progo fault or Progo-Muria fault is indicated as an old and active fault since before the Oligocene. 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 create sedimentary basins or rise of magma to the surface forming a volcano. The presence of Oligocene volcano and the late Miocene volcano show this fault is very old and continues to be activated.

A complex of volcanism according to Alvarez et al. (2002) 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 (The Menoreh-Gajah-Ijo Mountain is higher than the area in the west and east). In the Menoreh-Gajah-Ijo Mountain rocks grow on Eocene sediments, Late Miocene volcanism grows above the Jonggrangan Formation and Oligocene volcanic rocks.

Alvarez et al. (2002) states, based on kinematics fault, stratigraphy and volume of volcanic rock, the volcanic body allows it to form due to the maximum extension, which allows magma to flow into the low pressure zone. Volcanic rock sequences show that volcanism is related to normal faults and magma occupies the room in the strain zone produced by strike-slip fault. In the Menoreh-Gajah-Ijo Mountains, left lateral Progo-Muria fault, patterned left stepping can create tension zones composed of normal faults that allow magmatism and vulcanism to grow in this low pressure zone.

Concha-Dimas et al. (2005) states that volcanism is often associated with faults and tensional fractures that allow magma to flow and fill in existing space. Pre-existing tectonic geological structures such as faults and joints contribute to the straightness of the volcanic body. Fig. 9, illustrates the sketch of the influence of volcano-tectonic properties and models on the formation of volcanic collapse (Concha-Dimas et al., 2005).

In Fig. 9 part A, illustrats the appearance of a contour pattern showing the tendency of the dyke and parasitic volcanic vent directions. In the study area, the dike is commonly found in Gajah volcano, in the northwest-southeast direction, in the direction of the normal faults that cause the collapse of Gajah volcano.

Intrusion hills such as Mount Kukusan, Mount Telu, Gunung Kuku, Gunung Agung around the volcanic center of Ijo volcano is a parasitic volcanic vent that develops in the Menoreh-Gajah-Ijo Mountains.

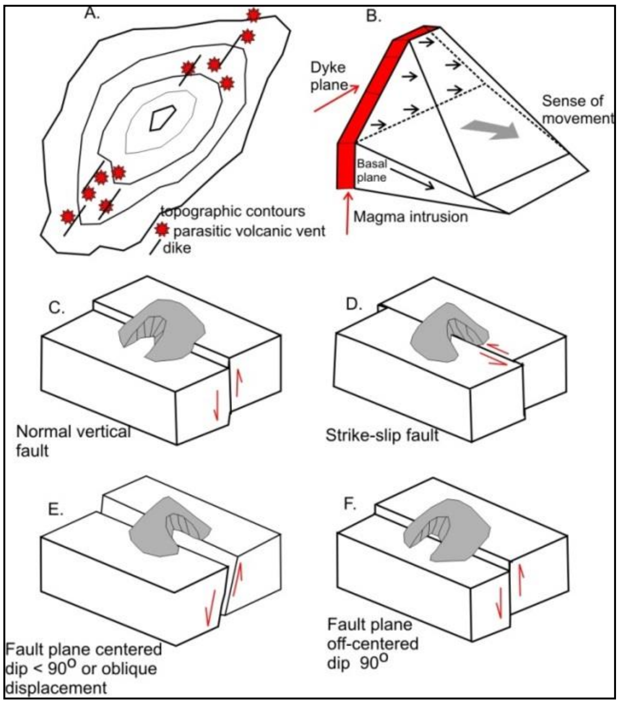

Figure 9. Effect of volcano-tectonic properties and models on volcanoes according to Concha-Dimas et al. (2005).

In Fig. 9 part B, it depicted the presence of dyke and direction of the volcanic slope collapse. In some places the presence of dyke is indicated to control the occurrence of landslides. The presence of dyke on the rocks in the field is cutting the rock body with a certain position. The rock in front of or above the slope of the dyke, where its position is a slope will be easy to landslide. While the rocks under the dyke, will be protected by the dyke body.

Fig. 9 part C describes the presence of a normal fault in the volcanic bedrock. The collapse of Gajah volcano on the southern side is due to the structure according to the drawing model C. Figure D, the state of strike-slip faults occurs on Menoreh volcano on the northern side of Menoreh-Gajah-Ijo Mountain. The collapse of Menoreh volcano is also controlled by a normal fault according to the F-figure model where the vertical fault plane is not centered. Figure E, volcanic conditions at normal faults in the central part of the volcano and the influence of the oblique fault field. This happened in the western part of Gajah volcano, which resulted in the body of Gajah volcano no longer symmetry.

6. Conclusions

1. N-S compression that produces left stepping left lateral fault, allowing the Tertiary volcano in Menoreh-Gajah-Ijo Mountains to be in one direction of NNE-SSW straightness.
2. Compression from the southeast (SE) to form thrust fault and normal faults on the east side of Gajah volcano, resulting in the emergence of

Nanggulan Formation and morphology of north-west trending hills.
3. Morphology of the southern and western sides Gajah volcano has been collapsed by normal faults in the Oligocene.
4. North side Menoreh volcano has been collapsed by normal west-east faults by N-S extension force on Pliocene Age.

References

Akmaluddin, Setijadji, D.L., Watanabe, K., and Itaya, T., 2005. New Interpretation on Magmatic Belts Evolution During the Neogene-Quarternary Periods as Revealed from Newly Collected K-Ar Ages from Central-East Java, Indonesia. Proceedings Joint Convention Surabaya-HAGI-IAGI-PERHAPI, The 30th HAGI, The 34th IAGI, and The 14th PERHAPI Annual Conference and Exhibition, Surabaya.

Alvarez, S.A., Samaniego, A.F.N., Zenteno, D.J.M., and Aldave, L.A., 2002. Rhyolitic volcanism in extension zone associated with strike-slip tectonics in the Taxco region, southern Mexico. Journal of Volcanology and Geothermal Research 118, 1-14.

Ansori, A.Z.L, Stefano, A.D., Jyalita, J. and Amijaya, D.H., 2015. Relationships of Depositional Environment and Mineralogy on Rock Fracturability (Brittleness): Case Studdy of Eocene Nanggulan Shale, Kulon Progo, Yogyakarta. Proceedings Indonesian Petroleum Association, 39th Annual Convention & Exhibition.

Bolliger, W. and De Ruiter, P.A.C, 1975. Geology of The South Central Java Offshore Area. Proceedings Indonesian Petroleum Association, 4th Annual Convention.

Budiadi, E., 2009, The Role of Tectonism in Controlling Geomorphology in Kulon Progo Area, Yogyakarta, Proceedings PIT IAGI Semarang, The 38th IAGI Annual Conventional and Exhibition.

Concha-Dimas, A., Cerca, M.,Rodriguez, S.R. and Watters, R.J., 2005. *Geomorphological* evidence of the influence of pre-volcanic basement structure on emplacement and deformation of volcanic edifices at the Cofre de Perote–Pico de Orizaba chain and implications for avalanche generation. Geomorphology 72,19–39.

Hall, R., Clements, B., Smyth, H.R., Cottam, M. A., 2007. A New Interpretation Of Java's Structure. Proceedings, Indonesian Petroleum Association, May, 2007.

Harjanto, A., 2011. Vulkanostratigrafi di Daerah Kulon Progo dan Sekitarnya, Daerah Istimewa Yogyakarta. Jurnal Ilmiah MTG, Vol. 4 No. 2, Yogyakarta.

Harley M.M and Morley R.J., 1995, Ultrastructural studies of some fossil and extant palm pollen, and the reconstruction of the biogeographical history of subtribes Iguanurinae and Calaminae, Review of Palaeobotany and Palynology, Elsevier Science,153-182. DOI: 10.1016/0034-6667(94)00133-5

Hartono, H.G. dan Pambudi, S., 2015. Gunung Api Purba Mujil, Kulon Progo, Yogyakarta: Suatu Bukti dan Pemikiran. Seminar Nasional ReTII Ke-10 Tahun 2015, STTNAS, Yogyakarta.

Husein, S., dan Nukman, M., 2015. Rekonstruksi Tektonik Mikrokontinen Pegunungan Selatan Jawa Timur: Sebuah Hipotesis berdasarkan Analisis Kemagnetan Purba. Proseding Seminar Nasional Kebumian Ke-8, FT-UGM.

Idrus, A., Warmada, I.W. dan Putri, R.I., 2013. Mineralisasi Emas di Gunung Gupit, Magelang, Jawa Tengah: Sebuah Penemuan Baru Prospek Emas Tipe Epitermal Sulfida Tinggi Pada Rangkaian Pegunungan Kulon Progo-Menoreh. Annual Engineering Seminar 2013, Proceeding, FT-UGM, Yogyakarta.

Idrus, A., Warmada, I.W., Satriadi dan Nabila A.W., 2014. Mineralisasi Emas di Kalisat Magelang, Jawa Tengah: Prospek Emas Tipe Epitermal Sulfida Rendah Di Pegunungan Kulon Progo-Menoreh. Annual engineering Seminar 2014, FT-UGM, Yoyakarta

Nakamura, K., 1977. Volcanoes as possible indicators of tectonic stress orientation — principle and proposal. J. Volcanol. Geotherm. Res. 2, 1–16. https://doi.org/https://doi.org/10.1016/0377-0273(77)90012-9

Prasetyadi, C., 2008. Provenan Batupasir Eosen Jawa Bagian Timur. Proseding Pertemuan Ilmiah Tahunan IAGI ke 37, IAGI, Bandung.

Premonowati, 1994. Informasi Paleobatimetri Asosiasi Fosil Moluska. Preceedings Geologi dan Geotektonik Pulau Jawa Sejak Akhir Mesozoik Hingga Kuarter, Yogyakarta.

Purnamawati, D.I., dan Tapilatu, S.R., 2012. Genesa dan Kelimpahan Mineral Logam Emas dan Asosiasinya Berdasarkan Analisis Petrografi dan Atomic Absorbsion Spectophotometri (AAS) di Daerah Sangon, Kabupaten Kulon Progo, Propinsi DIY. Jurnal Teknologi 5 (2).

Rahardjo, W., Sukandarrumidi, Rosidi, HMD., 1995. Peta Geologi Lembar Yogyakarta. Pusat Penelitian dan Pengembangan Geologi, Bandung.

Rahardjo, W., Sukanarrumidi, Rosidi, HMD., 2012. Peta Geologi Lembar Yogyakarta. Pusat Survey Geologi-Badan Geologi-Kementrian Energi dan Sumberdaya Mineral.

Rahmad, B., Maha, M. dan Rodhi, A., 2008. Reflektan Vitrinit dan Komposisi Maseral Seam Batubara Eosen Formasi Nanggulan Daerah Kalisonggo, Kecamatan Girimulyo, kabupaten Kulon Progo, DIY. Prosiding PIT IAGI Ke-37, Bandung.

Riandari, B.L. dan Wijono, S., 2013. Biostratigrafi Foraminifera Plangtonik dan Lingkungan Sedimentasi Formasi Sentolo Jalur Sungai Niten, Sungai Serang dan Dusun Ngramang-Kulon Progo. Proseiding Sem. Nas. Kebumian Ke-6, T. Geo UGM.

Sabins, F.F., 1996, Remote Sensing Principles and Interpretation, 3rd edition, New York, 93.

Saputra, R. dan Akmaluddin, 2015. Biostratigrafi Nannofosil Gampingan Formasi Nanggulan Bagian Bawah Berdasarkan Batuan Inti dari Kec. Girimulyo dan Kec. Nanggulan, Kab. Kulon Progo, D.I. Yogyakarta. Proseding Sem. Nas. Kebumian Ke-8, FT-UGM.

Satyana, A.H. dan Purwaningsih, M.E.M., 2003. Oligo-Miocene Carbonates of Java: Tectonic setting and effects of Vulcanism. Proceedings of Joint Convention Jakarta 2003, The 32nd IAGI and 28th HAGI Annual Convention and Exhibition.

Satyana, A.H., 2005. Oligo-Miocene Carbonates of Java, Indonesia : Tectonic-Volcanic Setting and Petroleum Implications. Proceedings Indonesian Petroleum Association The 13 th Annual Convention and Exhibition.

Setiabudi, B.T., 2005. Penyebaran Merkuri Akibat Usaha Pertambangan Emas Di Daerah Sangon, Kabupaten Kulon Progo, Propinsi D.I. Yogyakarta. Kolokium Hasil Lapangan, Direktorat Inventarisasi Sumberdaya Mineral/DIM 2005

Smyth H.R., Hall R., Hamilton J. and Kinny P., 2005. East Java : Cenozoic basins, Volcanoes and Ancient Basement, Proceedings Indonesian Petroleum Association.

Smyth H.R., Hall R., and Nichols G.J., 2008, Significant Volcanic Contribution to Some Quartz-Rich Sandstone, East Java, Indonesia, Journal of Sedimentary Research 78, 335–356. DOI: 10.2110/jsr.2008.039

Soeria-Atmadja,R., Maury, R.C., Bellon, H., Pringgopawiro, H., Polves, M., *and* Priadi, B., 1994. Tertiary Magmatic Belts In Java, Journal of Southeast Asian Earth Sciences 9 (1). DOI: 10.1016/0743-9547(94)90062-0

Sudradjat, A., Syafri, I., dan Budiadi, E., 2010. The Geotectonic configuration of Kulon Progo Area, Yogyakarta. Proceeding PIT IAGI Lombok 2010, The 39th IAGI Convention and Exhibition, Lombok.

Sulistyoningrum,D. dan Rahardjo, W., 2010. Identification and Paleoecology of Coraline Fossil (Cnidaria: Anthozoa) from

Jonggrangan Limestone, Western Slope of Kucir Hill, West Progo Area, Yogyakarta Special Province. Proceedings PIT IAGI Lombok 2010, The 39th IAGI Annual Convention and Exhibition.

Suroso, Rodhi, A., dan Sutanto, 1987. Usulan Penyesuaian Tata Nama Litostratigrafi Kulon Progo, Daerah Istimewa Yogyakarta. Kumpulan Makalah Pertemuan Ilmiah Tahunan XV Ikatan Ahli Geologi Indonesia, Yogyakarta, 1,

Van Bemmelen, R.W., 1949. The Geology of Indonesia. Vol. IA, General Geology of Indonesia and Adjacent Archipelago, Government Printing Office, The Hague.