# Characteristics of volcanic rocks and associated intrusions based on petrography analysis in Jari-Krondonan Area, Bojonegoro Regency, East Java

*by* Tri Winarno

**Submission date:** 17-Mar-2023 10:30AM (UTC+0700)
**Submission ID:** 2039065076
**File name:** IOP_2022_2nd_author.pdf (1.89M)
**Word count:** 3781
**Character count:** 21596

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To cite this article: J Marin *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1047** 012034

IOP Conf. Series: Earth and Environmental Science 1047 (2022) 012034 doi:10.1088/1755-1315/1047/1/012034

# Characteristics of volcanic rocks and associated intrusions based on petrography analysis in Jari-Krondonan Area, Bojonegoro Regency, East Java

**J Marin[1], Y M Muhammad[1] and T Winarno[1]**

1 Department of Geological Engineering, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Tembalang, Semarang, Jawa Tengah, Indonesia 50275

Corresponding author: jenianmarin@gmail.com

**Abstract:** Pandan volcano is one of the dormant Quaternary volcanoes in East Java characterized by several volcanic centers which extend to the northern part. This study is aimed to identify the volcanic rocks and intrusions of Jari - Krondonan area, Bojonegoro as well as determine their petrology and mineralogical characteristics. Geological observation was conducted to obtain primary data and to collect samples. Thin section of samples was prepared to analyze the petrographic aspects. Field observation shows several volcanic hills at Mount Jati, Mount Puru, Mount Watu, and Mount Lawang sites. Based on field mapping, lithologies of the research area are andesitic lava and intrusion with columnar joint or sheeting joint structure, surrounded by andesitic breccia. Andesite characterized by porphyritic texture with visible phenocrysts and volcanic glass groundmass. Samples from Mount Lawang and Mount Watu are composed of plagioclase and hornblende as main minerals. Samples from Mount Jati and Mount Puru are composed of plagioclase and pyroxene. Quartz, sanidine, and olivine present as accessory minerals. Plagioclase and pyroxene occasionally formed glomerocryst and poikilitic texture, which play an important role in the fractionation and crystal settling processes. Sieve and regular zoning in plagioclase suggest magma mixing. Gabbro and metamorphic xenoliths found in Mount Lawang and Mount Watu indicates an interaction with country rock during magma rising.

## 1. Introduction

Pandan Volcano is a Pleistocene volcano [1], part of the Quaternary Sunda-Java volcanic arc magmatism [2]. The volcano is located in the Wilis – Lasem arc segment, East Java Province (Figure 1). Currently, the volcano is not active but still shows magmatic activity as indicated by the presence of geothermal manifestations such as hot springs and travertine on the northern slope of the volcano [1, 3]. Stratigraphy of Pandan Volcano is composed of the Pandan Breccia Formation consisting of andesite breccia and andesite lava as well as several intrusions were found in the northern part around Jari and Krondonan, Gondang District, Bojonegoro Regency, East Java. Pandan Volcano, which is Lower Pleistocene, situated in the Kendeng Zone. Kendeng Zone is Neogene sedimentary rock formations consist of volcaniclastic and pelagic marine successions [4] (Figure 2).

Petrology and volcanostratigraphy studies are discussed in several sites of igneous rocks from Pandan Volcano, particularly associated with geothermal manifestations. Several volcanic centers of Pandan Volcano on the northern slope are produced andesite lava, pyroclastic fall deposit, and pyroclastic flow breccia. There is also porphyritic andesite intrusion of Selo Gajah Hill which cause contact metamorphism effect on its surrounded sedimentary rocks [5]. Previous study on the petrological and geochemical characteristics of Pandan Volcano stated that magmatic activity is the source of heat in the surrounding geothermal system. The study found that the igneous rocks in the area are hornblende andesite and basaltic andesite originating from basaltic-andesitic magma with calc-alkaline affinity [3]. A long history of volcanoes and their evolution are related to magmatic processes which produce igneous rocks that built them. Igneous texture recorded in volcanic rocks and intrusions is an essential key in recognizing these processes. The aims of this study were to identify the distribution of volcanic rocks and intrusions of the research area, determine their petrographic and mineralogical characteristics, and interpret the magmatic processes. The results were expected to provide more detailed information as an integrated igneous petrology study of magmatism in Java Island and the evolution of Pandan Volcano as well.

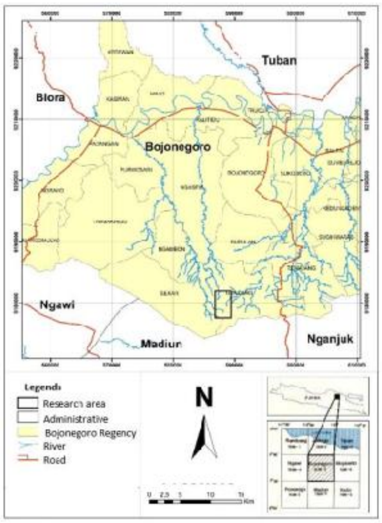


**Figure 1.** Administrative location of the research area in Bojonegoro Regency, East Java

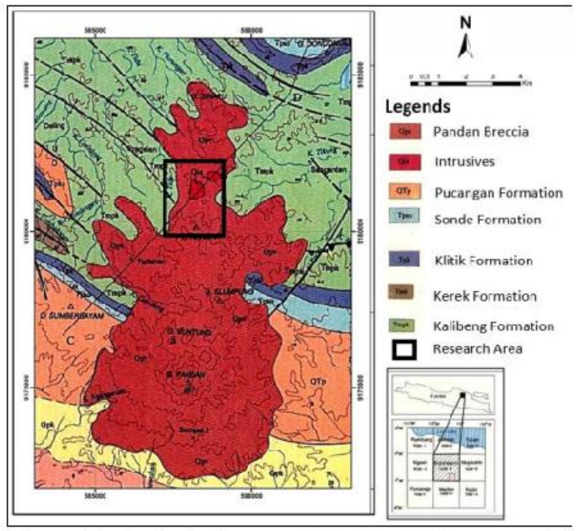


**Figure 2.** Geological map of Pandan Volcano and its surrounding [4]

## 2. Methods

Field observation and geological mapping were conducted specifically at Jari-Krondonan village area to collect geological field data consist of geomorphology, lithologic description, and geological structure measurement. To delineate the geological unit of the volcanic area, it is noteworthy to correlate the geomorphological feature with lithological unit. Rock sample were taken from igneous rocks of lava and intrusion, as volcaniclastic rock cannot be used to determine primary magmatic processes due to its nature as secondary product of volcanic activity.

Eight selected rock samples were prepared as thin section with 30 $\mu$m thickness to represent each volcanic rocks and intrusions sites found in the field. To obtain the best results, the rock samples had to be as fresh as possible with minimum weathering. Petrographic analysis was performed by observing thin section under polarization microscope to determine mineralogical composition and igneous textures.

## 3. Results and Discussion

### *3.1. Geological setting of the study area*

Based on the geological mapping, there are four sites of volcanic rocks and intrusions in the study area, namely hornblende andesite from Mount Watu and Mount Lawang and pyroxene andesite from Mount Jati, and Mount Puru (Figure 3). Morphology of the study area shows moderate – steep slope volcanic hill (Figure 4). The lithology units can be distinguished based on geomorphological and physical characteristics of the outcrop, the latter confirmed further by petrography analysis. In addition to igneous rocks from the four main locations as mentioned above, several other units are volcanic breccia from Pandan Breccia Formation, also sandstone and claystone that belong Kalibeng Formation.

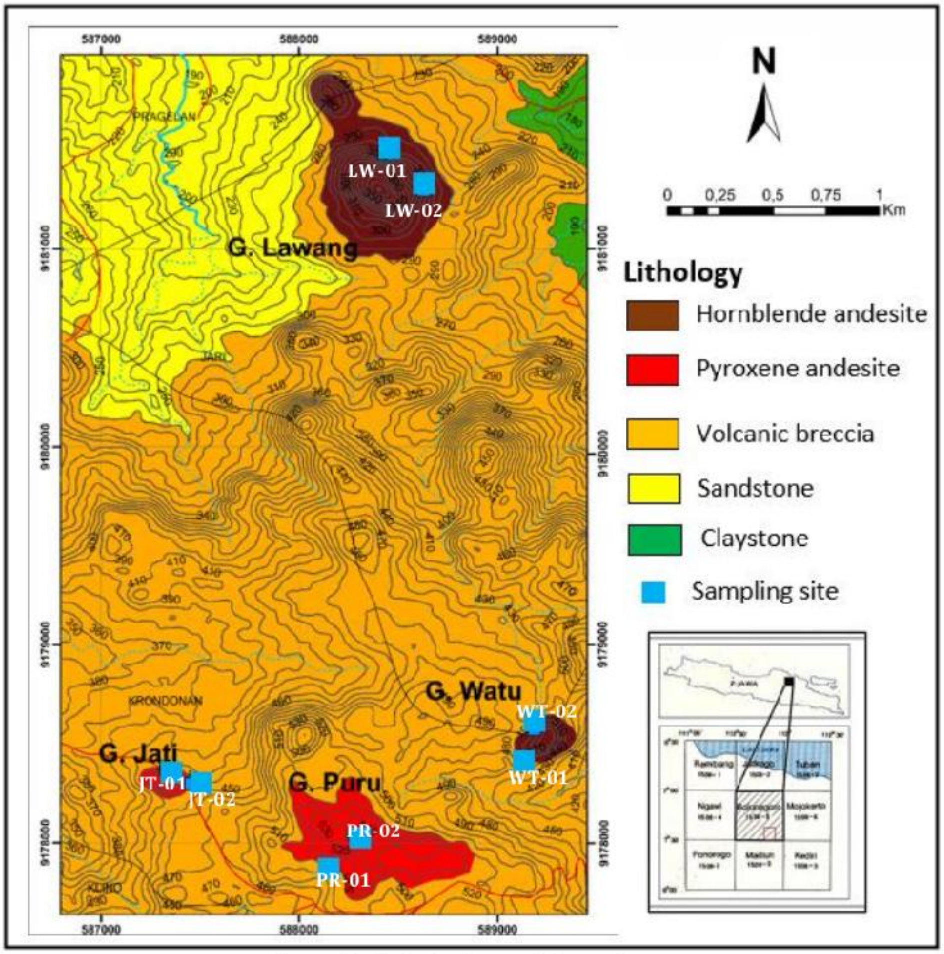


**Figure 3.** Geological map of the study area

*3.1.1. Mount Lawang.* This site is located in the western part of Jari Village, Gondang District. The morphology is characterized by steep intrusive hill with maximum elevation of 390 m and slope 60° - 80°. Igneous rocks are exposed by outcrops along the cliffs and the distribution of fresh boulders throughout the hill. Irregular columnar joint can be observed as the result of magmatic solidification process when the rock cooled and contracted during its formation. Lithology of this site is hornblende andesite characterized by light grey color, hypocrystalline, porphyritic texture, the main phenocrysts are plagioclase and hornblende surrounded by finer groundmass. Xenoliths are found in rock outcrops, consisting of mafic igneous rocks and metamorphic rocks which size is approximately 2-3 cm up to 10 cm. Igneous xenoliths are identified as gabbro by the dark color and coarse crystal size, while metamorphic xenoliths are greenish gray color and have phyllitic structure. Xenoliths are firmly embedded in rock bodies making them difficult to sample separately (Figure 5).

*3.1.2. Mount Watu*. Mount Watu is located in the Krondonan Village, Gondang District. This site is a lava dome with 250 m x 300 m dimension, maximum elevation of about 490 m and the slope is around 40° - 50°. On the western part of Mount Watu, sheeting joints were found with the main orientation of NE-SW that developed parallel to the hill slopes. Rather than tectonic related process, this structure is formed as extensive fracture in response to unloading in the shallow part of rock bodies. Lithology of MountWatu is hornblende andesite with characteristics of dark-grey color, hypocrystalline, medium to strongly weathered except in the fresh outcrop. The megascopic appearance and rock composition is similar to Mount Lawang with plagioclase and hornblende as main phenocrysts as well.

*3.1.3. Mount Jati*. Located in the southern part of the study area, Mount Jati has maximum elevation of 460 m and forms a volcanic hill in the northern part of Pandan Volcano. Based on the geomorphological appearance, Mount Jati is an intrusive hill that easily distinguished apart its surrounding. Several outcrop sites can be observed with fresh and slightly weathered rock condition. Field observation shows that this site is composed of pyroxene andesite, gray color, hypocrystalline, porphyritic texture with phenocrysts visible to the naked eye consisting of pyroxene and plagioclase and the aphanitic groundmass.


**Figure 4.** Geological feature of the four volcanic rocks and intrusion sites, show geomorphology of moderate – steep slope volcanic hill, columnar joints at Mount Lawang (red lines), sheeting joints at Mount Watu

*3.1.4. Mount Puru*. This site is located in Krondonan Village, also in the southern part in between Mount Jati and Mount Watu. Elevation at the top of Mount Puru is 540 m, while the slope is 15° - 25°, relatively gentler than other sites and it occupies an area of 400 m x 500 m. The lithology is pyroxene andesite lava which characteristics are similar to Mount Jati that can be observed from numerous igneous rock boulders scattered throughout the hill slopes. No geological structure was observed at this location.

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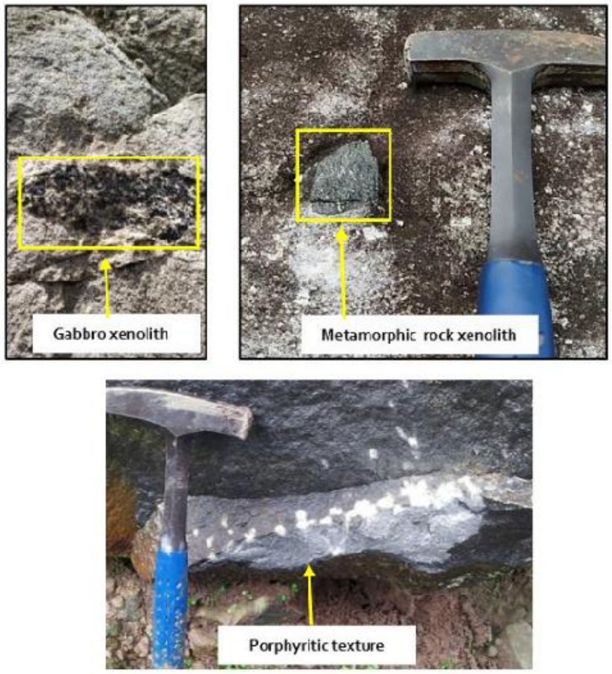


**Figure 5.** Megascopic appearance of hornblende andesite and pyroxene andesite from the outcrops show porphyritic texture and xenoliths

### *3.2. Mineralogy of rocks*

Pandan Volcano was formed in an island arc tectonic environment with medium – high K calc-alkaline magma affinity. The morphology of the volcano is constantly evolving, where this strato volcano consists of several volcanic centers and the youngest eruptive center is the main edifice of Pandan Volcano itself. Spatially, this Pleistocene (1.2 Ma) volcanic complex tends to move younger to the south [3][6].

These volcanic activities produce igneous rock with basaltic-andesite characteristics from intrusive, extrusive, and pyroclastic mechanisms. In this study, the mineralogical characteristics are focused on intrusive and extrusive rocks or lava which is the result of direct magma crystallization from eight thin section samples as summarized in Table 1.

**Table 1.** Composition of rock samples from Mount Lawang, Watu, Jati dan Puru

| Site | Sample | Type | Composition (%) | | | | | | | | | Xenolith |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Plg | Hbl | Cpx | Opx | Opq | Qz | Sa | Ser | V | |
| Mount Lawang | LW-01 | Hornblende andesite | 55 | 16 | 3 | - | 2 | 2 | 4 | - | 15 | Gabbro, Phyllite |
| | LW-02 | Hornblende andesite | 53 | 15 | 2 | - | 5 | 2 | 5 | - | 17 | |
| Mount Watu | WT-01 | Hornblende andesite | 53 | 15 | 3 | - | 4 | - | - | 6 | 19 | Gabbro |
| | WT-02 | Hornblende andesite | 50 | 15 | 5 | - | 2 | - | - | 5 | 23 | |
| Mount Jati | JT-01 | Pyroxene andesite | 58 | - | 14 | 4 | 5 | - | - | - | 19 | |
| | JT-02 | Pyroxene andesite | 55 | - | 14 | 3 | 5 | 3 | 1 | - | 19 | |
| Mount Puru | PR-01 | Pyroxene andesite | 58 | - | 15 | 5 | 5 | - | - | - | 14 | |
| | PR-02 | Pyroxene andesite | 55 | - | 15 | 5 | 7 | 2 | - | - | 16 | |

Notes:
Plg = Plagioclase, Hbl = Hornblende, Cpx = Clinopyroxene, Opx = Orthopyroxene, Qz = Quartz, Sa = Sanidine, Ser = Sericite, Opq = Opaque mineral, V = Volcanic glass

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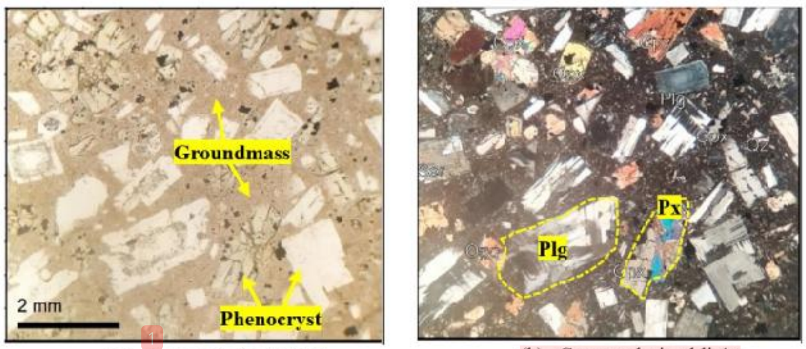
Observation in the rock outcrops show the general appearance of light gray to slightly dark gray color which is typical of intermediate igneous rocks. Igneous rocks in the study area are grouped into two types based on the mineral composition observed from petrographic analysis, which are hornblende andesite and pyroxene andesite. The main composition of the rock consists of phenocryst and groundmass with hypocrystalline and porphyritic texture (Figure 6a.). Volcanic glass as groundmass is counted for about 15-23% with its appearance in hornblende andesite is relatively lighter in color than in pyroxene andesite, probably due to slightly more acidic composition. The main phenocryst is plagioclase with abundance > 50% in all analyzed samples. The appearance of plagioclase under a polarizing microscope is colorless, low relief, subhedral-euhedral, 0.1 – 2.5 mm in size, prismatic and lathlike shape, order 1 interference color, and shows Carlsbad-albit and albite twins. The mineral has extinction angle of 22°-34°, hence the plagioclase composition is andesine to labradorite (An40 – An60). Other than as larger phenocryst, plagioclase is abundant as finer grained microlite as well, which is the result of later and more rapid crystallization.



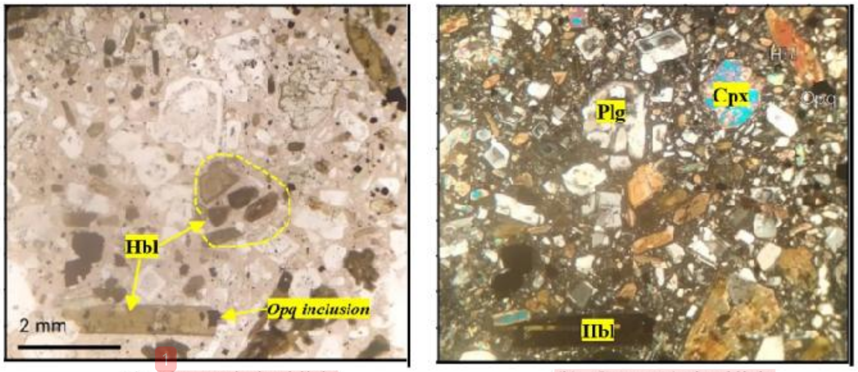

(a) Plane polarized light (b) Cross polarized light

**Figure 6.** (a) Photomicrograph of thin section rock shows porphyritic andesite with groundmass and phenocryst, (b) Plagioclase (Plg) and pyroxene (Px) are the main phenocryst in pyroxene andesite from Mount Puru (PR-1)

Pyroxene is the next abundant phenocryst in pyroxene andesite samples. This mafic mineral presents as clinopyroxene (14-15%) and orthopyroxene (3-5%) in Mount Jati and Mount Puru (Figure 6b.). The characteristics of clinopyroxene are colorless to pale green, moderate relief, 0,1-2 mm in size, subhedral-euhedral, prismatic shape, order 2 interference color, inclined extinction, and shows simple contact twinning. While orthopyroxene has nearly similar characteristics, it tend to be lighter in color, lower order of interference color, and has parallel extinction. Some pyroxene phenocrysts show inclusion of opaque minerals.

Samples from Mount Watu and MountLawang contain significant amount of hornblende as main phenocryst beside of plagioclase with the average of 15% (Figure 7a., 7b.). In the plane polarized light, this phenocryst is easily distinguishable among the others. It has noticeable brown color and some crystal show pleochroism, which absent in other associated minerals. Other characteristics are moderate relief, 0,1-3 mm in size, subhedral-euhedral, prismatic and bladed shape, two-directional cleavage, order 2 interference color, inclined extinction, and shows simple contact twinning. Opaque mineral is commonly featured as inclusion inside the larger hornblende crystals. While pyroxene is present as accessory mineral in hornblende andesite (Figure 7b), hornblende is rather absent in pyroxene andesite from Mount Jati and Mount Puru.

Since metamorphic rocks and mafic igneous rocks are generally found deeper in the subsurface, the xenoliths presence indicates the interaction of magma with country rocks during its rising to the surface. According to regional study [7], the basement of Kendeng – Rembang Zone is most likely composed of volcanic arc and ophiolithic rocks similar to the rock complexes in Karangsambung. Therefore, it is suggested that the xenoliths found in Mount Lawang and Mount Watu is part of the Kendeng Zone basement.




(a) Plane polarized light (b) Cross polarized light

**Figure 7.** (a) Photomicrograph of thin section rock of WT-1 sample light-dark brown hornblende (Hbl) phenocryst featured opaque mineral (Opq) inclusion, (b) Clinopyroxene (Cpx) as accessory mineral in hornblende andesite

Besides opaque minerals as mentioned above, samples contain other minerals as minor composition which accounted for less than 5%. Quartz presents in both pyroxene andesite and hornblende andesite with characteristics colorless, low relief, anhedral, and 0.1-0.2 mm size. Sanidine is more frequent in Mount Lawang, colorless, low relief, size less than 0.25 mm, subhedral-euhedral, and shows Carlsbad twinning. Sericite is alteration product replacing plagioclase which can be found in Mount Watu.

### *3.3. Igneous Textures and Magmatic Processes Interpretation*

Formation of crystal through cooling of magma can be straightforward and simple or can be highly complex. In igneous petrogenesis study, textures of igneous rock help to understand what magmatic processes have formed them [8]. Volcanic rocks and intrusions in the study area are porphyritic andesite with more than 50% phenocrysts embedded in volcanic glass and microlite groundmass. Petrographic analysis of thin section has identified more detailed textural relationship that is essential to understand the origin of rocks (Table 2.).

**Table 2.** Igneous texture found in the sample

| Site | Sample | Textures | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Porphyritic | Intergranular | Pilotassitic | Glomerophyric | *Zoning* | *Sieve* | Poikilitic |
| Mount Lawang | LW-01 | ++ | - | - | ++ | ++ | - | * |
| | LW-02 | ++ | - | - | ++ | ++ | - | * |
| Mount Watu | WT-01 | ++ | - | - | ++ | ++ | * | * |
| | WT-02 | ++ | - | - | ++ | ++ | * | * |
| Mount Jati | JT-01 | ++ | ++ | - | ++ | ++ | - | * |
| | JT-02 | ++ | ++ | - | ++ | ++ | * | * |
| Mount Puru | PR-01 | ++ | - | ++ | ++ | ++ | ++ | ++ |
| | PR-02 | ++ | - | ++ | ++ | ++ | ++ | ++ |

Symbol: ++ = frequent, * = less common, - = absent

Thin section from Mount Puru lava shows an additional texture involving the arrangement of microlites in the groundmass. Plagioclase microcrystalline laths exhibit pilotassitic texture, the sub parallel

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arrangement amongst them (Figure 8). The phenocryst in igneous rock tend to formed by slower crystallization in the magma chamber that the modification processes are inevitable. Whereas, microlite crystallizes quicker so it directly records the magma flow during rock emplacement, typically lava flow. Particular texture also can be identified from Mount Jati, namely intergranular texture which exhibits space filling amongst plagioclase phenocrysts by other crystals commonly pyroxene (Figure 9). This texture formed when early formed crystals trapped magma and it crystallized later [9].

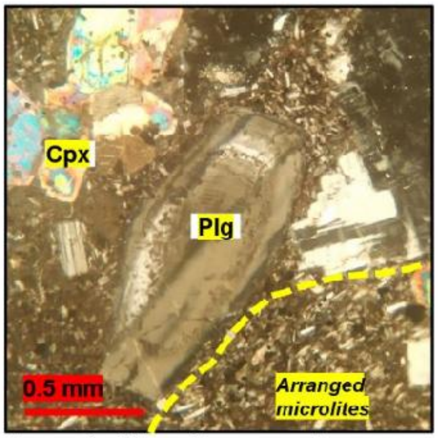


**Figure 8.** Pilotassitic texture in pyroxene andesite from Mount Puru (PR-2) shows plagioclase microlite arrangement in sub parallel pattern

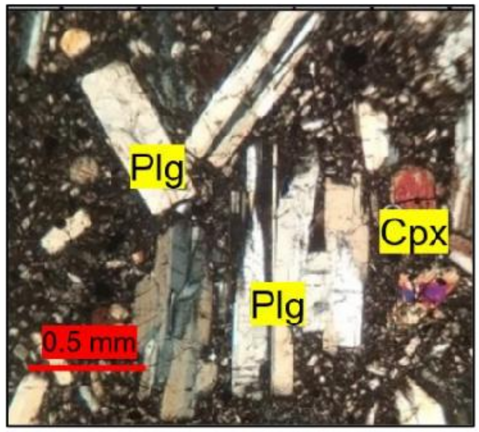


**Figure 9.** Intergranular texture in JT-1 sample from Mount Jati shows angular space between plagioclase laths is filled by another crystal grains

Plagioclase as the most common phenocryst shows regular zoning pattern which is an indication to changes in magma composition during the crystal growth. This phenomenon can be identified using cross polarized microscope as the crystal changes color and angle of extinction during rotation due to the difference in mineral composition from core to rim (Figure 10.). Despite the fact that petrographic observation is insufficient to determine whether the variation of chemical composition is normal or reversed, zoned plagioclase shows continuous reaction of initial crystal to the magma melt. This reaction can be the result of the difference in crystal composition to the evolved magma or influx of fresh magma to the residual magma inside the chamber. Furthermore, plagioclase with sieve texture is also found in several samples (Figure 11.), which also can be the effect of influx of the more calcic magma [10]. Another possible cause of sieved plagioclase is the magma decompression during its rise towards the surface [11], in which the crystal corroded in melt while it continued to grow.

The phenocryst cluster composed of plagioclase and pyroxene often form crystal aggregates, also called glomerocryst, as known to be glomerophyric texture (Figure 12.). This intergrowth occurs as indication of simultaneous crystal growth, in account for heterogenous nucleation rates amongst crystals. In the fractionation process, glomerocryst is heavier than the individual crystals so it is more prone to sinking. In addition, another form of crystal aggregate occasionally presents as poikilitic texture when the phenocryst contains other minerals. The order of crystallization can be determined, which the enclosed crystal (chadacryst) must be crystallized earlier than the enclosing crystal (oikocryst). Figure 13 shows smaller grain clinopyroxene enclosed in larger clinopyroxene.

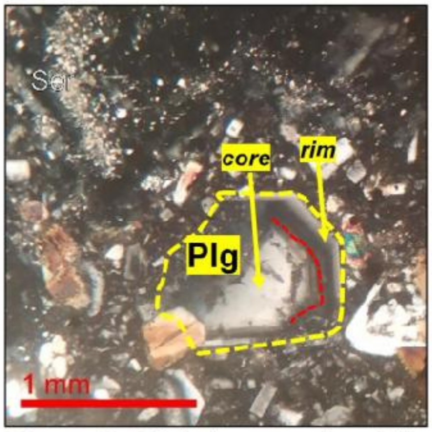


**Figure 10.** Plagioclase crystals exhibit concentric pattern or regular zoning texture from Mount Jati (JT-2)

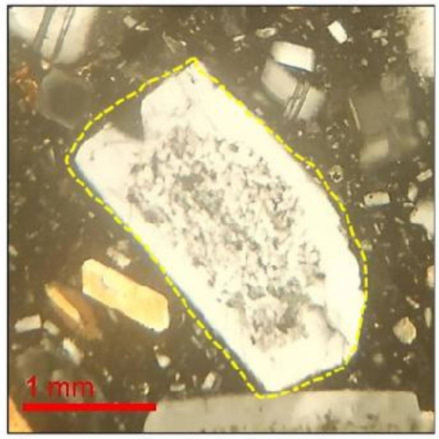


**Figure 11.** Sieved plagioclase from Mount Watu (WT-2)

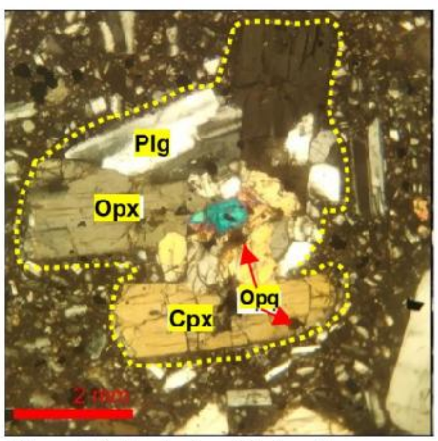


**Figure 12.** Plagioclase (Plg), orthopyroxene (Opx), and clinopyroxene (Cpx) cluster from MountJati (JT-2)

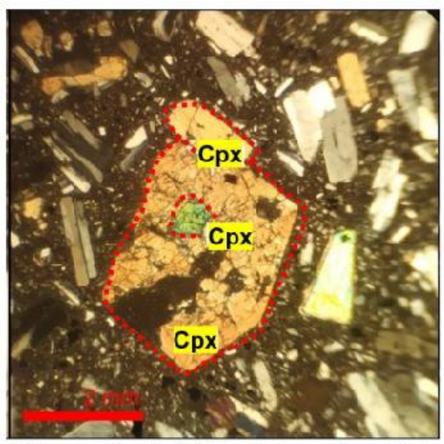


**Figure 13.** Poikilitic texture in which clinopyroxenes (Cpx) occur both as enclosed and enclosing crystal from MountJati sample (JT-2)

## 4. Conclusions

Volcanic activity in Pandan Volcano formed volcanic rocks and intrusions extends to the northern part/foot slope. Rock type in the research area is porphyritic andesite with fine grained groundmass and main phenocrysts of plagioclase, hornblende, pyroxene. Rock textures indicate magmatic processes such as crystal fractionation, basement interaction, magma mixing, and change in magmatic composition. Future research suggestion is geochemistry analysis to determine magmatic affinity and to construct petrogenetic model

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**Acknowledgments**
This research is supported by research grant from Faculty of Engineering, Diponegoro University 2022. Finally, special thanks to our colleagues for the endless help and encouragement during the course of this study.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11