

## The Facies Modeling of Muria Volcano in the Kedungbamban Area Using GIS

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### ABSTRACT

Indonesia is an archipelago located in the Pacific Ring of Fire, known for its high volcanic activity. Indonesia is home to 129 active and 500 inactive volcanoes, representing 13% of the world's total. This research is expected to provide an overview of the facies of the Muria volcano and the geological aspects of the study area. To analyze and resolve issues in this study, geological mapping, and data processing are employed to make volcano facies models using GIS. The volcanic facies in the study area are proximal facies, which can be divided into three zones: proximal facies of Muria basalt, proximal facies of Maar Bambang basanite, and proximal facies of Muria andesite.

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## **INTRODUCTION**

Indonesia is an archipelago known for its high volcanic activity. Because it is in the Pacific Ring of Fire, where four of the world's major tectonic plates converge, Indonesia is threatened by natural hazards such as earthquakes, tsunamis, and volcanic eruptions (Siagian et al., 2014). The marine record of widespread and well-preserved tephra layers linked to the Pacific Circumpolar chain of volcanoes, also called the "Ring of Fire," shows about half the length of active plate subduction (Kutterolf et al., 2013). This pattern of time is seen on a worldwide scale, throughout the Pacific "Ring of Fire" area, and locally at certain particular volcanoes. This region also referred to as the "Pacific Ring of Fire" (ROF), is active seismically and volcanically (Masum & Ali Akbar, 2019). Over the past three hundred years, volcanic activity has shown statistically significant levels (Mason et al., 2004). Indonesia is home to 129 active and 500 inactive volcanoes, representing 13% of the world's total. In fact, of the 10 largest eruptions in the world, 2 of them are in Indonesia. The 1815 eruption of Mount Tambora killed 80,000 people, while the 1883 eruption of Mount Krakatau killed 36,000. (Davidson et al., 2000). Research on volcanic processes has developed through the collaboration of theoretical and numerical models, laboratory experimentation, and field observations (James et al., 2020).

The large number of volcanoes in Indonesia needs more attention to monitor active volcanoes in Indonesia to support disaster mitigation. To maximize scientific gains from future volcanic unrest and encourage cooperation, collaboration, and coordination within the volcano science community (Lin et al., 2023). Therefore, a key component of mitigating the risk associated with volcanoes is comprehending the significant physical, chemical, and other processes that occur within the subvolcanic magma system and how these processes relate to the geophysical, geochemical, and other signals observed through volcano monitoring (Kent et al., 2023). However, it appears that accurately predicting the flow pattern and anticipated risks during rhyolite lava effusion is challenging for volcanologists (Furukawa et al., 2021). All volcanic eruptions have styles, intensities, and durations that are reflective of the physical and chemical characteristics of the magma (Kelly Russell et al., 2019). According to data from the Center for Volcanology and Geological Hazard Mitigation, there are three types of active volcanic eruptions in Indonesia. Since 1600, 79 mountains have erupted with type A, 29 with type B, and 21 with type C. (van Bemmelen, 1949); (van Padang, 1955). The facies division of the Maria volcano is covered in this essay. An overview of the geological features of the study region and the facies of the Muria volcano are anticipated to be provided by this research.

In general, geology has a relationship with volcanoes, and so do volcanoes related to igneous rocks where igneous rocks come from freezing magma. The purpose of this study is to comprehend and characterize the differences in the properties and forms of the volcanic rocks in the studied region. Describe rock aspects such as texture, mineral composition, and structure of rock layers formed during volcanic activity as well as other geological aspects that support the creation of a 3D model of the gunning fire facies. In the study of volcano facies,

it is also possible to describe the evolution of the volcanic environment over time and understand the geological processes involved in the formation of these facies. It also provides important insights for geologists in understanding the geological history of the area as well as the potential risk of future volcanic eruptions and disaster management.

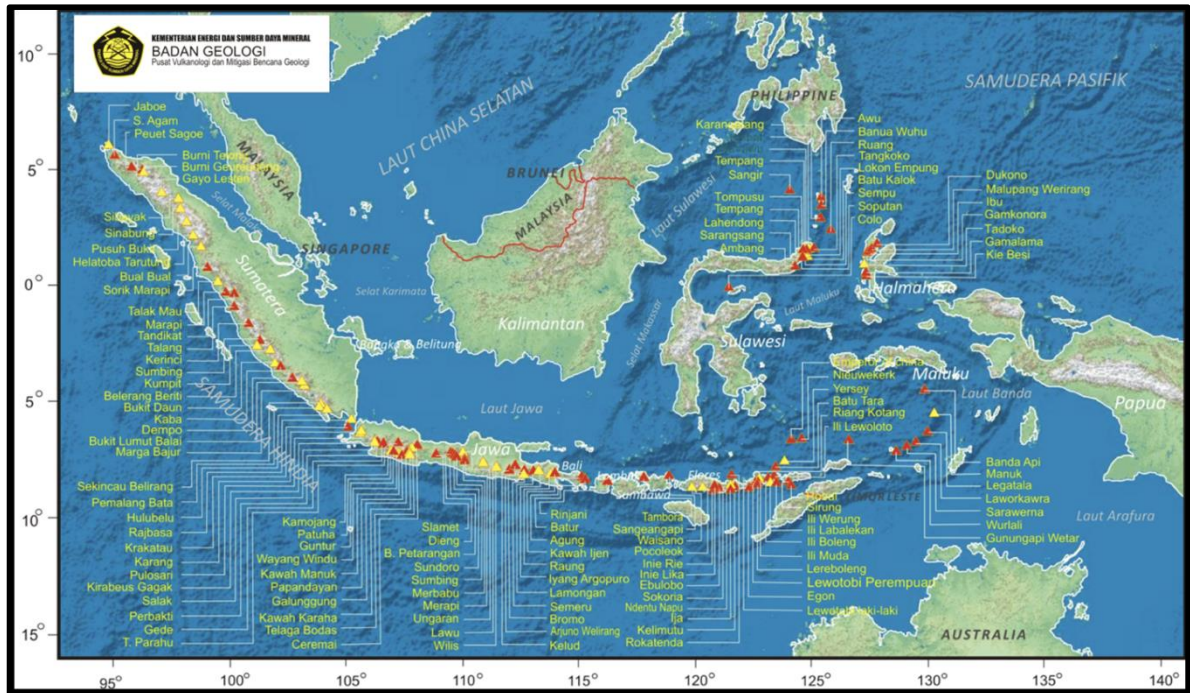


Figure 1. Distribution of Gunungapi Indonesia Map  
(Source: Ministry of Energy and Mineral Resources (Geological Agency), 2016)

### Study Area

Located in Pati Regency, Central Java Province, the research area is approximately 181 km north of downtown Yogyakarta. It can be reached in around 5 hours by car or motorcycle. The research area has a map scale of 1: 25,000 The study area covers 81 square kilometers (9 km × 9 km). Astronomically, the study area is located at 06°32'30"-06°37'30" S and 110°55'00"-111°00'00" E. The research project took a total of four months to complete, starting with field data collection and ending with data processing.

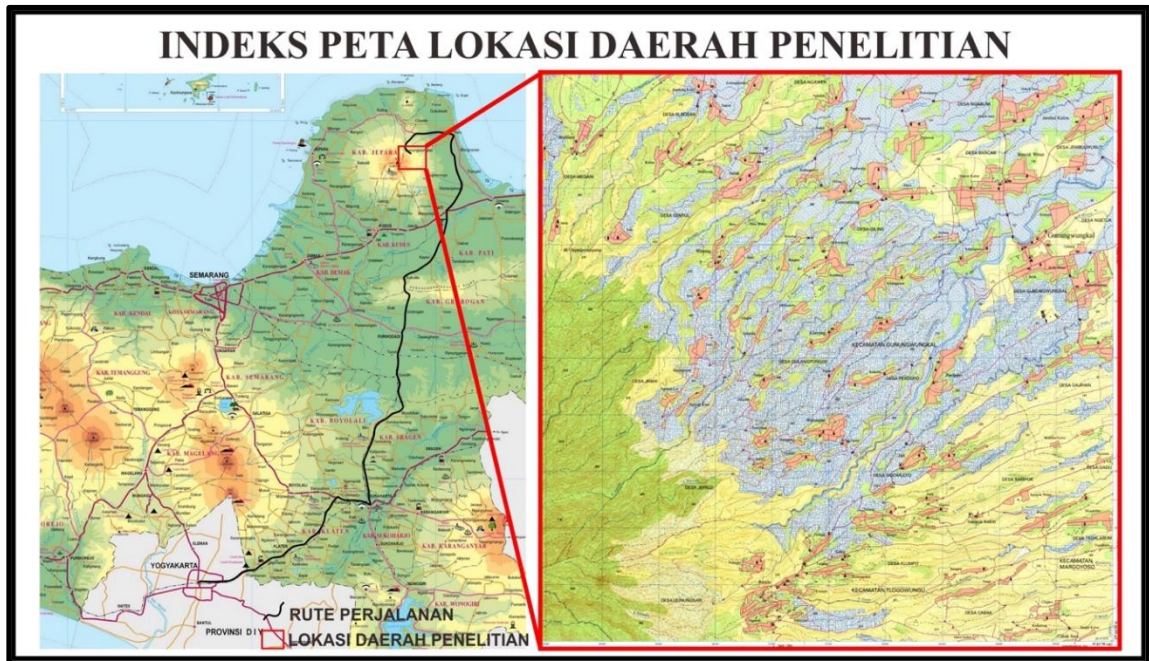


Figure 2. RBI Map of Plaosan sheet  
(Source: Bakosurtanal, 2000)

## THEORETICAL REVIEW

### METHODOLOGY

The study utilizes geological mapping and data processing to produce models of volcanic facies using GIS. Geological mapping of surface bedrock, like many other geoscience endeavors, begins with the creation of a model for a given geographic area by field-based surveys (Brodaric et al., 2004). Geological field systems with computer assistance are a key tool for advancing geoscience into the information era (Brodaric, 2004). Numerous earth science applications, including lithological and structural mapping, are studied through the use of remote sensing, particularly in the field of geology (Elaaraj et al., 2022). By conducting field mapping to get data on the type of rock distribution and as data for making geological maps. The geological data will be used as data for making 3d models of volcano facies.

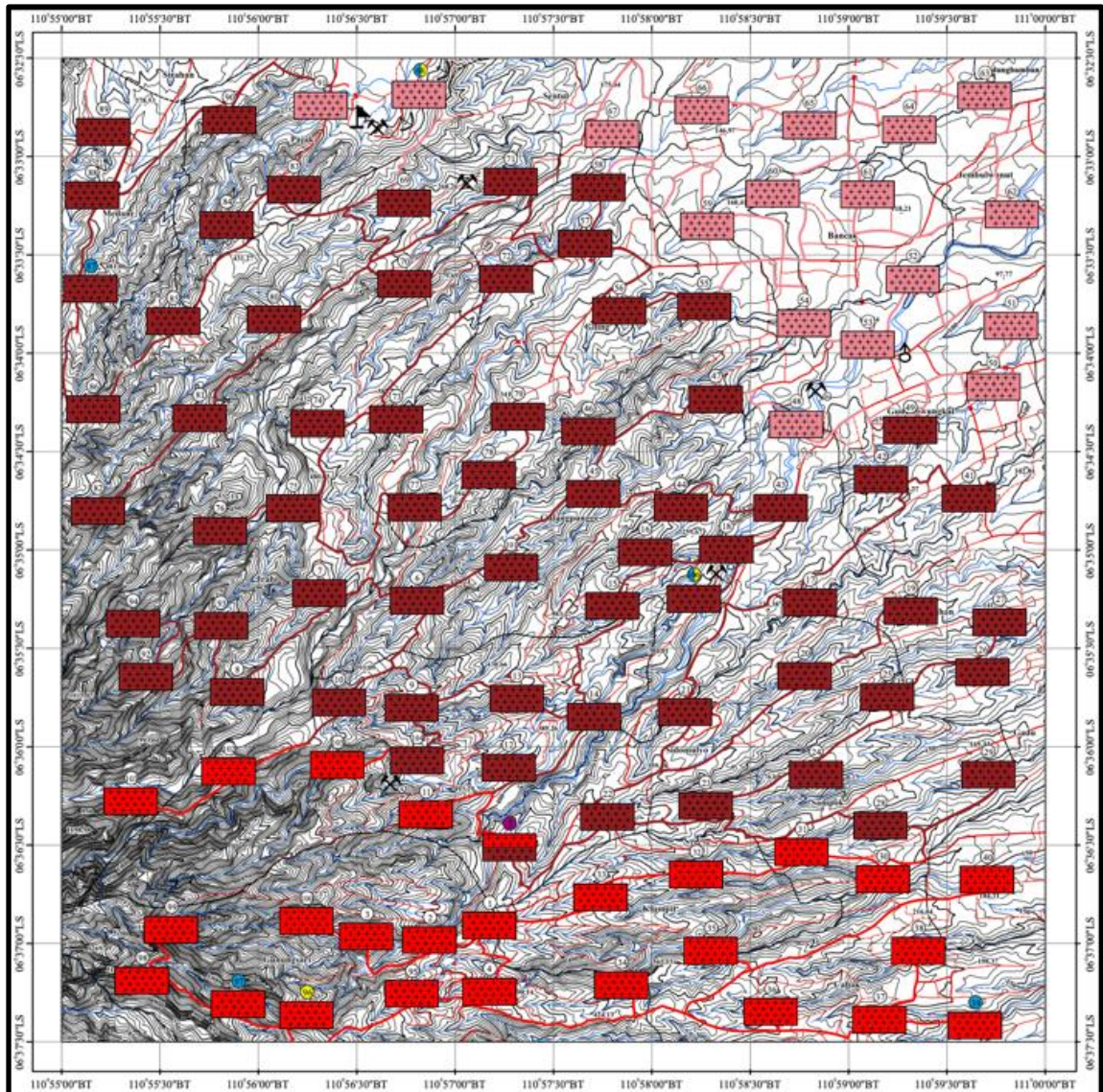


Figure 3. Track map and observation location (Red: andesite lava, Maroon: basalt lava, Pink: basanite lava)

Trajectory maps and observation locations are essential tools in helping to plan observation routes, carry out field observations, and record geological data such as when observations were made, weather, observation locations, rock formations, and rock data: rock type, rock color, rock structure, rock texture, crystal shape, and rock composition. Geological mapping in volcanic terrains necessitates the integration of volcanic systems into the stratigraphic framework, taking into account styles of eruption, pyroclast transport, and stratigraphic nomenclature (Németh & Palmer, 2019). By removing geometrical features from traces, the Trace Information Extraction (TIE) technique enhances the interpretation of geological maps and makes it possible to compare them more accurately with other structure data and orientation measurements (Rauch et al., 2019). 105 observation locations with three different kinds of rocks – andesite, basalt, and basanite – were identified from the field mapping. This research also uses a comparison with previous research where the comparison is the volcano

facies model from Bogie and Mackenzie. With this comparison, it can strengthen the data and research results. Predicting subsurface resources has long been the focus of research on geological facies modeling. Because volcanic deposits are intricate, converting the volcanic facies and facies associations to lithostratigraphic units is challenging (Bull et al., 2020). The practice of combining different observable data and geological patterns to forecast the range of geographical distribution of geological facies beneath the surface is known as geological facies modeling (Song et al., 2021). Facies are certain lithological and paleontological characteristics that a deposit at a certain site indicates (BRONTO, 2006). The separation of volcanic facies into four categories: Proximal, Medial, Distal, and Central / Vent facies. B ation of the volcanic facies by the lithological properties (chemistry and physics) of the volcanic rocks at a certain site (Bogie et al., 1998).

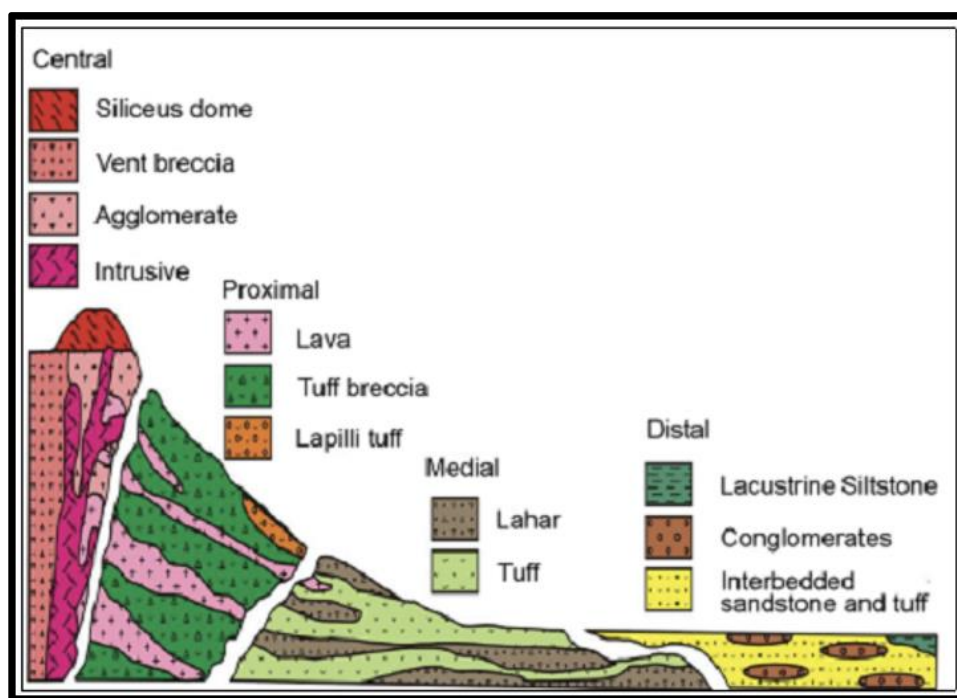


Figure 4. Four-facies model of a structurally undisturbed andesitic stratovolcano  
(Source: Bogie et al., 1998)

### **Geological Background**

The Muria volcano is situated at the center of the Muria Peninsula. The Genuk Volcano is situated towards the northeast of the Muria Volcano. The landscape of the Muria Peninsula was formed by volcanic activity from Muria Volcano, Genuk Volcano, and other parasitic volcanoes (BRONTO, 2006). The three primary landform types that define the Muria Peninsula are marine, fluvial, and volcanic. The process by which seafloor volcanoes became volcanic islands is what created the volcanic seabed that forms the Muria Peninsula (Wibowo et al., 2011). Although it still has the capacity to erupt, the Muria and Genuk volcanoes are no longer experiencing volcanic activity (McBirney et al., 2003). After analyzing aerial photos, it is clear that the summit area of Mount Muria is

very rough, and four depression areas reflect volcanic craters. Volcanic craters formed due to Mount Muria's activity can be seen in (Figure 2) (Suntoko, 2000).

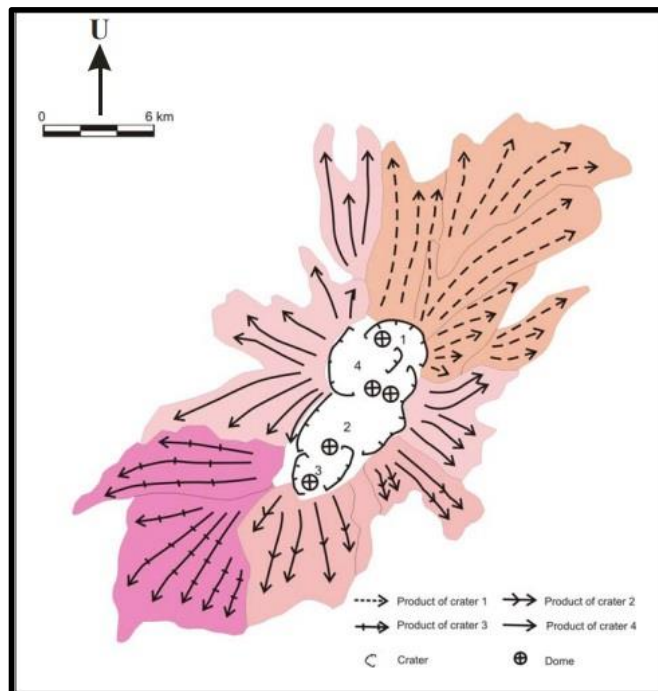


Figure 5. The crater of Mount Muria and the spread of its volcanic products around the highest peak  
(Source: NEWJEC, 1996)

The Muria Peninsula is home to three distinct volcanic centers, per the identification results. Mount Berap Patiayam, Genuk Volcano, and Muria Volcano are a few of these. Muria Volcano is a massive composite cone composed of lava, tephra, and shallow intrusive rocks that rise to a height of 1625 meters. The potassic nature of the volcano is high. The northernmost point of Muria is home to the 670-meter-tall, eroded dome complex known as the Genuk Volcano. Situated 17 miles to the south-southeast of Muria, Gurung Berapi Patiayam is 350 meters high (McBirney et al., 2003). Age-wise, magmatic activity has been divided into five primary phases, which are listed from oldest to youngest: the first Muria stage, the middle Muria stage, the young Genuk stage, the first Genuk stage, and the stage of young Muria (Nicholls & Whitford, 1983).

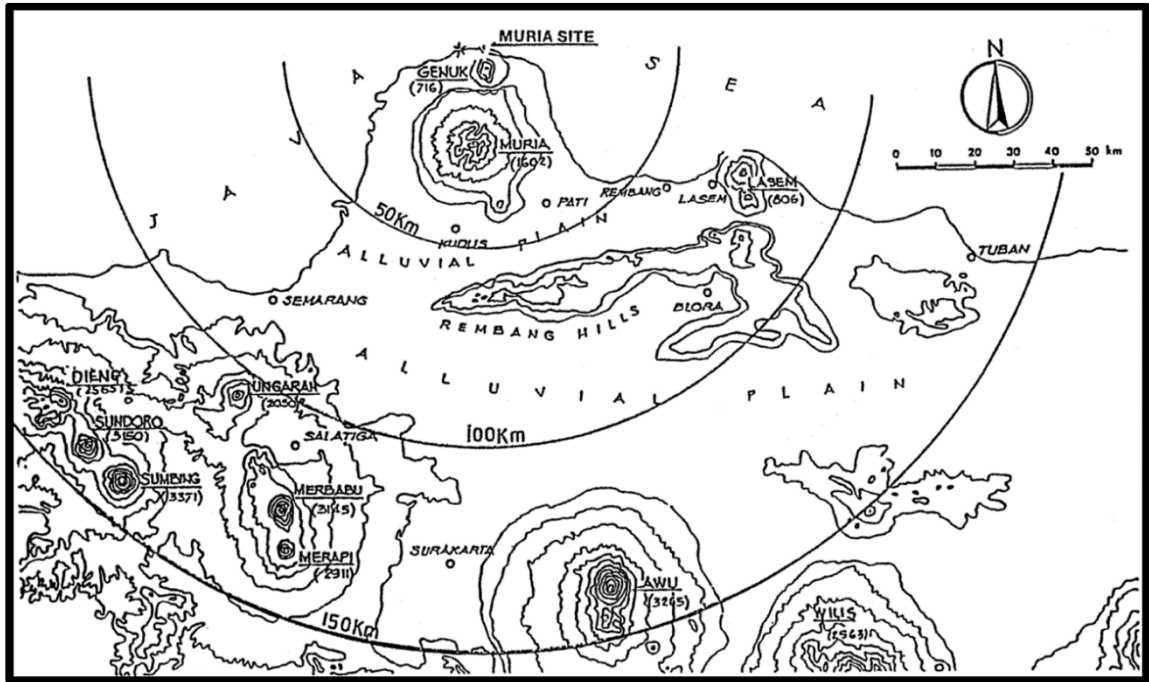


Figure 6. The volcano is within 150 km of the Muria Site.  
(Source: McBirney et al., 2003)

The results of field mapping data carried out and matched with geological history data on Mount Muria, the geological map and rock descriptions are as follows. Lava Andesite Muria (LAM): Andesite lava has a bright gray fresh color, reddish brown weathered color, massive structure, with hypocrySTALLINE crystallization degree texture, porphyritic granularity, anhedral-subhedral crystal shape, inequigranular crystal relationship, hornblende and plagioclase mineral composition. Lava Basanit Bambang (LBB): basanite lava has a dark gray fresh color, reddish brown weathered color, massive structure, with a texture of hypocrySTALLINE crystallization degree, porphyritic granularity, anhedral-subhedral crystal shape, inequigranular crystal relations, mineral composition of pyroxene, biotite, olivine, and leucite. Lava Basalt Muria (LBM): Muria basalt lava has a fresh blackish color, reddish brown weathered color, massive structure, with a texture of hypocrySTALLINE crystallization degree, porphyritic granularity, anhedral-subhedral crystal shape, inequigranular crystal relationship, mineral composition of pyroxene, biotite, and olivine. The following is geological map of the study area in Figure 7 below.

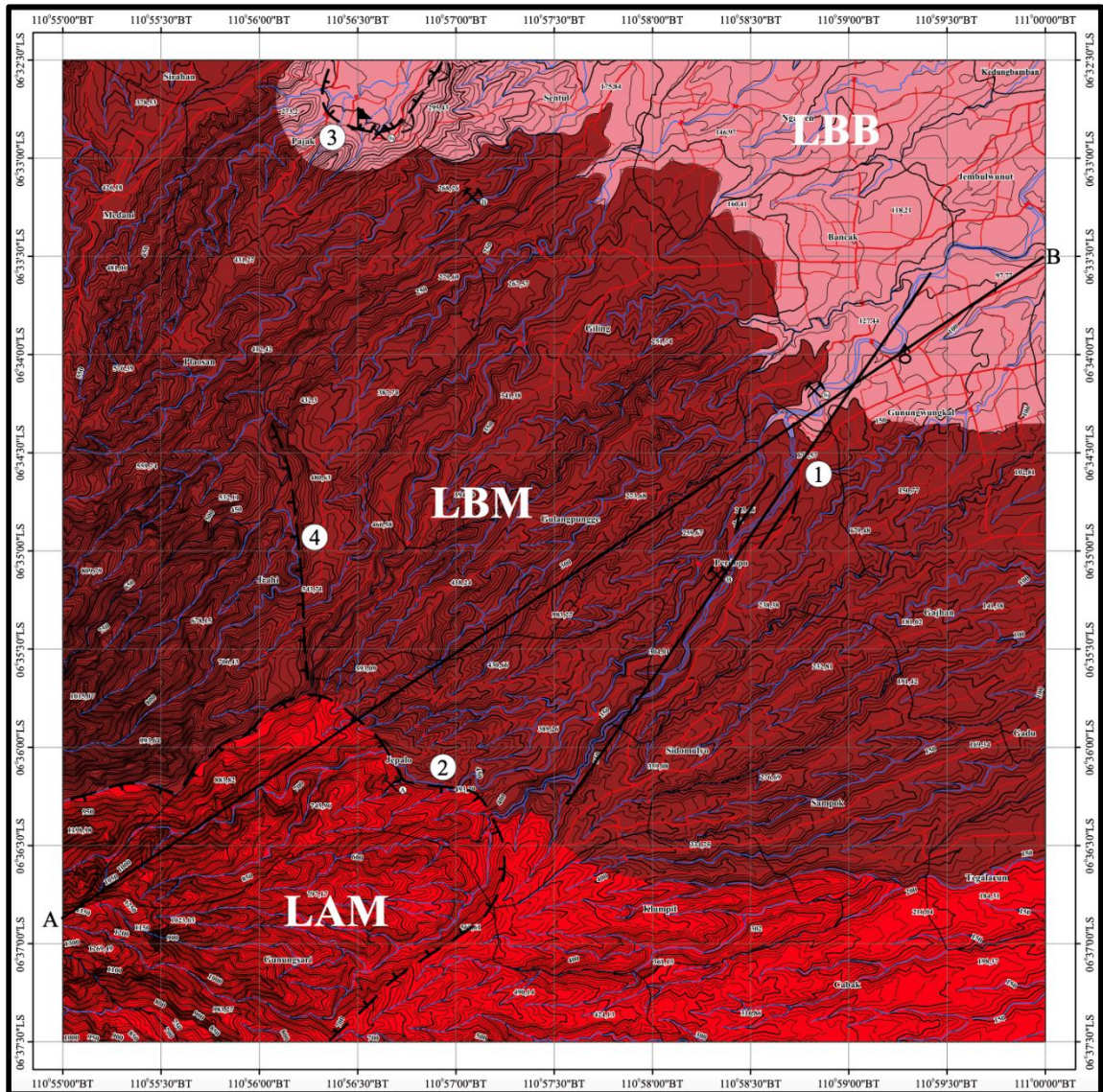


Figure 7. Geological map of the study area

The volcano stratigraphy or relationship between rocks will be explained using 2D modeling of the A-B cross-section line incision on the geological map. With the help of the A-B cross-section line incision, researchers try to illustrate the subsurface condition of the A-B cross-section line.

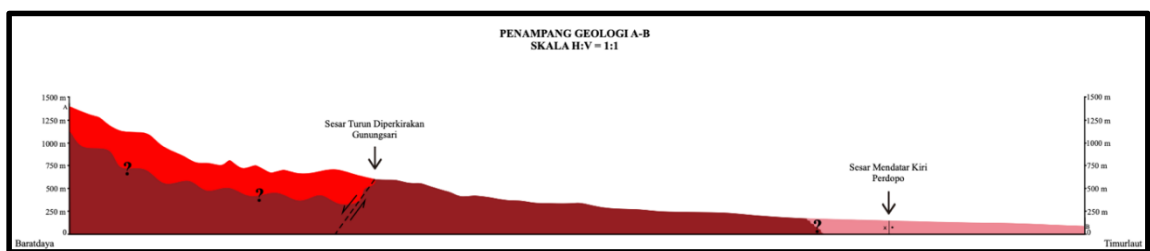


Figure 8. Geological cross-sections A-B

LBM is the oldest rock in the geological cross-section above with Lower Pleistocene age (1.00-0.77 Ma) which has a misaligned relationship to the rocks on it, namely LBB. LBB has an Upper Pleistocene age (0.53 Ma) that has a misaligned relationship with the rock above it, namely LAM. LAM is the youngest rock in the study area which has an Upper Pleistocene age (0.47-0.32 Ma). It can be concluded that the oldest to the youngest rocks in the research area are LBM, LBB, and LAM.

## **RESULT**

This research successfully applied field mapping and data processing methods using GIS. GISs improve geographical research and applications and help with spatial decision support by gathering, organizing, analyzing, and visualizing geospatial data (Liu, 2022). Using GIS can help process spatial data. GIS is an essential location analytical tool since it allows for map-based display, the development, storage, and manipulation of geographic data, as well as suitability assessment (Murray et al., 2019). The 3D modeling of volcano facies was made using Global Mapper software by combining geological maps and DEM data of the study area. After the modeling is complete, the data is adjusted to the volcano facies model of previous researchers. The results of the data processing recorded that the facies of the research area are proximal facies.

Proximal facies is the volcano area closest to the source location or central facies. The rock association on the composite volcano cone is dominated by lava flow interludes with pyroclastic breccia and agglomerate. Proximal facies are rocks laid on the slopes and outer sides of the volcanic complex characterized as follows: dominated by extensive and thick lava, partially bonded and intercalated lava coarse-grained pyroclastic with poor sorting, pyroclastic breccia, Steep slope. In the proximal facies is a silica dome on the side of the stratovolcano. The procyclical facies are the area surrounding and extending the central part of a volcano from 5 to 10 km from the volcano's center/vent source (Bogie et al., 1998).

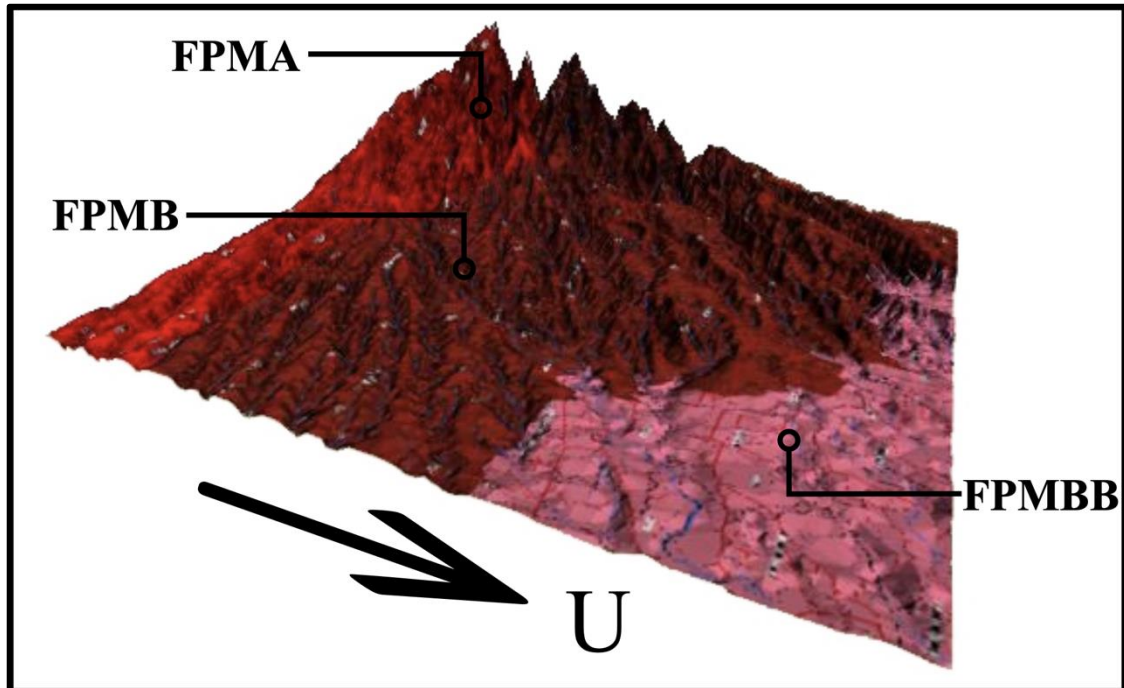


Figure 8. 3D model of volcano facies research area

#### ***Proximal facies of Muria basalt (FPMB)***

In the proximal facies of Muria basalt, this is determined based on the eruption point and eruption results. This facies has basalt lava lithology which is a lava flow from Muria volcano. The morphology of this facies is the geomorphology of the subunits of the upper volcanic slope and the middle volcanic slope in this facies zone composed of Muria basalt lava. This lithology is spread in the proximal zone of Muria basalt around the areas of Gadu, Gulangpungge, Plaosan, Sirahan, Giling, Sidomulyo, Sampok, Gajhan, Medani, and Perdopo.

#### ***Proximal Facies of Maar Bambang basanite (FPMBB)***

In the proximal facies of Muria, this andesite is determined based on the eruption point and eruption result. This facies has andesite lava lithology, a lava flow from Muria volcano with a different eruption point from previous eruptions. The morphology of this facies is the geomorphology of the subunits of the upper volcanic slope and the middle volcanic slope in this facies zone composed of Muria andesite lava. This lithology is spread in the proximal zone of Muria andesite around the areas of Gunungsari, Jepalo, Klumpit, Cabak, and Tegalarum.

#### ***Proximal Facies of Muria Andesite (FPMA)***

In the proximal facies of Muria, this andesite is determined based on the eruption point and eruption result. This facies has andesite lava lithology, a lava flow from Muria volcano with a different eruption point from previous eruptions. The morphology of this facies is the geomorphology of the subunits of the upper volcanic slope and the middle volcanic slope in this facies zone

composed of Muria andesite lava. This lithology is spread in the proximal zone of Muria andesite around the areas of Gunungsari, Jepalo, Klumpit, Cabak, and Tegalarum.

## **DISCUSSION**

Research on volcano facies provides new insights into understanding the evolution of volcanic environments over time. An understanding of the volcanic environment is crucial for understanding the activity level of volcanoes (Giudicepietro et al., 2021). Volcanology modeling has greatly improved our knowledge of volcanic processes and made it possible to forecast future eruptions (Kavanagh et al., 2018). To know the volcanic activities from time to time of the volcano, a volcano stratigraphy is needed to know the age of the volcanic rock to know its geological history. Understanding the spatial and temporal links between volcanic products and processes is made possible by the data that volcanic stratigraphy offers, which is crucial for resource exploitation and geological development (Martí et al., 2018). Through facies analysis, researchers can track changes in environmental conditions over a given geologic period, including the volcanic activity that occurred. This allows geologists to understand the geological processes involved in the formation of volcanic facies, such as eruption types, pyroclastic deposition, and lava formation.

More than just an overview of the geologic history of a particular area, volcano facies studies also provide an in-depth understanding of the potential risk of future volcanic eruptions. Important data for hazard assessment and its temporal evolution are obtained from monitoring volcanic eruptions (Bignami et al., 2020). Not only volcanic eruption hazards, geohazards must also be studied and assessed using GIS. Extreme geohazards that cascade, such as earthquakes, landslides, tsunamis, and volcanic eruptions, can have catastrophic consequences and are challenging to forecast and prepare for (López-Saavedra et al., 2021). By analyzing patterns and trends in facies evolution, researchers can identify areas vulnerable to volcanic activity and develop more effective disaster management strategies. This is important to protect people and the environment from the impacts of possible eruptions. Thus, research on volcano facies not only contributes to geological science but also has important implications for disaster management and understanding future geological risks.

## **CONCLUSION**

The division of volcanic facies at the study site is determined based on the eruption point, the results of eruption products, and rocks found in the field. Supported data from 3D models generated using GIS applications and harmonized with the Volcano Facies Model (Bogie et al., 1998). It was found that the facies of Muria volcano in the study area are proximal facies divided into 3 parts as follows: F proximal facies Muria basalt, Proximal facies Maar Bambang basanite, Proximal facies Muria andesite. This is because the study area has 3 eruption points and different types of lava.

## RECOMMENDATION

## FURTHER STUDY

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