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RESEARCH ARTICLE

Evolution Magmatism of Nagasari Volcano Dieng, Central Java, Indonesia

Dwi Fitri Yudiantoro [1]*, Intan Paramita Haty[1], Setia Pambudi[1], Elisabet Magdalena[1], Armala Putri[1], I. Takashima[2], M. Abdurrachman[3]

[1] *Geology Engineering Department, Volcanology, UPN Veteran Yogyakarta, Indonesia.*
[2] *Geological Department, Volcanology, Akita University, Japan*
[3] *Geology Engineering Department, Volcanology, ITB Bandung, Indonesia*

* Corresponding author : d_fitriyudiantoro@upnyk.ac.id
Tel.:+62-8122964012
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Abstract

Nagasari Volcano, part of the Dieng volcanic complex, is one of the unique volcanoes in Central Java. Around this volcano grow eruption craters, volcanic cones, and pyroclastic flow ridges. There were several 14 eruption centers around Mount Nagasari, so it is necessary to know the development of magmatism evolution. The aims of the research to determine the evolutionary development of magmatism. The methodology used is geological mapping and petrographic analysis. The observations of rocks found in the study area include andesite lava, lapilli-tuff, fallen pyroclastic breccias, and flow pyroclastic breccias. Meanwhile, geological mapping and petrographic observations of volcanic rock samples show that the evolution of magmatism in the study area from the oldest to the youngest is basaltic magma that formed Prau Volcano in the pre-caldera period. On the other hand, magmatism in the post-caldera I period was of the type of pyroxene andesite forming the Gembol to Jimat Volcano group. In contrast, in the post-caldera II period, the hornblende-biotite andesite group formed the Dieng Kulon to Kendil group.

Keywords: Andesite, Basalt, Dieng, Nagasari, Volcanic Rock

1. Introduction

Indonesia is a regional country at the confluence of the Eurasian plate, the Pacific plate, and the India-Australia plate. The interaction of the plates that meet is subduction which forms magmatism activity and causes the formation of a volcanic arc or ring of fire. This volcanic arc on the island of Java is lined from west to east.

The Dieng Plateau, located in Central Java Province, is composed of an active volcanic complex with various sizes of volcanoes, both small and medium in size. The volcanic complex grows in the old volcanic complex of the Jembangan Young Pleistocene caldera (Nugraha et al., 2013). Meanwhile, according to Pardyanto (1970), the Dieng Plateau and its surroundings are mountainous and highland. The mountainous areas include: Mount Seroja, Mount Kunir, Mount Prambanan, Mount Pakuwaja, Mount Kendil, Mount Butak, Mount Patarangan, Mount Prau, Mount Patakbanteng, Mount Jurangsawah, Mount Blumbang, and Mount Bisma and Mount Nagasari. Generally, these mountains have open craters. Meanwhile, Mount Seroja has the oldest crater shaped like a horseshoe that opens to the east, and the youngest is circular. The highland area consists of the Dieng plateau (2200 masl), the Batur plateau, and the Sidongkal plateau. The Dieng Plateau includes: Mount Prahu and parts of Mount Pakuwadja, Mount Kendil, Mount Pangonan, and Mount Sipandu. Several lakes are located on this plateau, including Telaga Warna, Telaga Pengilon, Lake Continue, Lake Lumut, and Lake Balekambang. In contrast, the highlands of Batur (1600 masl) include Mount Bisma, Mount Nagasari, Mount Djimat, and Mount Petarangan. The Sidongkal highlands (1800 masl) are overgrown by Mount Klaras, Mount Alang, Mount Petarangan, and Mount Butak. This plateau is in the form of depression.

The Dieng Volcanic Complex area is a Quaternary volcanic complex part of the Quaternary Sunda volcanic arc (Harijoko *et al.*, 2010). Dieng volcanic rocks consist of basaltic-andesitic lava and pyroclastic rocks (Salihin et al., 2020). In addition, the Dieng volcanic complex is also a productive geothermal field with a high temperature with a liquid domination system (Layman et al., 2002; Harijoko *et al.*, 2016; Akbar and Khasani, 2017). Dieng's geothermal energy potential is installed at 60 MW and is used as a source of power generation. Geothermal manifestations in the area are characterized by high temperatures and acidic pH (Rosid and Sibarani, 2021). These manifestations are fumaroles, hot springs, mud pools, and alteration.

This study aims to conduct geological mapping and microscopic observations of volcanic rocks so that the evolutionary development of magmatism in Mount Nagari and its surroundings can be arranged. The Gunung Nagasari area is administratively located in Dieng Kulon Village, Batur District, Banjarnegara Regency, Central Java Province (Fig. 1). In this area, several volcanoes grow, and there are geothermal manifestations to be done well regarding the development of magmatism evolution.

2. Data and Methodology

This research was conducted to determine the characteristics of volcanic rocks and the evolution of magmatism in the Dieng volcanic complex, especially in the Dieng Kulon area and its surroundings. The analytical methods used are geological mapping and petrographic analysis. Mapping volcanoes mainly carry out geological mapping. Meanwhile, field activities include outcrop observations, lithological descriptions, outcrop profile measurements, rock layer position measurements, geological structure measurements, and rock sampling. The rock outcrop data is then plotted on a base map based on the observation point using a GPS (Global Positioning System).

Thin sections were made on 17 samples representing rock units in the study area. These samples were expected to be representative to explain the petrogenesis of volcanic rocks in the study area. Bonding rocks carried out samples for petrographic analysis with a thickness of 0.03 mm. This is done so that it can be observed under a polarizing microscope. Using a polarizing microscope, it can be identified that the mineralogy of volcanic rocks includes structure, texture, and mineral composition. The analysis results are used to determine the type of rock and the magmatic evolution of the volcanic rocks exposed in the study area.

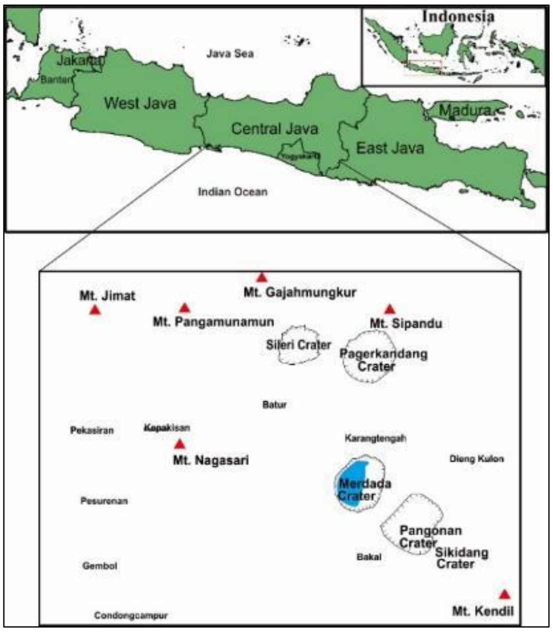

Fig 1. Research area map of Dieng Volcano

3. Result and Discussion

3.1 Geological Setting

The compression force influences the geological setting of Java Island due to the orogenesis of the Sunda Arc. This orogenesis occurred in the late Neogene and produced a magmatic arc on the island of Java. The Dieng Volcanic Complex is part of the Java magmatic arc and consists of parts of the Quaternary volcanic chain in the NW-SE direction (Setijadji, 2010). Dieng is a highland with an altitude ranging from 1,600 to 2,100 meters above sea level. This plateau is surrounded by volcanic peaks as high as 2,200-2,565 m above sea level. The caldera structure is visible on the west side of Mount Prahu.

The Dieng Volcano Complex consists of a complex of late Quaternary strato-cones to the present-day volcano. The oldest volcanic activity forms the edge of the Dieng Volcanic Complex, which remains an old caldera. The rest of the caldera is referred to as Mount Prahu. Then a new eruption center appeared, starting in the southwest to the southeast. The centers of this eruption were Pagerkandang, Pangonan-Merdada, and Pakuwaja.

Sukhyar et al. (1986), Harijoko et al. (2010), and Salihin et al. (2020) have divided the Dieng Volcanic Complex into three periods. The following is the division of the Dieng Volcanic Complex period based on its relationship to the caldera structure and distribution, and radiometric age (Fig. 2). Radiometric age data were determined using the K-Ar dating method: pre-caldera, post-caldera I, and post-caldera II groups. The pre-caldera group is aged (~ 3 Ma) which includes: Prahu, Rogojembangan and Telerejo. The post-caldera group I (~1 - 2 Ma) consisted of Nagasari (2.99 Ma), Bhishma (2.53 Ma), Sidede, Bucu, and Jimat. While the post-caldera II group (< 1Ma) included: Pagerkandang (0.46 Ma), Pangonan Merdada (0.37 Ma), Butak, Kendil (0.19 Ma), Pakuwaja (0.09 Ma), Prambanan, Seroja (0.07 Ma), and Sikunir.

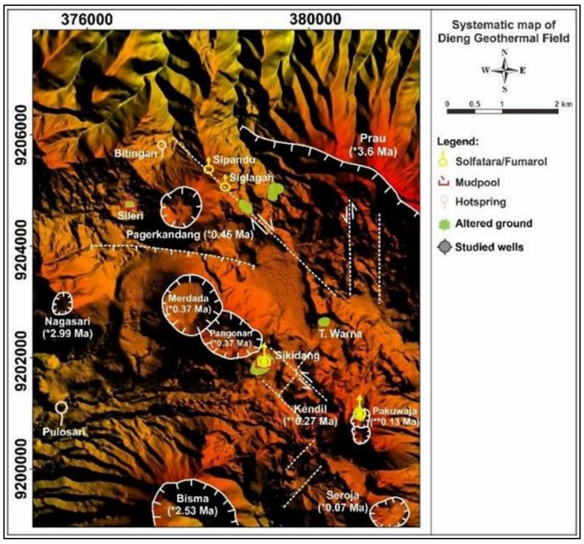

Fig 2. Systematic map showing the distribution of volcanoes and their age in the Dieng volcanic complex (Salihin et al. 2020).

3.2 Lithostratigraphy of Dieng Kulon and Surrounding area

The stratigraphy of this research area is prepared using informal units, which refers to the division of nomenclature following the rules of Indonesian Stratigraphic Codes (1996). The research area is generally dominated by falling pyroclastic rock lithology, pyroclastic flows, and lava. However, the author tries to divide it into more precise rock units based on the characteristics of each dominant lithology. The stratigraphy research area is divided into 24 units (Fig. 23). The stratigraphic sequence from oldest to youngest includes:

3.2.1 Pyroclastic flow Prau 1 (Prpa1)

Pyroclastic flows are fast-moving flows of hot gas and volcanic material or tephra. The hot volcanic material flows along the volcanic valley at a speed of 100 to 700 km/hour with a temperature of around 1,000 °C (Branney and Kokelaar, 2002), (Branney and Kokelaar, 2017; Benites *et al.*, 2020). The pyroclastic flow of this unit in the study area is a product of the Prau Volcano. The rocks that make up this unit include pyroclastic flow breccia and pyroclastic fall lapilli-tuff. This unit is generally found in weathered conditions, brown in colour, and loose.

The pyroclastic flow breccia (Fig. 3) has a dark brown colour, massive structure, angular fragment, and is poorly separated. The composition of the fragment is dominated by blocky andesite sized lapilli – block, pyroxene, pumice, and matrix in the form of coarse tuff.

Fig 3. Outcrop of pyroclastic flow breccia Prau 1 (Figure A and B), massive and angular fragment. The fragment is dominated by blocky andesite and pumice.

3.2.2 Pyroclastic Flow Prau 2 (Prpa2)

This unit is a product of the Prau Volcano, this unit's lithology is pyroclastic flow breccia, pyroclastic fall lapilli-tuff, and andesite lava. The pyroclastic flow breccia has a brown colour and massive structure. The angular fragments are very poorly separated. The fragments consist of blocky andesite, and reddish-brown pumice.

3.2.3 Pyroclastic Flow Gembol (Gbpa)

The eruption products of Gembol Volcano include pyroclastic flow breccias and pyroclastic flow lapilli-tuff (Fig. 4). Lapilli-block-sized blocky andesite and pumice fragments are embedded in a coarse tuff matrix. Angular shaped fragments are often found from andesite and pumice fragments.

Fig 4. The outcrop showing the pyroclastic flow Gembol deposit unit has a massive structure with andesite fragments and contains pumice.

3.2.4 Pyroclastic Flow Pangamunamun (Pnpa)

The pyroclastic flow unit of Pangamunamun is composed of pyroclastic flow breccias, pyroclastic flow lapilli-tuff, and pyroclastic fall lapilli-tuff (Fig. 5). This unit is in weathered condition, reddish-brown in colour, and is loose. The reddish-brown colour dominates the pyroclastic flow breccia. The fragments are blocky andesite and reddish-brown pumice with lapilli-block size. Pumice characterizes that magma has an acidic composition (Hastuti, 2017). The angular shape of the fragments and the sorting are very bad.

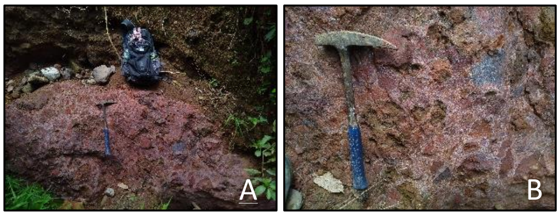

Fig 5. This pyroclastic flow unit is in weathered condition, so it is reddish-brown in color (A and B). The fresh gray fragments were identified as blocky andesite, while the reddish-brown color was identified as pumice. The angular shape of the fragments and their sorting are very poor

3.2.5 Pyroclastic Flow Sedringo (Sepa)

This unit is a product of the Sedringo Volcano. The rocks that make up this unit include pyroclastic flows breccia and andesite lava (Fig. 6). This unit is generally found in weathered, brown, and altered conditions.

Pyroclastic flow breccia has a dark brown colour, massive structure, angular, very poorly disaggregated, composition dominated by fragments of blocky andesite sized lapilli-block, reddish-brown pumice, and a matrix of coarse tuff.

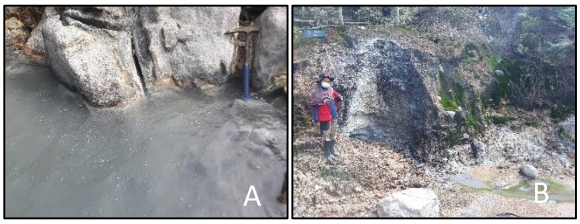

Fig 6. Outcrop of the pyroclastic flows breccia in the pyroclastic flow Sedringo unit (A and B). The breccia fragments consist of pyroxene andesite: plagioclase, pyroxene, opaque minerals, and glass as groundmass.

3.2.6 Pyroclastic Fall Nagasari (Ngpj)

This pyroclastic fall covers the entire geometry of the volcanic body either near or further from the eruption source. Pyroclastic material carried in the eruption plume form umbrella clouds then fall on the ground to form pyroclastic fall deposits (Giordano and Cas, 2021). Bed and grading is a reflection of the sorting of grains. Pyroclastic fragments can consist of juvenile or foreign body properties clastic (Houghton and Carey, 2015). The rock that composes this unit is pyroclastic fall lapilli-tuff. This unit is generally found in weathered conditions, brown in colour, and loose. Pyroclastic fall lapilli-tuff has a reddish-brown colour, parallel layered structure, and graded bedding (Fig. 7). The fragments show a subangular and are well separated. The fragments consist of quartz, plagioclase, ferromagnesian mineral hornblende, pyroxene, andesite scoria, and oxidized pumice in a volcanic fine ash volcanic matrix. Scoria andesite is a juvenile material (Vásconez Müller *et al.*, 2022).

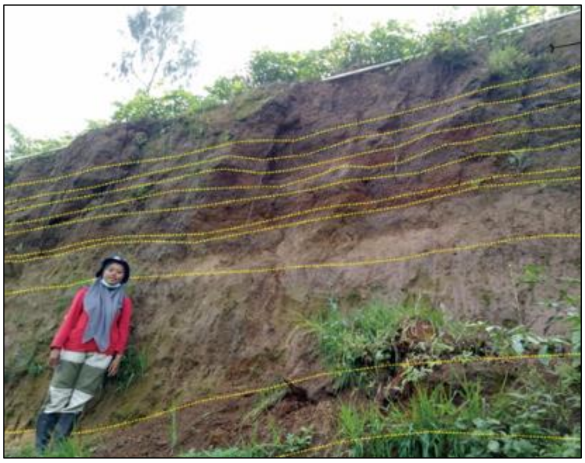

Fig 7. Outcrop of pyroclastic fall lapilli-tuff in the pyroclastic fall Nagasari unit. Pyroclastic fall lapilli-tuff has a parallel layered structure and graded bedding. The fragments consist of quartz, plagioclase, hornblende, pyroxene, andesite scoria, and oxidized pumice.

3.2.7 Pyroclastic Flow Nagasari 1 (Ngpa1)

The rocks that make up the pyroclastic flow Nagasari 1 unit include pyroclastic flow breccias, pyroclastic flow lapilli-tuff, andesite lava, and pyroclastic fall lapilli-tuff. The pyroclastic flow breccia has a brownish colour and massive structure. The fragments are angularly shaped and very poorly separated. The fragments are in the form of blocky andesite-sized lapilli – blocks. Reddish-brown pumice is sometimes found in this unit, and the matrix is composed of coarse tuff.

Fig 8. A. The pyroclastic outcrop fall lapilli-tuff in the Nagasari 3 unit.

3.2.8 Pyroclastic Flow Nagasari 2 (Ngpa2)

This unit is the product of the Nagasari Volcano's eruption, and the unit's rock constituents include pyroclastic flow breccia, andesite lava, and pyroclastic fall lapilli-tuff. The pyroclastic flow breccia has a light brown colour with a massive structure. The fragments were poorly sorted (Scarpati et al., 2020) and consisted of andesite-block-sized lapilli, lithic, pumice, and a matrix of coarse tuff.

3.2.9 Pyroclastic Flow Nagasari 3 (Ngpa3)

This rock unit consists of pyroclastic flow breccia and pyroclastic fall lapilli-tuff (Fig. 8). This unit is generally found in weathered conditions, brown in colour, and has not been rocked loose and loose. The pyroclastic flows breccia exhibits half-angled fragments and very poor sorting. The rock constituent fragments include lapilli-block-sized andesite blocky, pumice embedded in a coarse tuff matrix. Meanwhile, the pyroclastic fall lapilli-tuff showed a perfect parallel layer structure. As a result, the fragments look angular, such as andesite and pumice. Other minerals such as fragments are plagioclase and pyroxene.

3.2.10 Nagasari Lava (Ngl)

Lava is the outpouring of lava during an effusive eruption (Rodriguez-Gonzalez *et al.*, 2022). Lava can flow great distances before cooling (Zorn *et al.*, 2020), causing it to harden. This unit results from the eruption of pyroxene andesite lava melt from Nagasari Volcano. Pyroxene andesite lava has a gray color and massive structure (Fig. 9). The degree of hypocrystalline crystallinity and aphanitic-phaneritic granularity were moderate (1-5 mm) inequigranular texture (Wijaya and Setijadji, 2022). The minerals that make up the rock are plagioclase, pyroxene, opaque minerals, and glass as groundmass.

Fig 9. Andesite lava outcrop in the Nagasari andesite lava unit shows the dome cone's morphology.

3.2.11 Pyroclastic Flow Jimat (Jipa)

This unit is a product of the eruption of the Jimat Volcano. The rocks that make up this unit include pyroclastic flow breccia and andesite lava. This unit is generally found in weathered conditions, brown in colour, and has not been rocked loose and loose. A matrix of coarse tuff is present surrounding the fragments of the pyroclastic flow breccia (Fig. 10). The angular-shaped fragments were represented by lapilli-block-sized blocky andesite and reddish-brown pumice.

3.2.12 Pyroclastic Fall Dieng Kulon (Dkpj)

Pyroclastic fall lapilli-tuff and pyroclastic flow breccias are the constituent rocks of this unit. This unit is generally found in weathered conditions, brown in colour, and has not been rocked loose and loose.

Pyroclastic fall lapilli-tuff has reddish-brown colour, parallel layer structure and graded bedding, angular, well-sorted, mineral composition is quartz sialic, plagioclase, hornblende, pyroxene, and andesite scoria, oxidized pumice, fine volcanic ash (Fig. 11).

Fig 10. Outcrop of pyroclastic flow breccia in the pyroclastic flow deposit of Jimat unit. A. Far away photo. B. Close up photo.

Fig 11. The pyroclastic outcrop fell lapilli-tuff in the Dieng Kulon unit, which was abundant and interspersed with several pyroclastic fall deposits.

3.2.13 Pyroclastic Flow Gajahmungkur (Gmpa)

This unit is a volcanic product from Gajahmungkur Volcano. Pyroclastic flow breccia, pyroclastic flow lapilli-tuff, and pyroclastic fall lapilli-tuff are generally found in weathered conditions. The colour of the rock outcrops is brown and loose. The pyroclastic flow breccia has a dark brown colour and massive structure. The fragment's shape is angular with the composition of the fragment in the form of blocky andesite by showing spheroidal weathering. Pumice appears reddish-brown in a matrix of coarse tuff.

3.2.14 Pyroclastic Flow Sipandu (Sppa)

The rocks that make up this unit are pyroclastic flow breccias and andesite lava. This unit is generally found in weathered conditions, brown in colour, and has not been rocked loose and loose. The pyroclastic flow breccia has a brown colour, massive structure, angular, very poorly separated, fragments of blocky andesite dominate the composition sized lapilli – block, reddish-brown pumice a matrix of coarse tuff (Fig. 12).

Fig 12. Outcrop of pyroclastic flow breccia in the pyroclastic flow Sipandu unit.

3.2.15 Pyroclastic Fall Pagerkandang (Pkpj)

Pyroclastic fall lapilli-tuff, andesite igneous rocks, andesite lava, and pyroclastic flow breccias make up this unit. Weathered conditions, brown in colour and not yet rocked and loose, are common in this unit.

Pyroclastic fall lapilli-tuff has a reddish-brown colour. Parallel and reverse graded bedding structures are often found in this unit (Fig. 13). The fragments are angular in shape and well separated. The composition of minerals is plagioclase, pyroxene, andesite, and pumice in a volcanic fine dust matrix.

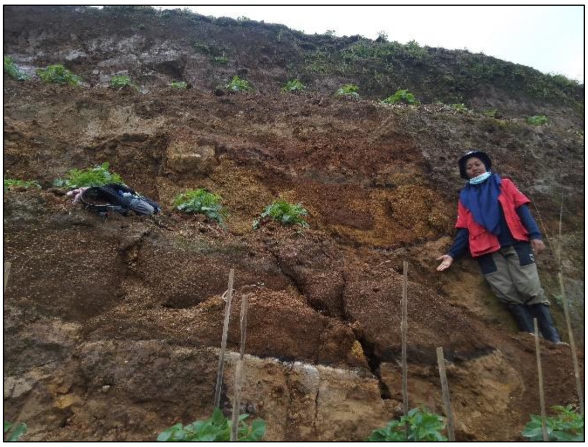

Fig 13. Pyroclastic fall lapilli-tuff outcrop in the pyroclastic fall unit of the Pagerkandang which was abundant and interspersed with several pyroclastic fall deposits.

3.2.16 Pyroclastic Flow Sileri (Sipa)

Sileri Crater produces eruption products in the form of pyroclastic flow breccia and andesite lava. This unit is generally in weathered condition, brown in colour, and has not been rocked or loose. The pyroclastic flow breccia is reddish-brown with a massive sedimentary structure. Fragments show angles of responsibility that are very severely sorted. Blocky andesite and pumice sized lapilli – block as fragments in a coarse tuff matrix.

3.2.17 Pyroclastic Flow Pangonan (Pgpa)

This unit is a product of the Pangonan Volcano. The rocks that make up this unit include pyroclastic flow breccia. This unit is generally found in weathered conditions, brown in colour, and has not been rocked loose and loose. The pyroclastic flow breccia has a dark brown colour, massive structure, angular, and very poorly separated (Fig. 14). The composition is dominated by blocky andesite-sized lapilli-block fragments, reddish-brown pumice, and a matrix of coarse tuff.

Fig 14. Outcrop of pyroclastic flow breccia in Pangonan pyroclastic flow unit. The pyroclastic flow breccia has a massive structure, angular, and very poorly sorted. The composition of the fragment is dominated by blocky andesite-sized lapilli-block and reddish-brown pumice.

Fig 15. Outcrop of pyroclastic fall lapilli-tuff in the Pangonan pyroclastic fall unit was abundant and interspersed with several pyroclastic fall deposits.

3.2.18 Pyroclastic Fall Pangonan (Pgpj)

The Pangonan volcanic cone produces pyroclastic fall lapilli-tuff (Fig. 15), pyroclastic flow breccia, and pyroclastic flow lapilli. This unit is generally found in weathered condition, brown in color, and has not been lithified. Pyroclastic fall lapilli-tuff has a parallel layered structure and graded bedding. A volcanic ash matrix is present along with plagioclase, pyroxene, andesite, and pumice.

3.2.19 Pyroclastic Fall Merdada 1 (Mdpj1)

Pyroclastic fall lapilli-tuffs with parallel layered structures are commonly found in weathered conditions and are brown in colour. Pyroclastic fall tuffs have reddish-brown colour, parallel layered structure, subrounded, well-sorted, plagioclase fragments, andesite scoria, pyroxene, and pumice oxidized to give a reddish colour (Fig. 16).

Fig 16. Outcrop of tuff lapilli in pyroclastic fall Merdada 1 unit. Pyroclastic fall tuff lapilli has parallel layered structures. The fragments are well-sorted: plagioclase, scoria andesite, pyroxene, and oxidized pumice.

Fig 17. Outcrop of pyroclastic fall lapilli-tuff in the pyroclastic fall Merdada 2 unit was abundant and interspersed with several pyroclastic fall deposits.

3.2.20 Pyroclastic Fall Merdada 2 (Mdpj2)

Merdada Volcano produces rock units: pyroclastic fall lapilli-tuff and andesite lava. This unit is generally found in weathered conditions, brown in colour, and loose.

Pyroclastic fall lapilli-tuff has a parallel layered structure (Fig. 17). Fragments are angular and well separated. Andesite, pyroxene, plagioclase, and oxidized pumice fragments are embedded in the volcanic fine ash matrix.

3.2.21 Kendil Lava 1 (Kdl1)

This unit is andesitic lava from Kendil Volcano, generally with scoria and vesicular structure. The primary constituent minerals such as plagioclase, hornblende, pyroxene, and biotite are embedded in the bottom mass of volcanic glass (Fig. 18).

Fig 18. Outcrop of andesite lava in the Kendil 1 lava unit shows the dome cone's morphology. Plagioclase, hornblende, and pyroxene phenocrysts are visible megascopically in this rock outcrop.

3.2.22 Kendil Lava 2 (Kdl2)

This unit is the product of the melt eruption of Kendil Volcano, which is andesitic lava. Andesite lava has a scoria and vesicular structure. The primary minerals present in this lava are plagioclase, hornblende, pyroxene, and biotite. The phenocrysts are embedded in the bottom mass of volcanic glass.

3.2.23 Pyroclastic Flow Kendil (Kdpa)

The rocks that make up this unit result from the eruption of the Kendil Volcano, a pyroclastic flow breccia. The fragments are composed of blocky andesite and pumice, and the matrix in the form of coarse tuff has a reddish-brown colour. Massive sedimentary structures, unsorted texture, and very poorly disaggregated fragments.

3.2.24 Pyroclastic Fall Kendil (Kdpj)

The rocks that make up this pyroclastic fall Kendil unit are pyroclastic fall lapilli-tuff and pyroclastic flow breccias. Pyroclastic fall lapilli-tuff has a reddish-brown colour with a parallel layered structure. Fragments are generally angular and well separated. Several minerals such as quartz, plagioclase, ferromagnesian mineral hornblende, and pyroxene are present among the oxidized andesite and pumice fragments.

3.3. Volcanic Rocks

3.3.1. Petrography

Petrographic observations were carried out on 14 samples of volcanic rock in the study area representing several volcanic units, the order of volcanic units containing lava from old to young is as follows: Mount Prau 2 (sample Lp 48 and 49), Mount Pangamunamun (sample 133), Mount Sedringo (sample Lp 27 and Lp 158), Mount Nagasari 1 (sample Lp 83), Mount Nagasari 2 (sample Lp 24), Mount Nagasari 4 (sample Lp 87), Mount Jimat (sample Lp 14, 103, 138), Mount Gajahmungkur (sample Lp 128), Mount Merdada 1 (sample Lp 38 and Mount Kendil (sample Lp 63).

This study's naming of volcanic rocks follows William's classification (1954). The petrographic analysis show basalt, pyroxene andesite, and hornblende-biotite andesite (Table 1). Basalt rocks are represented by Mount Prau 2 (sample Lp 48 and 49). Pyroxene andesite belongs to sample from Mount Pangamunamun (sample 133), Mount Sedringo (samples Lp 27 and Lp 158), Mount Nagasari 1 (sample Lp 83), Mount Nagasari 2 (sample Lp 24), Mount Nagasari 4 (sample Lp 87), Mount Jimat (sample Lp 14, 103, 138), Mount Gajahmungkur (sample Lp 128). Meanwhile, hornblende-biotite andesite is represented by rock samples from Mount Merdada (sample Lp 38) and Mount Kendil (sample Lp 63).

4.1.1. Basalt

Basalt is found as a basic type of lava (Fig. 19). Microscopically it is grey in colour, showing the scoria structure. The phenocrysts (80-85%) are fine to medium (0.1-0.2 mm) in size with a porphyritic intersertal texture. Phenocryst consists of plagioclase, pyroxene, olivine, and opaque minerals. The groundmass (15-20%) also has a pilotaxitic flow texture. Pilotaxitic textures can be found on groundmass (Mattioli *et al.*, 2020). Some phenocrysts show to have been converted to chlorite.

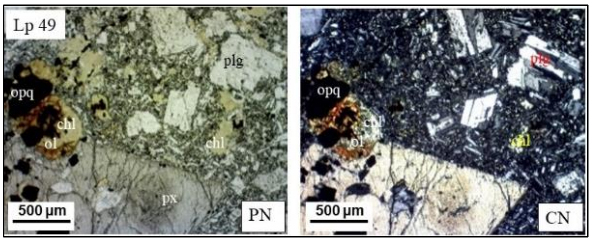

Fig 19. Petrography of basalt shows the presence of plagioclase, pyroxene, and olivine minerals. Olivine and groundmass are seen to be replace to chlorite. Intersertal texture is shown by clusters of plagioclase microliths around the phenocrysts. plg: plagioclase; ol: olivine; px: pyroxene; opq: opaque mineral; chl: chlorite; PN: parallel nicol; CN: cross nicol

Plagioclase is about 65-70% and appears colourless with a phenocryst crystal size of about 0.2-1.2 mm. The type of plagioclase in this rock is bytownite (An_{70}-An_{80}). Carlsbad-albite twins are commonly found as twins other than zoning. Plagioclase usually shows zoning with variations in composition (Cawthorn *et al.*, 2016).

Pyroxene (hypersthenes) is present in about 10% as short prismatic-shaped phenocrysts with a size of 0.2-0.4 mm. The opaque minerals present at about 5% are together with other micro minerals to form porphyritic and intergranular textures.

Olivine is present in about 5% present as phenocrysts and groundmass. The size of the phenocrysts was 0.2-0.3 mm spread between the ground masses. Some hornblende appears to be replaced by the mineral opaque and replaced by chlorite. Volcanic glass is present at around 15-20%

around the phenocryst, fine minerals such as plagioclase and pyroxene microlites, and opaque minerals (5%) forming an intersertal texture.

3.3.2. Pyroxene Andesite

In general, pyroxene andesite outcrops consist of intermediate-type lavas with scoria and vesicular structures. Microscopically, pyroxene andesite has a porphyritic texture with plagioclase, hornblende and pyroxene phenocrysts that are euhedral in shape and have an average size of 1.2 mm (Fig. 20). Composed of main minerals (80-85%) consisting of plagioclase (Andesine) and pyroxene (hypersthene, augite) and opaque minerals. Base mass (15-20%) includes micro pyroxene and micro plagioclase forming pilotaxic and vitroveric textures, each with a maximum size of 100-200 m. Some opaque minerals include pyroxene.

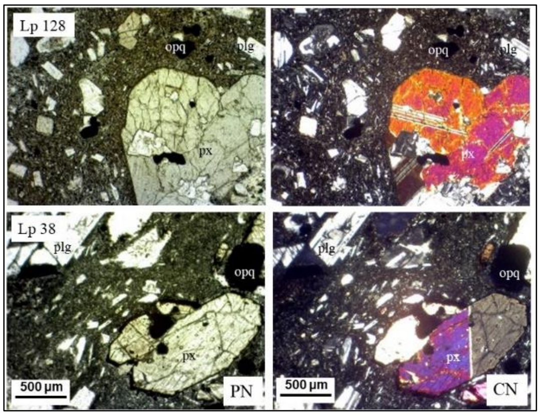

Fig 20. Petrographic of pyroxene andesite shows the presence of plagioclase, pyroxene, and opaq minerals. At the edge of the pyroxene it is seen that it is altered by opaque minerals. The intergranular texture is indicated by the assemblage of plagioclase microliths around the phenocrysts. plg: plagioclase; px: pyroxene; opq: opaque mineral; chl: chlorite; PN: parallel nicol; CN: cross nicol

Plagioclase in about 55-67% appears colourless, subhedral-anhedral, and long prismatic. As a phenocryst with a crystal size of about 0.2-1.2 mm and as a base mass in the form of Andesine-type micro plagioclase ($An_{45}An_{49}$). Plagioclase phenocrysts generally show albite, Carlsbad-albite twins, and some individuals exhibit compositional zonation. Chlorite and clay minerals are present to change some plagioclase at the edges and crystal fragments.

As phenocrysts and groundmasses, pyroxene (hypersthene, augite) is present in about 12-17%. Generally short prismatic or subhedral-anhedral with a size of 0.2-0.4 mm. Some of the pyroxenes undergo hydrothermal changes, especially at the edges of the crystal. As a result, pyroxene is converted into chlorite and opaque minerals. In addition, some individual phenocrysts show corrosion by the groundmass.

Opaque minerals are present in about 3-8%, sometimes clustered in the bedrock, and some include pyroxene. In some samples, opaque minerals (iron oxide) fill the veins that cut some phenocrysts and bedrock in the rock incision.

Ground mass is present in 15-20% of petrographic incisions. Comes is a fine-sized volcanic glass. This volcanic glass surrounds the phenocryst. Together with micro plagioclase, micro pyroxene and opaque minerals (3-8%) exhibit intergranular, pilotaxytic, and vitroveric textures.

3.3.3 Hornblende-Biotite Andesite

Hornblende-biotite andesite is found as lava from magma that solidifies at the surface. In the research area, this hornblende-biotite andesite was only found in rock units from Mount Kendil (sample Lp 63) and Mount Sedringo (sample Lp 27 and Lp 158). Microscopically, it is grey in colour showing scoria and vesicular structures (Fig. 21). The phenocrysts (77-85%) are fine to medium (0.1-0.2 mm) in size with a porphyritic and intergranular texture. This intergranular texture can be observed in the groundmass (Santi, Chaigneau and Renzulli, 2022). Phenocryst consists of plagioclase, hornblende, pyroxene, biotite, and opaque minerals. The bottom mass of volcanic glass (20-23%) with micro plagioclase is present around the phenocryst. On the ground floor also found the texture of the pilotaxitic flow.

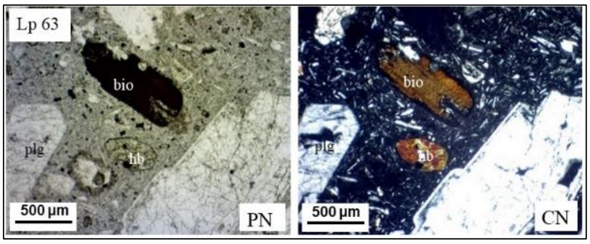

Fig 21. Petrographic of horblende-biotite andesite shows the presence of plagioclase, pyroxene, hornblende, biotite and opaque minerals. At the edges of biotite and hornblende it is seen that it was altered by the mineral opaque. These phenocrysts are surrounded by micro plagioclase forming an intergranular texture. plg: plagioclase; bio: biotite; hb: hornblende; opq: opaque mineral; PN: parallel nicol; CN: cross nicol

Plagioclase present about 48-57% appears colourless. The crystal form is subhedral-anhedral, measuring 0.2-1.2 mm as a phenocryst and as a base mass in the form of Andesine plagioclase microlites (An_{45}-An_{49}). In almost every individual, plagioclase shows albite and Carlsbad-albite twins.

Hornblende is about 13-15% present as phenocrysts and ground masses. Short prismatic phenocrysts with a size of 0.2-0.3 mm. Some of the edges of the phenocrysts are replaced by opaque minerals.

Pyroxene (augite) is present at about 5-8% present as phenocrysts and bedrock, In thin sections of rock showing short prismatic shapes with a size of 0.2-0.4 mm. In some individuals, phenocrysts show traces of corrosion by bedrock.

Biotite is about 4-5% present in the bedrock with plagioclase microns. Some present as phenocrysts with short prismatic phenocrysts. The size of biotite as a phenocryst is up to 0.2-0.3 mm.

Opaque minerals are around 2-5% present with other micro minerals to form porphyritic and intergranular textures. Sometimes opaque minerals are present in groups in the bedrock, including pyroxene.

Volcanic glass is present in a thin slice of rock at about 15-23%. This fine mineral is present as a bedrock with plagioclase microlites, pyroxene, and biotite to form an intergranular texture.

The results of petrographic observations of several samples of pyroxene andesite lava and hornblende andesite indicate that the volcanic rocks in the study area generally have a strong porphyritic texture which has phenocrysts around 80-85%. This feature shows that the volcanic rocks of the research area are tectonically formed in an island arc tectonic environment. The abundant phenocryst is about 80-85% consisting of the minerals plagioclase (48-67%), pyroxene (5-15%), and hornblende, about 3-16%. Meanwhile, biotite and opaque minerals are around 2-7%. The presence of pyroxene, hornblende, biotite, and opaque minerals indicates that the volcanic rocks in the study area were enriched with iron during the magma differentiation process. Based on these characteristics, petrographically the volcanic rocks in the study area have a calc-alkali composition and this Dieng volcano is a Quaternary volcano which is in a row with the Ungaran volcano in Central Java (Yudiantoro *et al.*, 2018).

Table 1. Result of petrography analysis of volcanic rocks in the study area.

No. Sample	Phn	Plg	Olv	Px	Hb	Bio	Opq	Texture	Name
Lp 63	♦	◊		Δ	□	Δ	Δ	intergranular	Hornblende-biotite andesite
Lp 38	♦	◊		Δ	□	Δ	Δ	intergranular	Hornblende-biotite andesite
Lp 128	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 14	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 103	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 138	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 87	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 24	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 83	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 27	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 158	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 133	♦	◊		□			Δ	intergranular	Pyroxene andesite
Lp 48	♦	◊	Δ	□			Δ	intersertal	Basalt
Lp 49	♦	◊	Δ	□			Δ	intersertal	Basalt

Annotation:

♦ > 75%; ◊ > 20%; □ 10-20%; Δ <10%

Phn: Phenocryst; Plg: Plagioclass; Olv: Olivine; Px: Pyroxene; Hb: Hornblende; Bio: Biotite; Opq: Opaq;

◊: Phenocryst and groundmass

3.4. Evolution of Magmatism

The evolution of magmatism of Nagasari Volcano and its surroundings is based on the division of the Dieng Volcanic Complex period that has been proposed by Sukhyar et al. (1986), Harijoko et al. (2010), and Salihin et al. (2020). Apart from that, geological field mapping, morphostratigraphic sequence arrangement, and petrographic analysis were used to determine the magmatism evolution of the study area. Based on the petrographic analysis, three magma types are found in the research area. Furthermore, from the distribution of samples, petrographic analysis shows a change in the magma composition, which is more directed to the presence of biotite minerals in younger episodes. Therefore, each episode has a distinctive magma composition. Thus, the evolution of magmatism in the study area is divided into three periods: pre-caldera period, post-caldera 1, and post-caldera 2.

Pre-caldera period: this period produces volcanic rocks from the eruption of Mount Prau. Petrographic observations show the basic magmatism type with bytownite as a characteristic of this magmatism type aged (~ 3 Ma). Bytownite has a chemical formula is Ab_3An_7. According to Salihin et al. (2020), basaltic lava consisting of plagioclase (labradorite), pyroxene, and minor olivine is considered part of the Old Dieng product.

The next period is the aged post-caldera group 1 (~1-2 Ma). In the research area, this group is represented by Gembol, Pangamunamun, Sedringo, Nagasari and Jimat volcanoes. The type of magmatism that makes up the volcano is intermediate with a pyroxene andesite composition. Hypersthenic and augite pyroxene minerals are very common in this volcanic rock unit, about 12-17%. Meanwhile, the chemical formula for hypersthenes (Mg, Fe) SiO_3) and augites (Ca (Mg, Fe) (Si, $O_3)_2[(Al, Fe)_2O_3]_x$. Andesitic lava consisting of andesine, pyroxene, and microcrystalline plagioclase is considered part of the Dieng Tengah product (Salihin et al., 2020).

While the post-caldera period II is aged (< 1 Ma). Dieng Kulon, Gajahmungkur, Sipandu, Pagerkandang, Sileri, Pangonan, Merdada and Kendil volcanoes are a group of post-caldera 2 volcanoes located in the study area. The minerals hornblende (13-16%) and about 4-5% biotite are present in the hornblende-biotite andesite lava. So that the mineral is a differentiator with volcanic rocks from the previous period, the biotite (K_2 (Mg, Fe)$_2$(OH)$_2$($AlSi_3O_{10}$)). Biotite andesite lava consists of plagioclase (oligoclase-andesine), pyroxene, and biotite embedded in microcrystalline plagioclase. The bottom mass of volcanic glass is part of the Dieng Muda product (Salihin et al., 2020). The presence of biotite minerals indicates a change in magmatism from the Ca-rich intermediate to the more potassium-rich intermediate in this period. The presence of biotite indicates that the evolution of magmatism in the study area towards a younger age indicates that the magma composition is getting more acidic than before. In addition, the development of the eruption center in the study area is trending from the northwest to the southeast. According to Harijoko et al. (2016), changes follow the distribution of changes in the center of the eruption in the magma composition. The magma composition is more acid from older to younger episodes. Changes in the center of the eruption and the composition of magma following this follow lineaments that are relatively northwest-southeast and southwest-northeast (Harijoko et al., 2016).

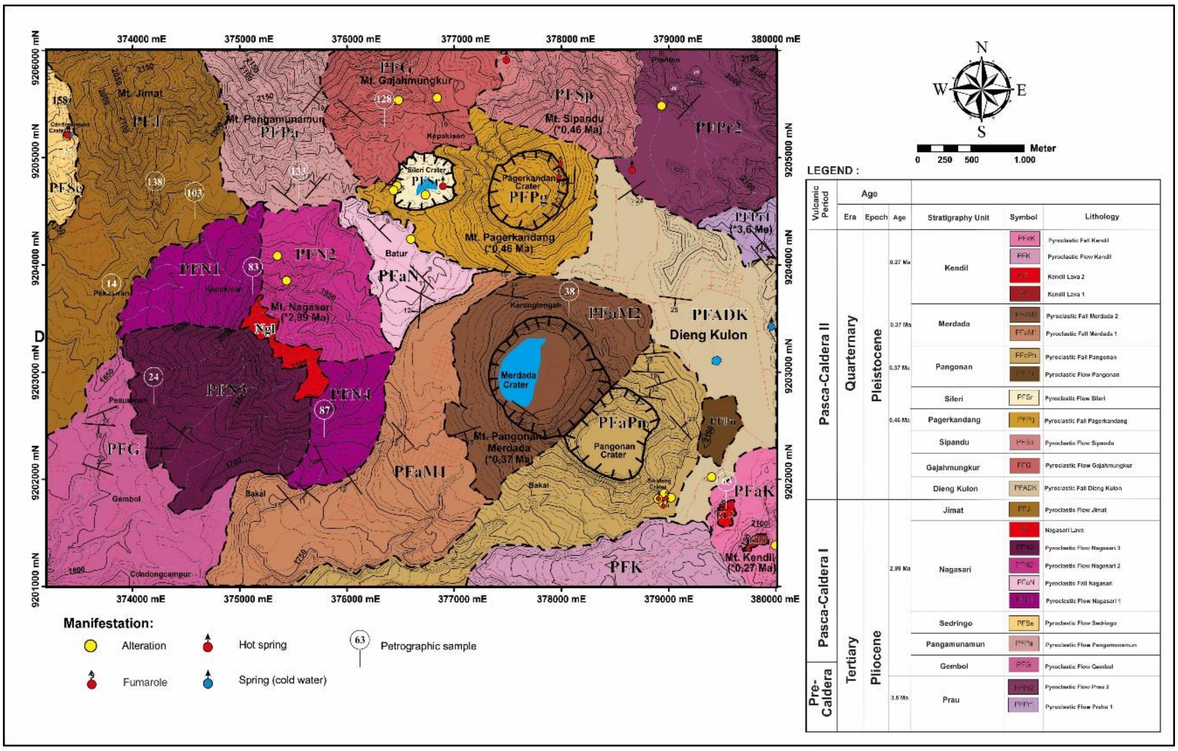

Fig 22. Geological map of the study area.

4. Conclusions

Volcano Nagasari and its surroundings have 14 volcanic cones and 24 units of pyroclastic rock and lava. The types of lava consist of basalt lava, pyroxene andesite and hornblende-biotite andesite. The pyroclastic rocks are flow pyroclastic tuff, falling pyroclastic tuff, and flow pyroclastic breccia.

The research results show that the development of magmatism evolution in the Nagasari Volcano area can be divided into three magmatism processes: the pre-caldera, post-caldera I, and post-caldera II periods.

The pre-caldera period is a product of Old Dieng. This period produces volcanic rock from the eruption of Mount Prau. The petrographic observations show the type of alkaline magmatism aged (~ 3 Ma) characterized by basalt lava. The presence of bytownite plagioclase minerals ($An_{70}An_{80}$) is a characteristic of this type of magmatism.

The post-caldera I period aged (~1-2 Ma) with pyroxene andesitic magmatism. Andesitic lava is part of Central Dieng products. Volcanic groups of this period include: Gembol, Pangamunamun, Sedringo, Nagasari and Jimat.

The post-caldera II period (< 1 Ma) includes volcanic groups such as: Dieng Kulon, Gajahmungkur, Sipandu, Pagerkandang, Sileri, Pangonan, Merdada and Kendil. The type of magmatism of this period is hornblende-biotite andesite. This period of magmatism is part of the product Dieng Muda.

During the evolutionary development of magmatism from Old Dieng to Young Dieng, there were a change in the magma composition from magma which has a lot of Ca (bytownite) elements to the presence of biotite containing K elements. Northeast.

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