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# Volcano Stratigraphy of Kulon Progo Super Brigade

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**Abstract -** The research location is in the Kulon Progo Mountains, west of the Daerah Istimewa Yogyakarta province and part of Central Java. Several previous researchers have discussed the stratigraphy of the Kulon Progo Mountains region, following the rock unit grouping rules that have evolved from the past to the present. Approaches to clarify the geological conditions of the Kulon Progo Mountains and efforts to comply with Indonesian Stratigraphic Code standards are continuously being carried out. The purpose of this study is to identify volcanic stratigraphic units in the Kulon Progo Mountains using the principles and concepts of volcanic stratigraphy. The research methods used were surface geology research and remote sensing. The research conducted through surveys or field visits at specific locations was identified as key areas of interest. Remote sensing and topographic map analysis were also conducted to delineate the distribution of volcanic rocks and the boundaries of volcanic stratigraphic units. Laboratory analysis was conducted to strengthen the interpretation of volcanic rock genesis and thus support the interpretation of the presence of volcanoes in the study area. Comprehensive analysis is used to determine the location of ancient eruption sources, descriptions of coherent and pyroclastic lava, and the origin of volcanoes, which have developed quite significantly, as well as the volcanic stratigraphic units in the study area. The volcanic stratigraphic units of the Kulon Progo Mountains from the early to late activity periods are grouped into the Gajah Brigade, Ijo Brigade, and Menoreh Brigade stratigraphic units. The collection of volcanic stratigraphic units from the three brigades that built the Kulon Progo Mountains and were mapped at a scale of 1:100,000 is called Super Brigade Kulon Progo. The Gajah Brigade Unit is in the center, the Ijo Brigade Unit is in the south, and the Menoreh Brigade Unit occupies the northern part of Super Brigade Kulon Progo, which is in a relatively northeast-southwest trend. The Gajah Brigade covers the north side of Crown Bujel, which is bounded by a long escarpment that opens to the west, and the flat Crown Pencu is bounded by a curved escarpment that also opens to the west. Ijo Brigade is in the southern part of the Kulon Progo Mountains and has a relatively rounded shape, bounded by steep escarpments, especially on the north and east sides. The geological elements of the ancient volcano Ijo Brigade appear much clearer than those of the other brigade, so it is estimated that it is younger than the time the Gajah Brigade was formed. Ijo Brigade covers two ancient volcanic bodies, namely Ijo Crown in the north and Kukusan Crown in the south. Menoreh Brigade is in the northern part of the Kulon Progo Mountains and is the youngest of the three brigades that built Super Brigade Kulon Progo. The Menoreh Brigade encompasses the Gupit Crown, which is a dacite intrusive body, the smallest in diameter and the lowest in topography among the existing Crowns. The stratigraphy of the ancient volcanoes of the Kulon Progo Mountains is arranged by volcanic unit levels from large to small, namely Super Brigade, Brigade, and Crown.

**Keywords**: Crown, Brigade, Super Brigade, volcano, stratigraphy, Kulon Progo

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## Introduction

### Background

The research location is in the west of the Daerah Istimewa Yogyakarta province and part of Central Java (Figure 1). The discussion of the stratigraphy of the Kulon Progo Mountains region, Yogyakarta, has been carried out by previous geologists in accordance with the rock unit grouping rules that have developed from the past to the present. The Kulon Progo Mountains are composed of several ancient volcanoes to form the "oblong dome", which is an oval or elongated dome with a fairly steep dome slope in the Kulon Progo Mountains in the form of a longitudinal dome in the direction of NNE-SSW.

The approaches taken to clarify the geological conditions of the Kulon Progo Mountains and efforts to comply with the Indonesian Stratigraphic Code standards are continuing to the present. On the other hand, the results of this descriptive-interpretive study show that rocks are abundant from volcanic eruptions, melting, and shallow intrusions, but the application of the rock amalgamation has not been fully referred to volcanic stratigraphy (IAGI, 1996). The main idea in this research is to find out the approximate location of the source and/or former eruption, as well as the nomenclature or grouping of volcanic stratigraphic units in the Kulon Progo Mountains.

### An Overview of the Geological Research Area

Volcanoes are composed of lava and pyroclastic material. Coherent lava includes shallow intrusion rocks (subvolcanic intrusions) contained in the body of a volcano in the form of magma pockets, necks, sills, and silicate solutions that reach the earth's surface in the form of lava domes and lava flows (Bronto, 2013). Stratigraphy in a narrow sense, is a science that studies the strati-

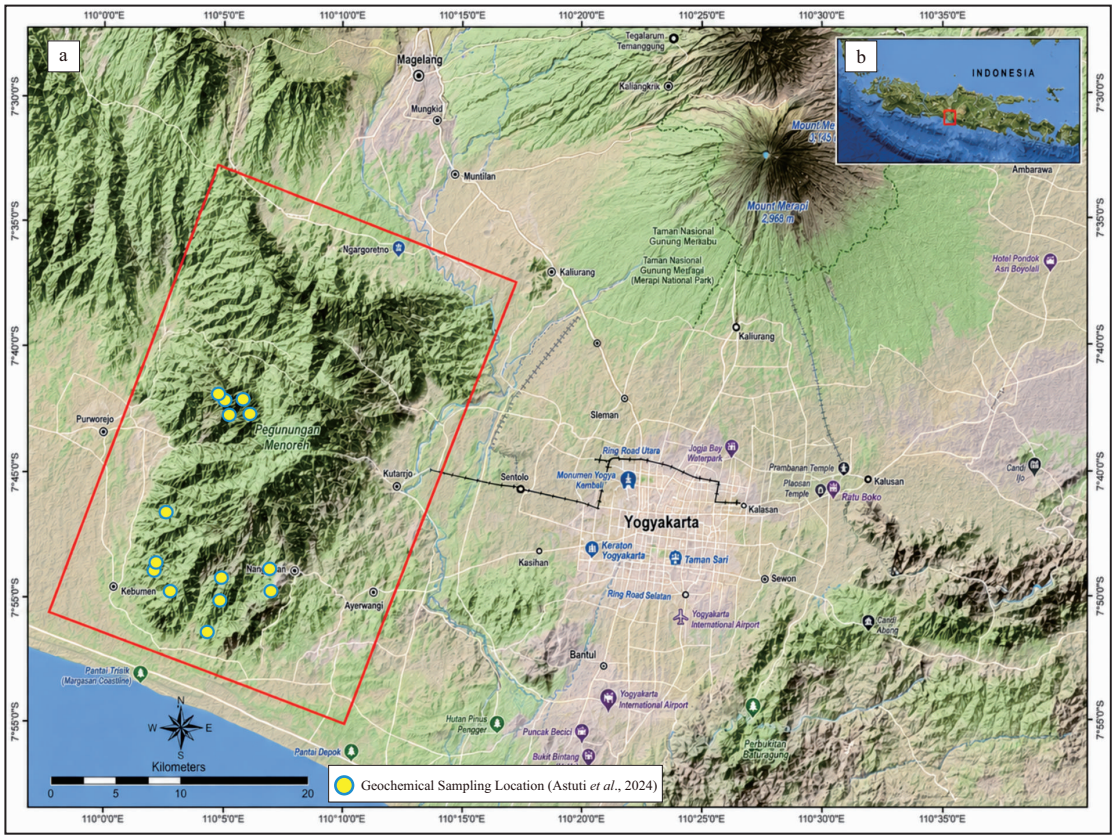



Figure 1. The location of the research area. Figure (a) is the location of the research area in the form of an "oblong dome" of the Kulon Progo Mountains Region , shown in a red box (modified from Google Map, 2026). The map of the location of Java Island with the sign; (b) is an index map. The yellow circle indicates the location of the geochemical analysis sample by Astuti *et al*. 2024, as shown in Figure 11.



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fication of rocks, while in a broad sense, it is a science that discusses the rules, relationships, and events (genesis) of various kinds of rocks in nature in space and time. The discussion focuses on volcanic rock or sediment stratigraphy, which aims to rearrange volcanic rocks according to the sequence of events, making the evolution of volcanic rock formation easier to learn and understand (IAGI, 1996). The Indonesian Stratigraphic Code (1996) states that the stratigraphic unit levels of volcanoes, from large to small, are Arc, Super Brigade, Brigade, Crown, and Hummock. The researchers made the model from the smallest to the largest stratigraphic units (Figure 2).

The volcanic arc is a volcanic stratigraphic unit consisting of the Crown, Brigade, and Super Brigade volcanoes, all of which share the same tectonic position. The Super Brigade volcano is a volcanic stratigraphic unit that includes the distribution of rocks or sediments resulting from volcanic eruptions involving more than one brigade across one or more volcanic bodies. The brigade volcano is also a volcanic stratigraphic unit that encompasses the distribution of volcanic deposits or rocks resulting from eruptions that consist of two or more crowns or are associated with the formation of a caldera or brigade. The crown volcano serves as the fundamental unit for grouping volcanic stratigraphic units. A crown represents a collection of rocks or sediments produced by one or more eruption points that form the body of a volcano, while a hummock is a part of the crown formed by an eruption occurring on the volcano's body, either from the central eruption or the side. One of the more comprehensive models discussing volcanic stratigraphy is found in the area of Mount Galunggung and its surroundings, as well as the stratigraphic model of Mount Slamet. According to volcanostratigraphic interpretations, Mount Galunggung and its surroundings contain five crown units: Galunggung, Talaga Bodas, Sawal,

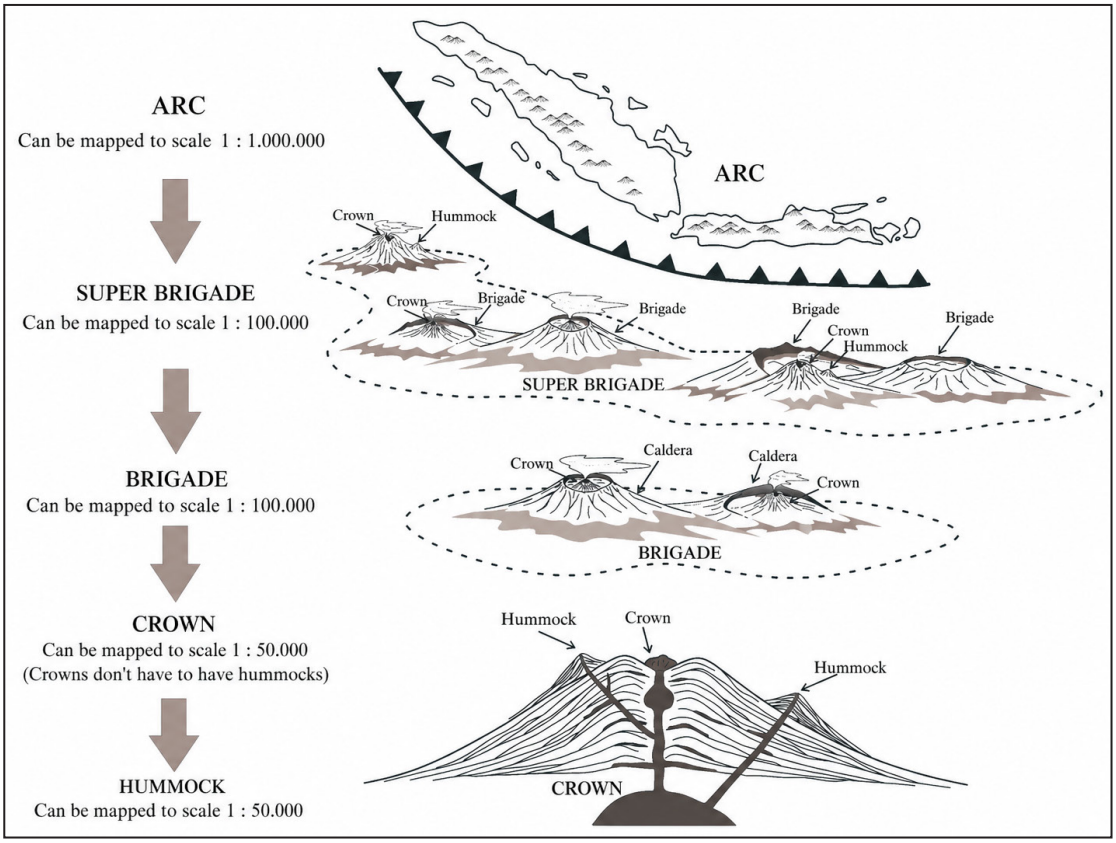



Figure 2. Illustrations that the researcher made to explain volcanic stratigraphic unit levels, starting from the smallest stratigraphic unit to the largest namely hummock, crown, brigade, superbrigade, and arch.



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Cakrabuana, and Sadakeling (Ramadhan *et al*., 2016). The volcanic stratigraphy units in the Slamet Volcanic Complex are divided into six crowns and two hummocks: Slamet Crown, Guci Crown, Baturraden Crown, Pandansari Crown, Batursari Crown, Karangtengah Crown, Pesanggrahan Hummock, and Malang Hummock (Assiddiqy *et al*., 2020). Volcanostratigraphic classification is a systematic grouping of volcanic rock or deposit bodies or strata. The ranks of volcano-stratigraphic formal units, from highest to lowest, are Arc, super brigade, Brigade, crown, and Hummock (Bronto *et al*., 2016). A Crown is a basic unit in the volcanostratigraphic classification. A hummock unit may reflect a short-lived geothermal system, whereas brigade and super-brigade units could indicate a very long-lived geothermal system (Bronto *et al*., 2016).

## Methods

The research methods employed in this study included a literature review, surface geology research, and remote sensing. Field research was conducted through surveys and visits to locations identified as key sites. Remote sensing and topographic map analysis were utilised to delineate the distribution of volcanic rocks and the boundaries of volcanic stratigraphic units. The laboratory analysis used is petrography using polarizing microscopy by analyzing the composition of the rocks and then naming use of the Streckeisen (1974) classification and Williams (1982) classification to interpret petrogenesis. Geochemical data and lithological distribution using secondary data from previous researchers were performed to enhance the understanding of volcanic rock genesis and to support interpretations regarding the presence of volcanoes in the study area. The geochemical components taken are the main oxides that will be used to determine the affinity of magma, the composition of magma origin, and the genetics of rock-forming magma in the research area. The tools and materials used for field research comprised a geological hammer, a geological compass, a magnifying glass, a scratcher, an HCl solution, and sample bags. Remote sensing data uses topographic maps and DEM (Digital Elevation Model) imagery overlaid with regional geological maps. Remote sensing image data processing involved the use of QGIS and ArcGIS software, integrated with topographic, field, and secondary data. A comprehensive analysis was then conducted based on the gathered data to determine the volcanic stratigraphic units in the study area.

## Result and Analysis

The stratigraphy of the Kulon Progo Mountains volcanoes can be identified early through the classical sheet geology map of Yogyakarta (Rahardjo *et al*., 2012) and the delineation of volcanic structures on digital image maps and topographical maps (Figure 3). Intrusive, effusive and explosive eruptions of volcanoes form distinctive patterns that can support the determination of boundaries in localizing the remains of ancient volcanic bodies. This distinctive pattern can appear as either a complete circle or a semicircle which is thought to be a crown or brigade opening structure. Based on a study of several patterns of volcanic formation, evidence of outcrops in the field and studies of laboratory analysis results that refer to the constituent rocks such as magma and volcanic rocks, the Kulon Progo Mountain is declared the remains of an ancient volcanic body.

The volcanic stratigraphic units of the Kulon Progo Mountains from the early to late activity periods are grouped into Gajah Brigade, Ijo Brigade, and Menoreh Brigade stratigraphic units. The collection of volcanic stratigraphic units from the three brigades that built the Kulon Progo Mountains and were mapped at a scale of 1:100,000 is Super Brigade Kulon Progo. The Gajah Brigade Unit is located in the center, the Ijo Brigade Unit is located in the south, and the Menoreh Brigade Unit occupies the northern part of Super Brigade Kulon Progo, which is a



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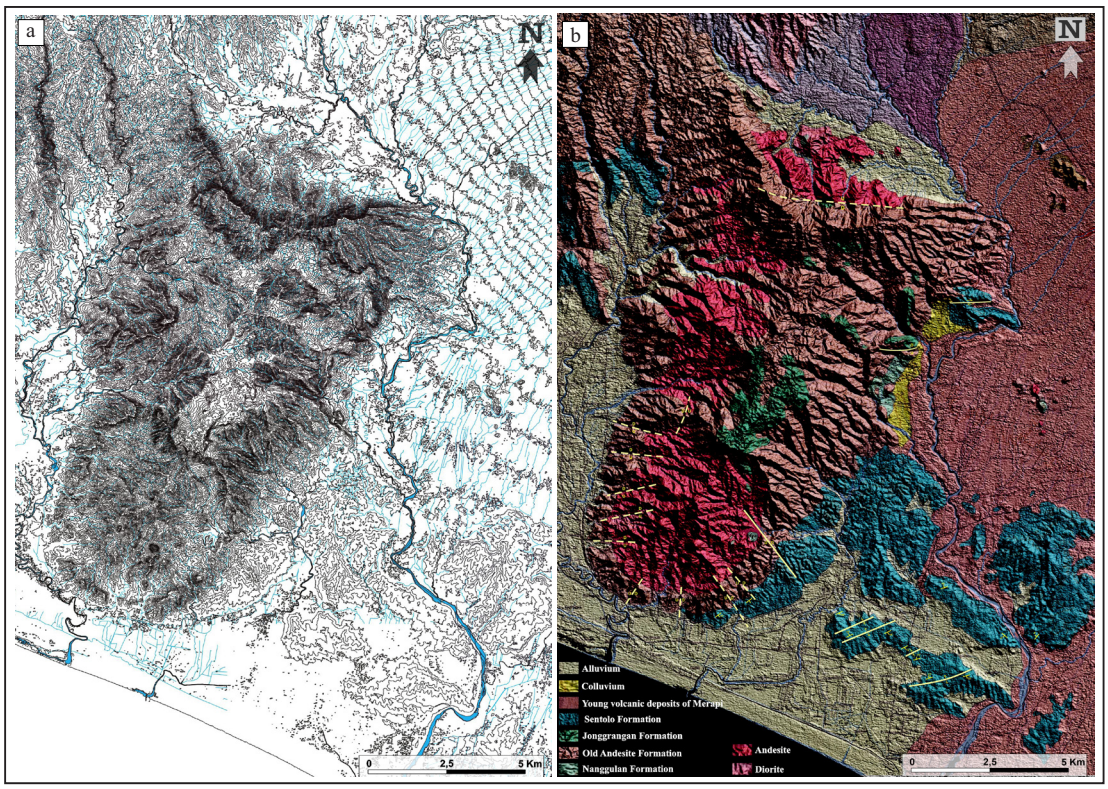



Figure 3. Typical patterns "oblonge dome" of volcanic activity that appear on digital image maps and topographic maps. (a) is a typographic map that shows the presence of a pattern of volcanic excesses with a trend in the relative northeast-southwest direction; (b) It is an overlay of DEM with a regional geological map (Rahardjo *et al*., 2012) that shows the research area is composed of volcanic rocks and coherent lava forming a row of former volcanoes.

relatively northeast-southwest trend.

The Gajah Brigade has the largest diameter (erosional diameter), reaching 10 km. The boundaries of the brigade's body wall, which are generally in the form of steep escarpments curving on the west and east sides, only leave unclear boundaries, causing the escarpment to become irregular in shape. Sparse contours develop on the north and south sides around each of the cone topographies, representing the inner topography. On the north side it is elongated from west to east, while on the south side it is curved, opening to the west (Figure 4). The interior of the western side of the Gajah Brigade is composed of andesite, basalt, dacite and micro-diorite igneous rocks, while the eastern part is dominated by volcanic breccia (Rahardjo *et al*., 2012).

The Gajah Brigade covers the north side of Bujel Crown, which is bounded by a long escarpment that opens to the west, and the fat Pencu Crown is bounded by a curved escarpment that also opens to the west. The size and height of the whole body of the Pencu Crown is estimated to be much larger than the Bujel Crown. The opening structure of the Mt Pencu landscape on the northwest side is bordered by the Gajah Brigade escarpment, while the southwest side is by the Ijo Brigade escarpment (Figure 5). The topography of Crown Bujel on the south side seems to be pushed over by the topography of Pencu Crown on the northeast side, so it is estimated that Crown Bujel is relatively older. In both crowns, in the opening structure, concentric contours are found as an indication of the center of the ancient volcanic eruption. The central part of Bujel Crown is composed of pyroclastic agglomerates or breccias forming isolated highs, and the central part of Crown Pencu is composed of andesitic igneous rocks in the shape of a subsurface dome or cryptodome which is exposed on the surface, hydrothermal alteration and high economic value mining materials are found (for example in Sum-



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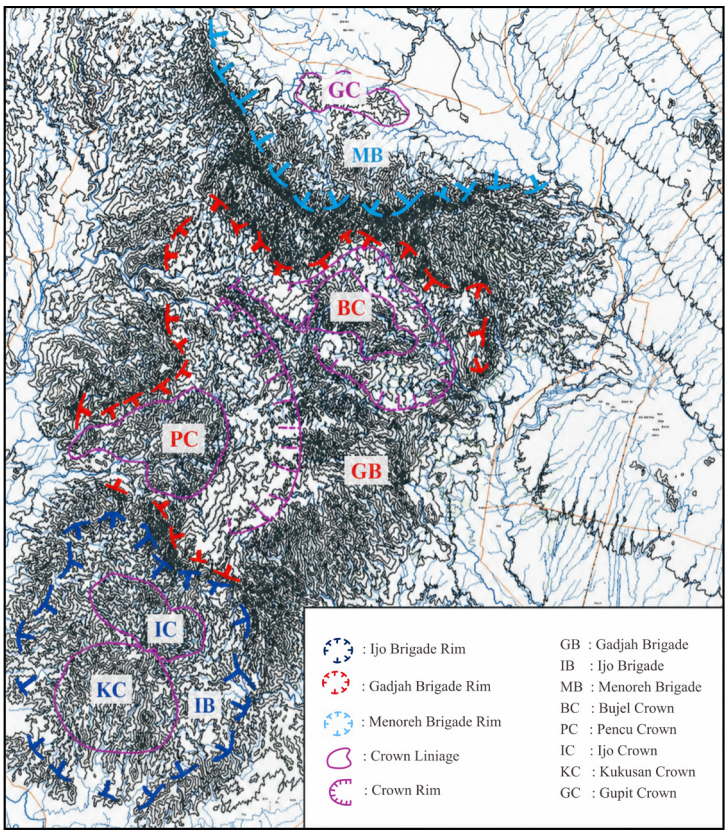



Figure 4. Analysis of the Gajah Brigade, Ijo Brigade, Menoreh Brigade and their crown which is made based on the relief pattern from the topographic map.

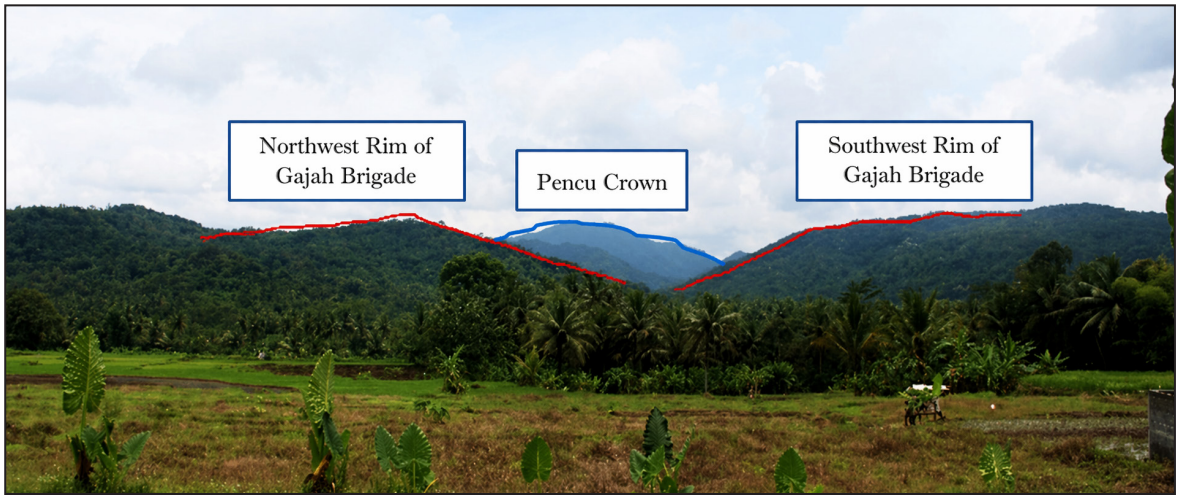



Figure 5. The photo captures the appearance of the body of the ancient volcano Pencu Crown, taken from the main road leading toward Purworejo, west of the Gajah Mountain range, as shown in Figure 1.

bersari Village).

Ijo Brigade is located in the southern part of the Kulon Progo Mountains, relatively rounded in shape, bounded by steep escarpments, especially on the north and east sides. The geological elements of the ancient volcano Ijo Brigade appear much clearer than those of the other brigade, so it is estimated that it is younger than the time the Gajah Brigade was formed. Remnants of the circular structure characteristic of volcanic



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formations are still discernible, remaining largely intact, with the principal opening measuring approximately 5 kilometers in diameter.

Ijo Brigade covers two ancient volcanic bodies, namely Ijo Crown in the north and Kukusan Crown in the south. Each crown forms a cone-shaped topography with rough relief, and some protrude on the inside of the cone shape, which has been eroded further (Figure 6), but both have different cone diameters. Ijo Crown has an oval shape extending west-east and is irregular; it looks pushed by Kukusan Crown, which is located to the south, and Kukusan Crown is relatively round in shape with a diameter of less than 2 km. The structure of the escarpment of the two crowns is not clearly demarcated as the escarpment of the crown in Gajah Brigade. Ijo Crown is composed of andesite and agglomerate igneous rocks, while Kukusan Crown is composed of andesite, dacite, micro diorite igneous rocks, and each crown is surrounded by pyroclastic or agglomerate breccias which form a steep, sloping relief away from the igneous rock area (breakthrough rock or lava). In Kukusan Crown, hydrothermal alteration rocks and minerals with high economic value develop ment, for example, in the Kokap and Bagelen area (Prasetyo *et al*., 2017; Setiyawan and Verdiansyah, 2021; Verdiansyah, 2022).

Menoreh Brigade is located in the northern part of the Kulon Progo Mountains and is the youngest of the three brigades of Super Brigade Kulon Progo. The Menoreh Brigade forms a typical crescent volcano structure with a diameter of less than 10 km, which is bounded by a steep, curved escarpment facing north (Figure 7), while the northern half of the escarpment is no longer there. The topography of the southern part is in the form of rough relief and several bulges at the ends of the western and eastern escarpments, but the northern part is a plain topography with several hills composed of pyroclastic agglomerates/breccias. Inside the Menoreh Brigade crescent structure, there is a Gupit Hill that has an elongated shape and a tenuous contour pattern, composed of dacite igneous rocks on the west side and andesite on the east side. Menoreh Brigade is an ancient volcano; if we look at the current volcano comparison, it is similar to the Ungaran volcano, which has undergone geothermal processes, alterations and mineralization. Mangopo and Suryantini (2024) mention that the geothermal area of Mount Ungaran is part of the Bregada Ungaran system, which is related to the formation of the Ungaran Caldera. Bregada Ungaran is estimated to consist of old formations (Old Ungaran Khuluk) such as Hummock Kaligesik and Hummock Tungku, as well as young formations (Young Ungaran Crown) such as Pengion Hummock, Songo Hummock, and Godong Hummock.

Discussion of the Gajah Brigade unit is the most difficult of the three Brigade units because the data collection or characterization of the geological elements of the ancient volcano is not clear/complete. These elements include the boundary of the brigade or caldera wall in the north, which is cut by the Menoreh Brigade, while the wall in the south is cut by the Ijo Brigade. The stratigraphy of the ancient volcanoes of the Kulon Progo Mountains is arranged by volcanic unit levels from large to small, namely Super Brigade, Brigade, and Crown. The age of volcanism in the

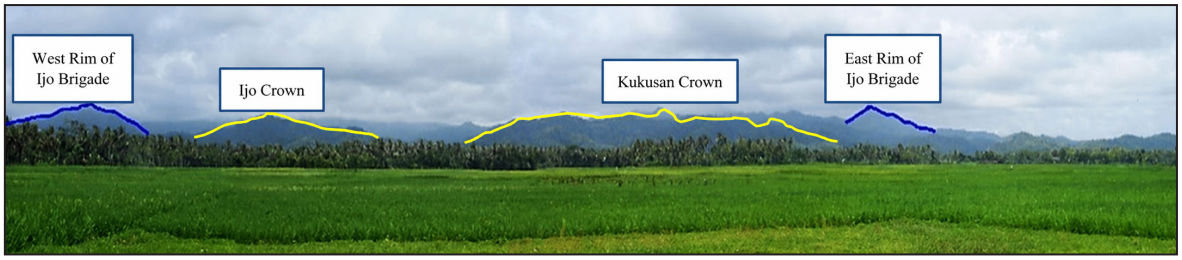



Figure 6. The image illustrates the bodies of the ancient volcanoes Ijo Crown and Kukusan Crown, captured from the highway leading to Bagelen, with the photograph taken to the south of Ijo Mountain.



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Figure 7. The Appearance of the steep escarpment on the west - east side of Menoreh Brigade, photo taken from the north of the Menoreh Mountains (a); The curved structure opens to the north of Menoreh Brigade taken from the summit on the west side (b) (https://www.flickr.com/photos/hanafichi/ 14324789537).

Kulon Progo area by several previous researchers (for example, Soeria-Atmadja *et al*., 1994; Ngkoimani, 2005; and Budiadi, 2009 - personal communication) gives the idea that the activities of each Brigade or crown alternate or can be compared with today's volcanoes such as the Mt Merapi - Mt Merbabu - Mt Ungaran line . The ancient volcanoes of the Kulonprogo Mountains in Yogyakarta, as derived from relevant sources, descriptions, and genesis, is presented in Table 1.

Some supporting evidence was taken from the field in relation to the stratigraphy of the Kulon Progo volcano. The supporting evidence is the accumulation of several volcanic rocks that display products of ancient volcanism, including lava and pyroclastic rocks such as tuff, lapilli, pyroclastic breccia, and agglomerates. Agglomerates are a product of volcanic volcanism as a clue to the eruption center because agglomerates are a collection of the dominance of volcanic bombs that form rock aggregates. Volcanic bombs tend to fall vertically from the eruption center or can also be slightly tilted but still form in the environment or area of the center of volcanic eruption, so that

Table 1. Volcano Stratigraphy of The Kulonprogo Mountains, Yogyakarta

| Activity Period | Stratigraphic Unit | | | Lithology |
|---|---|---|---|---|
| | Superbrigade | Brigade | Crown | |
| 3 | Kulonprogo | Menoreh | Gupit | Dacite Lava, Andesite, Aglomerate |
| 2 | | Ijo | Kukusan | Dacite Lava, Intrusion, Andesite, Aglomerate |
| | | | Ijo | Andesite Lava, Pyroclastic Breccia, Intrusion |
| 1 | | Gajah | Pencu | Andesite Lava, Aglomerate |
| | | | Bujel | Andesite Lava, Aglomerate, Pyroclastic Breccia |



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it can be used as the main clue to the eruption center in relation to the volcanic stratigraphic unit based on the eruption source (Figure 8). Andesite lava generally flows not far from the source, so that it can be used as a reference to be formed close to the eruption source area. Some of the data taken to support the existence of the Ijo Volcano (Ijo Brigade) is quite a lot, including both primary data and secondary data. From the primary data, petrographic incisions were made on the Ijo Brigade and the Gajah Brigade (Figure 9). The appearance of the petrographic sample taken in the Ijo Brigade area showed the appearance of sizeable crystals that were interpreted as porphyry andesite intrusion as part of the eruption center of Mount Ijo. The presence of a trachytic texture (lava flow pattern) shows the orientation of the alignment of the minerals interpreted by the activity of lava flowing from the eruption center of the Gadjah Brigade. Overall, the study indicates the presence of andesitic volcanic rocks, with petrographic analyses conducted in the Gajah Brigade revealing predominantly andesitic-basaltic volcanic rocks. Additionally, the presence of trachytic characteristics is observed, which is typical of lava flows in the region.

In the Menoreh Brigade, previous research conducted by Idrus *et al*. (2024) in the Gupit area, located in the central part of the Menoreh Brigade, revealed that the geological composition of the region is predominantly volcanic rocks (see Figure 10). In the Mount Gupit area, there are many rocks that make up the volcano in the eruption center area ranging from igneous rock intrusion, coherent lava to volcanic clastic, this supports that the Menoreh hilly area is an area that was the former eruption center of the Menoreh Brigade.

## Discussion

Based on the results and analysis, it shows that the Kulon Progo Mountains can be interpreted as




Figure 8. Agglomerate (a and b) and lava (c and d) outcrops found in the Gunung Ijo Peak and Mount Kukusan areas which indicates the area of the former eruption center.



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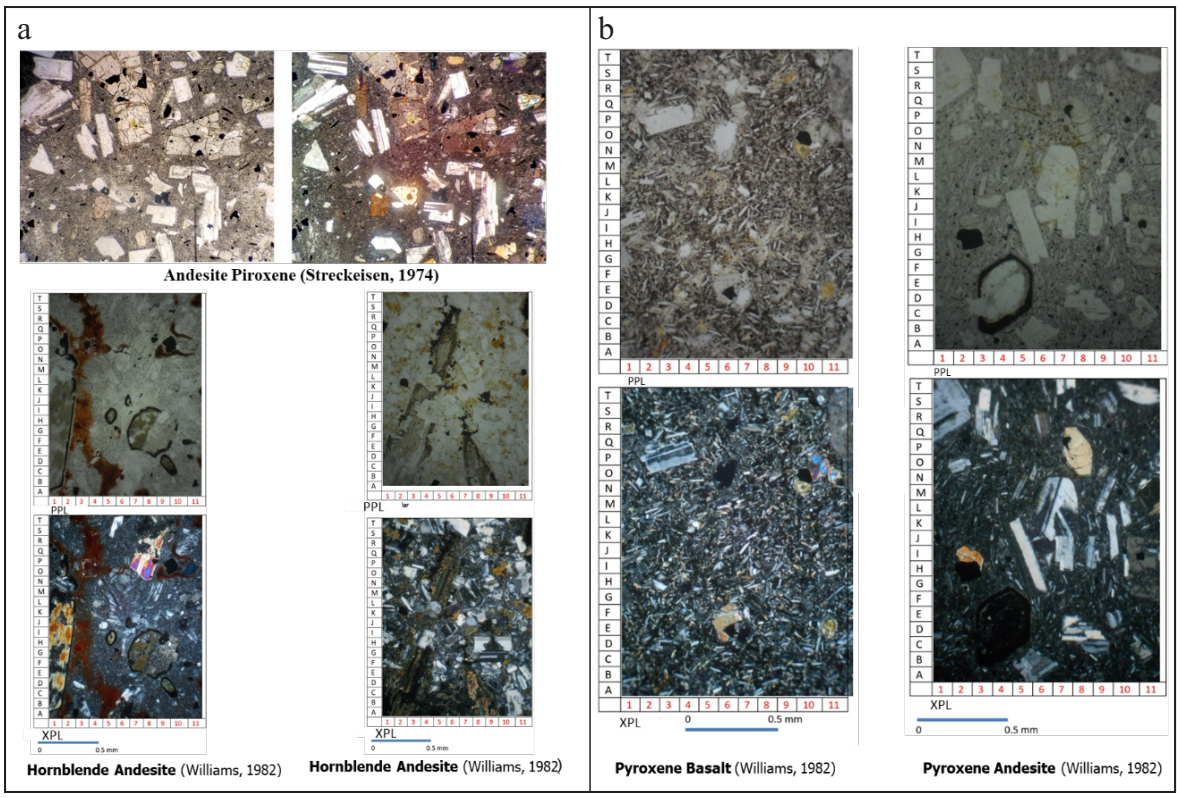



Figure 9. Petrographic appearance of several rocks taken from the Ijo Brigade. (a) in the form of incisions of porphyry andesite and andesite lava, as well as the Gajah Brigade; (b ) which shows andesite lava petrographic incisions with the texture of lava flows (trachytic).

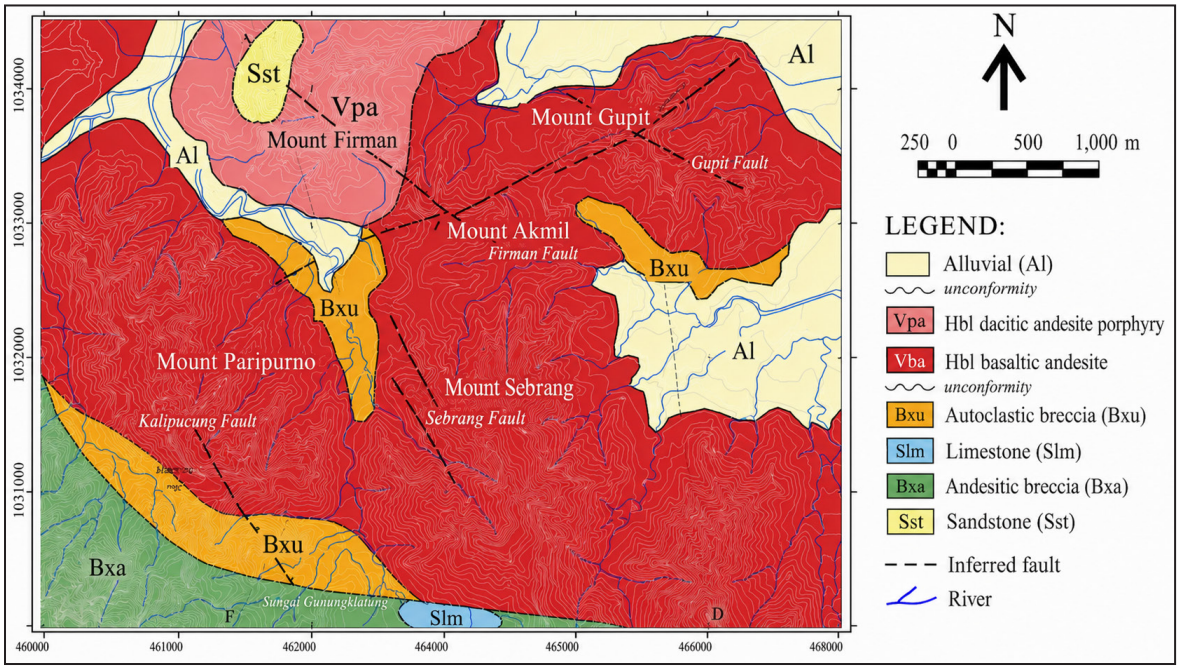



Figure 10. Geological map of Gunung Gupit and its vicinity (Idrus *et al*., 2024.

an ancient volcanic complex composed of several volcanic bodies with different levels of evolution. This interpretation is supported by a combination of morphological patterns, volcanic lithological



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distribution, field evidence in the form of lava, intrusion and agglomerates supported by petrographic analysis, and secondary geochemical data. In general, circular to semicircular relief patterns, the presence of steep gawir, and straightness in the northeast-southwest direction are important indicators in recognizing the boundaries of ancient volcanic bodies and the centers of past eruptions.

Referring to the statement (Bronto *et al*., 2016) that volcanostratigraphic classification is a systematic grouping of volcanic rock or deposit bodies or strata, which enables one to make a simpler description, arrangement and determine mutual relationships among volcanic rock or deposit strata. Based on this statement, the division of volcanostratigraphic units in the research area is divided into Gajah Brigade, Ijo Brigade, and Menoreh Brigade. The volcanic activity of Kulon Progo is not formed by a single eruption center, but by several volcanic systems that develop gradually. The Gajah Brigade is interpreted as the oldest unit because its morphological boundaries are more obscure and have been partially cut or overtaken by the development of the Ijo Brigade in the south and the Menoreh Brigade in the north. This condition shows the existence of further erosion processes and overlapping volcanic activities that cause the original shape of the body of the Gajah Brigade volcano to no longer show the features of the former circular volcano.

The Ijo Brigade shows more obvious morphological elements than the Gajah Brigade. The circular shape, relatively firm gawir, and the existence of the Ijo Crown and Kukusan Crown indicate that this unit is relatively younger. The presence of andesite, dacite, microdiorite, pyroclastic breccia, and agglomerate lavas strengthens the interpretation that this area is part of an ancient volcanic body with a relatively close eruption center. Agglomerates are important evidence because these materials generally form in a proximal environment, close to the center of volcanic material ejection.

The Menoreh Brigade is interpreted as the youngest unit in the Super Brigade of Kulon Progo. The morphological shape resembles a crescent, a steep gawir that opens to the north, and the existence of the Crown Cut, composed of dacites, andesites, and agglomerates, indicates that Menoreh is a volcanic system in itself. The discovery of dacite intrusion in the Crown Cut is also important because it can represent the supply line of magma or the remnants of the subvolcanic body that are then exposed due to the erosion process.

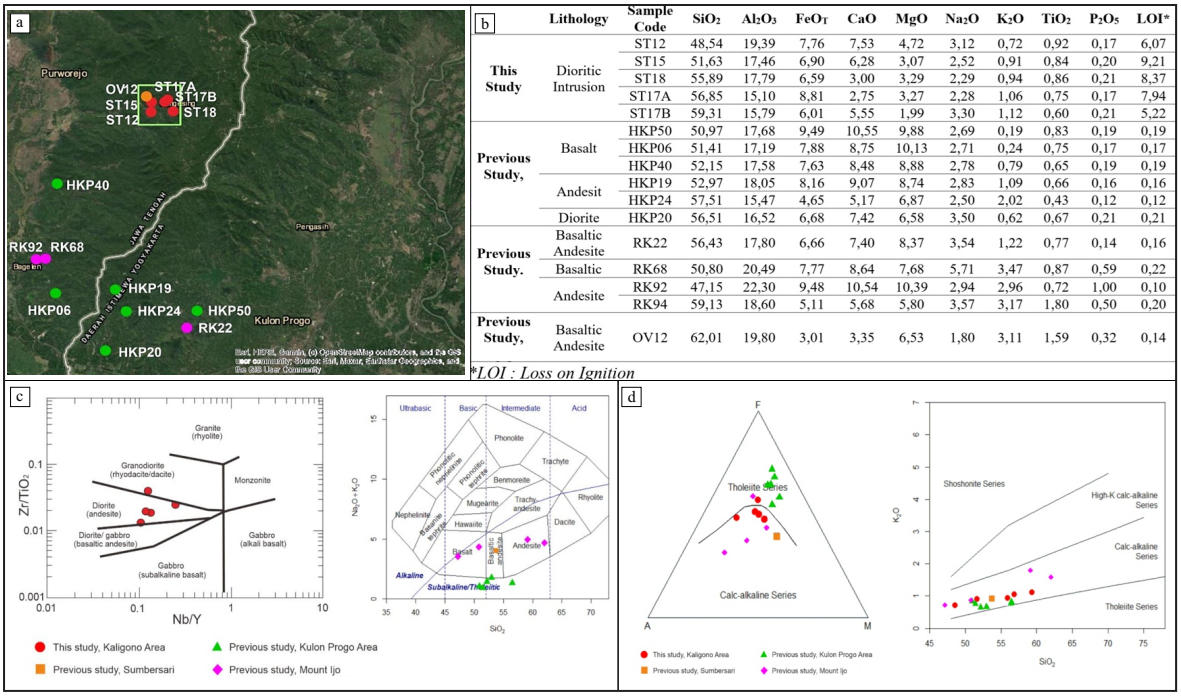
Petrographically, the dominance of andesitic to basaltic-andesitic rocks shows the character of intermediate magma that is commonly found in the archipelago arc environment. The trachitic texture of some of the lava indicates the presence of lava flows and mineral orientation due to the movement of magma during cooling. This supports the interpretation that some of the rocks in the study area are not only pyroclastic deposits but also coherent lava products that form close to the eruption center.

The discussion of the geochemistry of the research area is based on data from previous researchers. From secondary geochemical data taken at the location of the Ijo Brigade and Gadjah Brigade, the researchers showed that the volcanic rocks in the Kulon Progo area and its surroundings were calc-alkaline (Figure 11). This shows that the igneous rocks that make up the Kulon Progo Mountains come from the subduction of the Oligocene-Miocene with the tectonic arrangement being in the island arc with calcareous-alkaline magma affinity, as is the general condition in Kulon Progo. Geochemical data taken in the area of Ijo Brigade and Gajah Brigade show magma and igneous rocks formed with intermediate to alkaline compositions with predominantly calc-alkaline series affinity. With the tectonic order its formation is associated with a subduction system between the two Earth's plates.

A primarily calc-alkaline magma affinity is revealed by secondary geochemical data. The subduction tectonic environment, which is frequently observed in the Jawa Island magmatic arc, is congruent with this nature. As a result,



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| | Lithology | Sample Code | $SiO_2$ | $Al_2O_3$ | $FeO_T$ | CaO | MgO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | LOI* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| This Study | Dioritic Intrusion | ST12 | 48,54 | 19,39 | 7,76 | 7,53 | 4,72 | 3,12 | 0,72 | 0,92 | 0,17 | 6,07 |
| | | ST15 | 51,63 | 17,46 | 6,90 | 6,28 | 3,07 | 2,52 | 0,91 | 0,84 | 0,20 | 9,21 |
| | | ST18 | 55,89 | 17,79 | 6,59 | 3,00 | 3,29 | 2,29 | 0,94 | 0,86 | 0,21 | 8,37 |
| | | ST17A | 56,85 | 15,10 | 8,81 | 2,75 | 3,27 | 2,28 | 1,06 | 0,75 | 0,17 | 7,94 |
| | | ST17B | 59,31 | 15,79 | 6,01 | 5,55 | 1,99 | 3,30 | 1,12 | 0,60 | 0,21 | 5,22 |
| Previous Study, | Basalt | HKP50 | 50,97 | 17,68 | 9,49 | 10,55 | 9,88 | 2,69 | 0,19 | 0,83 | 0,19 | 0,19 |
| | | HKP06 | 51,41 | 17,19 | 7,88 | 8,75 | 10,13 | 2,71 | 0,24 | 0,75 | 0,17 | 0,17 |
| | | HKP40 | 52,15 | 17,58 | 7,63 | 8,48 | 8,88 | 2,78 | 0,79 | 0,65 | 0,19 | 0,19 |
| | Andesit | HKP19 | 52,97 | 18,05 | 8,16 | 9,07 | 8,74 | 2,83 | 1,09 | 0,66 | 0,16 | 0,16 |
| | | HKP24 | 57,51 | 15,47 | 4,65 | 5,17 | 6,87 | 2,50 | 2,02 | 0,43 | 0,12 | 0,12 |
| | Diorite | HKP20 | 56,51 | 16,52 | 6,68 | 7,42 | 6,58 | 3,50 | 0,62 | 0,67 | 0,21 | 0,21 |
| Previous Study. | Basaltic Andesite | RK22 | 56,43 | 17,80 | 6,66 | 7,40 | 8,37 | 3,54 | 1,22 | 0,77 | 0,14 | 0,16 |
| | Basaltic | RK68 | 50,80 | 20,49 | 7,77 | 8,64 | 7,68 | 5,71 | 3,47 | 0,87 | 0,59 | 0,22 |
| | Andesite | RK92 | 47,15 | 22,30 | 9,48 | 10,54 | 10,39 | 2,94 | 2,96 | 0,72 | 1,00 | 0,10 |
| | | RK94 | 59,13 | 18,60 | 5,11 | 5,68 | 5,80 | 3,57 | 3,17 | 1,80 | 0,50 | 0,20 |
| Previous Study, | Basaltic Andesite | OV12 | 62,01 | 19,80 | 3,01 | 3,35 | 6,53 | 1,80 | 3,11 | 1,59 | 0,32 | 0,14 |

*LOI : Loss on Ignition

Figure 11. Geochemical data taken from the research by Astuti *et al*. (2024) with an explanation; (a) Sampling location and previous studies in Sumbersari (orange circle), Kulon Progo area (green circles), and Mount Ijo (purple circles); (b) Major oxides abundance (%) in several igneous rock samples; (c) $Zr/TiO_2$ *vs*. Nb/Y of Kaligono samples and Silica versus total alkali; (d) AFM ternary diagram and the $SiO_2$ *vs*. $K_2O$ diagram where data is taken at the location at Ijo Brigade, Gajah Brigade and its surroundings.

the Oligocene- Miocene magmatism activity associated with the ancient subduction system can be used to explain the evolution of Kulon Progo volcanism. Therefore, the division of volcanostratigraphy in this study aids in reconstructing the history of the formation of ancient volcanic systems in Kulon Progo in addition to explaining the order of rock units.

An important implication of this study is that the volcanostratigraphic approach is able to clarify the relationship between morphology, lithology, eruption centers, and potential geological resources. The existence of hydrothermal alterations and mineralization in several locations, such as around Pencu, Kukusan, Kokap, Bagelen, and Gupit, suggests that the ancient volcanic system of Kulon Progo has the potential to be related to hydrothermal processes and the formation of minerals of economic value. In addition, an understanding of the body of ancient volcanoes is also important for the study of geological disasters, slope stability, and spatial planning in the Kulon Progo Mountains area.

Understanding volcanostratigraphy and potential geological hazards is a critical component of disaster mitigation efforts in volcanic regions (Banggur *et al*., 2025). Analyzing ancient volcanic rocks in relation to volcanostratigraphy is essential, as it provides insight into the history of volcanic development from its inception to the eventual dormancy of the volcano, as recorded in the produced rock formations. This knowledge allows for a comparative analysis of current volcanic stratigraphy, which serves as an important basis for minimizing the risks associated with volcanic disasters. Thus, the concept of the Kulon Progo Super Brigade provides a more systematic stratigraphic framework to explain the relationships between ancient volcanic bodies in the research area. The division into the Gajah, Ijo, and Menoreh Brigades, along with their constituent crowns, successfully addressed the primary goal of the research, which was to identify the sources of ancient eruptions and compile the nomenclature of volanostratigraphic units in accordance with the principles of the Indonesian Stratigraphic Code.



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## Conclusions

The Kulon Progo Mountains represent a complex of ancient volcanic systems that can be effectively interpreted using an integrated volcanostratigraphic approach. The integration of surface geological surveys, remote sensing analysis, topographic and digital elevation model interpretation, petrographic examination, and secondary geochemical data establishes a comprehensive framework for reconstructing volcanic architecture. Morphological indicators such as circular to semicircular patterns, steep escarpments, and lineaments trending northeast-southwest are interpreted as remnants of ancient volcanic edifices and their structural boundaries. These findings address the primary objective of identifying paleo-eruption centers and establishing a consistent volcanostratigraphic nomenclature for the study area.

The volcanostratigraphic framework of the Kulon Progo Mountains, from early to late volcanic activity, is subdivided into three main brigades: the Gajah Brigade, Ijo Brigade, and Menoreh Brigade, which collectively form the Kulon Progo Superbrigade. Spatially, the Gajah Brigade occupies the central part, the Ijo Brigade is located in the southern part, and the Menoreh Brigade occurs in the northern part, forming an overall northeast-southwest alignment. The hierarchical volcanostratigraphy of this area from the largest to the smallest unit level consists of the Superbrigade-Brigade-Crown.

The Gajah Brigade is interpreted as the oldest volcanic unit and exhibits the largest erosional diameter; however, its boundaries are relatively obscured due to overprinting by younger volcanic activity from the Ijo and Menoreh Brigades. This unit includes the Bujel Crown and Pencu Crown, characterised by andesitic lava, agglomerates, and pyroclastic breccias. The Ijo Brigade represents a younger volcanic phase with more clearly preserved morphological features, which include the Ijo Crown and Kukusan Crown, made up of andesite, dacite, intrusive rocks, pyroclastic breccias, and agglomerates. The Menoreh Brigade is interpreted as the youngest unit, encompassing the Gupit Crown, which is dominated by dacitic intrusions, andesite, and agglomerates.

Field evidence, including lava flows, agglomerates, pyroclastic breccias, tuff, and lapilli, strongly supports the interpretation of the study area as a remnant of ancient volcanic systems. Agglomerates serve as key indicators of eruption centers due to their proximal depositional nature, while andesitic lava flows provide constraints on the location of magma sources. Petrographic analysis further confirms the dominance of andesitic to basaltic-andesite compositions, with trachytic textures indicative of lava flow processes. Secondary geochemical data indicate that the volcanic rocks are predominantly of intermediate composition with calc-alkaline affinity, reflecting magmatism associated with an island arc setting related to subduction processes during the Oligocene-Miocene. Overall, this study not only refines the volcanostratigraphic classification of the Kulon Progo Mountains but also provides important insights into the evolution of ancient volcanic systems, as well as implications for hydrothermal alteration, mineralization potential, and regional geological development.

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