Petrology and petrogenesis of igneous rock in Mount Endut, Banten Province

R Adikusuma¹, D N Sahdarani¹, F M H Sihombing¹, Supriyanto¹ and G T M Kadja²

¹Geoscience Study Program, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia
²Study Program of Chemistry, Faculty of Mathematics and Natural Sciences (FMIPA), Institut Teknologi Bandung, Jl. Ganesha No. 10 Bandung, Jawa Barat, 40132, Indonesia

Corresponding author’s email: supriyanto@sci.ui.ac.id

Abstract. Mount Endut is a volcano located in the eastern part of Banten Province. Previous studies revealed that Mount Endut consists mainly of Quaternary volcanic and Tertiary plutonic igneous rocks respectively. This research focuses on the petrology of igneous rocks found in the southern region of Mount Endut in order to determine the type of igneous rocks, evolution of magma, and reconfirming historical geological process occurring in Mount Endut area. Petrographic analysis was performed on 11 samples and geochemical analysis was performed on 30 samples. Petrographic analysis revealed three types of igneous rocks, andesite porphyry, diorite porphyry, and dacite porphyry. Furthermore, geochemical analysis revealed that the igneous rocks in Mount Endut are comprised of basaltic andesite, andesite, dacite, basaltic trachy-andesite, trachy-andesite, and trachyte or trachydacite which originated from calc-alkaline magma series. The integration of petrographic and geochemical analysis supports the regional geological process where Mount Endut was formed either in an island arc or an active continental margin.

Keywords: Igneous rock, Mount Endut, geochemistry, tectonic setting, petrogenesis, petrology

1. Introduction
Indonesia is in the encounter of several plates [1]. The southern and western parts of Indonesia, the Eurasian Plate collided with the Indo-Australian Plate [1]. Darman and Sidi [1] explained that the results of the collisions of these two plates caused the volcanic arc on the Java Island. The existence of this volcanic arc causes Indonesia to be in the zone of Ring of Fire where is directly associated with the amount of igneous rock formation [2]. According to Wilson [3] each igneous rock has different characteristics, as well as the chemical content they have. These differences can also indicate different sources or genesis of igneous rocks [3]. The research area, Mount Endut, is an area dominated by Quaternary intrusive igneous rocks that penetrate Tertiary sedimentary rocks [4]. However, in the southern part, there are intrusive igneous rocks that are thought to had formed before the eruption from Mount Endut [5]. This is what raises curiosity about the study of igneous petrology and petrogenesis in Mount Endut, Banten Province. The approaches of this research are to analyze the igneous rocks type
based on petrographic analysis, to determine igneous rocks type, magma series, magma evolution based on geochemical analysis, and to re-create tectonic setting occurred and formed the igneous rocks in research area.

2. Data and method
The research area is located on Mount Endut which has an area about 216 km². This research used 185 igneous rock samples from the research area. The samples which were further selected and analysed by using petrographic and geochemical analyses. The selected samples were fresh igneous rocks. Number of samples which were used in this petrographic analysis are 11 fresh samples. The thin sections of those igneous rocks were made at Obsidian, Bandung. The igneous rock classification which was used to determine the name of the igneous rocks in thin section is the igneous rock classification by Travis (1955) [6]. Geochemical analysis was used to determine the chemical elements and compounds (oxide) which are contained in the rocks. In this research, 30 fresh samples were used to do geochemical analysis to see the geochemical trends. The geochemical data analysed in this research were major oxides and trace elements or compounds. To obtain those geochemical compounds, samples were crushed into powder then were analysed by using x-ray fluorescence (XRF). This analysis was done by using Orbis Micro-XRF analyser at Institut Teknologi Bandung, Bandung to obtain the major elements or major compounds. The trace elements were obtained by using XRF at UPP IPD FMIPA UI, Depok. After the mayor compounds and trace elements were obtained, the contents of those elements were plotted into several diagrams. The diagrams are to identify the type of the rocks, magma series, tectonic settings that formed the igneous rocks in the research area, and the evolution of magma.

3. Results and discussion
Igneous rocks in this area were found in various features, those are extrusion and intrusion. In the northern part of the research area, igneous rocks were found in the form of lava or extrusion, whereas in the southern part, the research area was dominated by intrusive igneous rocks. Based on the size of their body and plagioclase phenocrysts, intrusive igneous rocks are thought to be differentiated into dike and stock intrusive rocks.

3.1. Petrographic analyses
11 igneous rock samples taken from each feature were analysed microscopically by observing minerals in thin sections to determine the type of igneous rocks referring to the Travis classification (1955) (table 1). In general, each rock sample shows inequigranular crystals, especially porphyritic, hypidiomorph minerals, and hypocrystalline. The samples have plagioclase, pyroxene, amphibole and opaque minerals as phenocrysts, and has a plagioclase, opaque and glass as the groundmass. In some samples, olivine, quartz and alkali feldspar minerals were found.

The main minerals contained in Mount Endut igneous rocks are plagioclase, amphibole and pyroxene. Plagioclase is the most dominant mineral found in all rock samples, ranging from 55–72.5 % of the total mineral. Pyroxenes appear with an amount of 0.5–16 % of the total mineral. In some thin section samples, olivines are found with a percentage of 1–6 %. The olivines were also replaced by pyroxene minerals characterized by the presence of a reaction rim in the minerals. Amphiboles have fewer amounts than plagioclases and pyroxenes, which have percentage of 1–8 %. In samples M5 D and M5.2 D, quartz minerals were found and only in groundmass of the thin section samples, ranging from 16–18 %. From this petrographic analysis, Mount Endut igneous rocks can be classified as andesite porphyry, diorite porphyry, and dacite porphyry (figure 1).

In some thin section samples, such as in samples F8 A, K8 A, 046 (05) A, I6 and J7 B, trachytic texture is found, which shows that when lava was freezing, lava was in the moving stage characterized by uniform orientation of plagioclases [7]. This texture is not dominant but was found in several parts
in the thin section samples. This shows that the lava moved at a low velocity so that the trachytic texture did not appear dominantly.

3.2. Geochemical analyses

To determine the composition and the origin of magma of igneous rocks, geochemical analysis is needed to identify the compounds or oxides contained in igneous rocks. 30 samples of Mount Endut igneous rocks had been analysed using X-Ray Fluorescence (XRF) to find out the oxides in the igneous rock. The results of the XRF analysis showed weight percentage of oxides, such as Na₂O, MgO, Al₂O₃, SiO₂, P₂O₅, K₂O, CaO, TiO₂, MnO and Fe₂O₃.

The silicon oxide contents contained in Mount Endut igneous rock samples have amounts between 51.83–67.91 %, which means that they vary from basic to acid based on Whitford (1975) [8]. Based on the TAS diagram [9] in figure 2a, Mount Endut igneous rocks have a very diverse distribution of rock types ranging from trachyte trachydacite, dacite, trachy andesite, andesite, basaltic trachy-andesite, to basaltic andesite.

Based on the diagram of K₂O against SiO₂ by Peccerillo and Taylor [10] in figure 2b, Mount Endut igneous rocks are mostly classified as subalkaline magma series. There are two rocks from lava units which belong to the alkaline magma series but are relatively close to the subalkaline zone. Rock samples also dominate the zone of calc-alkaline magma in the subalkaline magma series, although there are several rocks that enter the tholeiitic zone.

Subalkaline magma can also be differentiated into tholeiitic and calc-alkaline magma series using AFM diagrams [11] and Harker diagrams comparing SiO₂ with FeOtot/MgO [12] (figure 3). The usage of these two diagrams was intended to confirm the K₂O against SiO₂ diagram. All Mount Endut igneous rocks are classified as calc-alkaline magma series based on these two diagrams. In addition, calc-alkaline magma series show the association with convergent boundary setting such as subduction zone [13]. This is conformable with the tectonic environment which caused arc magmatism on the Java Island, i.e. subduction zone or active continental margin [14].

### Table 1. Mineral percentage based on petrographic analysis.

| Sample | Q2 (wt%) | Q1 (wt%) | Kf (wt%) | PI (wt%) | Cpx (wt%) | Opx (wt%) | Am (wt%) | Bi (wt%) | GI (wt%) | Op (wt%) | Cl (wt%) | Rock Type (Travis, 1955) |
|--------|----------|----------|----------|----------|-----------|-----------|----------|----------|----------|----------|----------|--------------------------|
| F8 A   | -        | 2        |          | 55       | 8         | 8         | 6        | 2        | 9         | 9        | 1        | Andesite porphyry        |
| K8 A   | -        | 1        |          | 62       | 1         | 2         | 1        | 4        | 13        | 13       | 3        | Andesite porphyry        |
| 046 (05) A | -      | -        |          | 65       | 4         | 5         | 2        | 3        | 11        | 8        | 2        | Andesite porphyry        |
| ST-67 W2 B | -      | -        |          | 72.5     | 0.5       | -         | -        | -        | 7         | 12       | 8        | Andesite porphyry        |
| ST-35 A | -        | 6        |          | 56       | 10        | 2         | 4        | -        | 7         | 10       | 5        | Andesite porphyry        |
| J7 B   | -        | -        |          | 61.5     | -         | -         | -        | -        | 8.5       | 10       | 20       | Andesite porphyry        |
| 16 B   | -        | -        |          | 65       | -         | -         | -        | -        | 10        | 18       | 7        | N/A                      |
| A11 C  | 3        | -        |          | 66.5     | 4.5       | 1         | 7        | -        | 8         | 9        | 1        | Diorite porphyry         |
| N8 C   | 8        | -        |          | 62.5     | 2         | 1         | 6        | -        | 7.5       | 10       | 3        | Diorite porphyry         |
| M 5 D  | 18       | -        | 0.5      | 64.5     | 2         | -         | 5        | -        | 2         | 6        | 2        | Diorite porphyry         |
| M 5 2 D | 16       | 0.5      | 63.5     | 2        | -         | 8        | -        | 4        | 4        | 4        | 2        | Diorite porphyry         |

Note: PI = Plagioclase, Cpx = Clinopyroxene, Opx = Orthopyroxene, Am = Amphibole, Bi = Biotite, Qr = Quartz, Kf = Alkali Feldspar, Op = Opaque, GI = Glass.
The chemical contents contained in rocks or magma itself can reflect where the magma was formed. Based on the FeOtot, MgO and Al₂O₃ diagram, igneous rock tectonic settings can be divided into Ocean Island, Mid Oceanic Ridge Basalt, Continental, Spreading Centre Island, and Island-arc and Active Continental Margin [15]. This diagram shows that the Mount Endut igneous rocks which contain SiO₂ 51–55 % were formed in the orogenic tectonic environments or island-arc and active continental margins (figure 4a). This supports the magma series gotten from the diagram earlier which shows that the Mount Endut igneous rocks are classified as the calc-alkaline magma series which associate with orogenic tectonic environments either Island-arc or Active Continental Margin.

In addition to major elements, trace elements could also be used to determine the tectonic setting which formed the igneous rocks in the research area, such as Rb, Zr and Y. Igneous rocks in N-MORB have the ratios of K/Rb about ± 1000, whereas igneous rocks which associate with continental crust have low amount of K/Rb ratios in average about ± 250 [16].

**Figure 1.** Mount Endut igneous rocks thin sections (a) Andesite porphyry, (b) Diorite porphyry, and (c) Dacite porphyry.
Figure 2. (a) Mount Endut igneous rocks classification based on TAS diagram, (b) Mount Endut magma series based on K$_2$O against SiO$_2$ diagram.

Figure 3. (a) FeO$_{tot}$ against MgO diagram to classified Mount Endut igneous rocks magma series into tholeiitic or calc-alkaline, (b) AFM diagram (A=Na$_2$O + K$_2$O, F = FeO$_{tot}$, M = MgO) to classified Mount Endut igneous rocks magma series into tholeiitic or calc-alkaline.

Sample F8 A and M5 D have a number of K/Rb ratios about 154 and 93.5 (table 2) which close to the average K/Rb ratios of continental crust. That means that the Mount Endut igneous rocks are related with the continental crust. Other than that, diagram Zr/Y–Zr could also determine whether the igneous rocks originated in continental arc or oceanic arc. Both sample F8 A and M5 D have the same number of Zr/Y ratios, so they were plotted at the same point. From this diagram, it could be concluded that the diagram also resulted that they were formed in the same tectonic setting, that is continental arc.

The Harker variation diagrams show the changes that occur in magma (figure 5). Variation diagrams of MgO and Fe$_2$O$_3$ against SiO$_2$ in each rock showed a negative correlation, which means that as the SiO$_2$ contents increase, the content of MgO and Fe$_2$O$_3$ decrease so that there was fractional crystallization of olivines. Because Mount Endut rocks are intermediate rocks based on petrographic analysis, olivines are rarely found but clinopyroxenes. This fractionation is supported by the curved trendline of MgO and Fe$_2$O$_3$ against SiO$_2$ which indicates the crystallization and accumulation of clinopyroxenes in rocks with low silica contents [17].
Figure 4. (a) FeOtot–MgO–Al₂O₃ diagram to determine the tectonic environment which formed igneous rocks in research area, (b) Zr/Y–Zr diagram shows that Mount Endut igneous rocks were originated in continental arc.

Table 2. Sample F8 A and M5 D K/Rb ratio.

| Sample | K/Rb |
|--------|------|
| F8 A   | 154  |
| M5 D   | 93.5 |

Figure 5. Variation diagram of Mount Endut igneous rocks.
The crystallization of the clinopyroxenes and olivines causes an increment in the concentration of Al$_2$O$_3$ in rocks with a silica contents ranging from 52–56%. In rocks with SiO$_2$ contents above 56%, Al$_2$O$_3$ contents begin to form a negative correlation with SiO$_2$ which indicate that minerals rich in aluminium, such as plagioclase, begin to undergo some fractionation [18]. Other major oxides that have association with plagioclase is Na$_2$O and CaO. In addition to describing the presence of clinopyroxenes fractionation, depletion in CaO contents along with increment in SiO$_2$ in igneous rocks also illustrates the fractionation of Ca-rich plagioclases.

This is in accordance with Bowen Reaction Series, which explains that Ca-rich plagioclase is formed in a high temperature condition, while Na-rich plagioclase is in conditions with relatively lower temperatures than Ca-rich plagioclase [19]. In intrusive igneous rocks samples, the correlation of Na$_2$O content against SiO$_2$ is normal or positively correlated which shows that as the SiO$_2$ contents increase, fractionation of Ca-rich plagioclases began to be replaced with Na-rich plagioclases. In samples of lava igneous rocks, the Na$_2$O content experienced a positive correlation with SiO$_2$ which SiO$_2$ contents amount to 52 to 64%.

4. Conclusion

The type of Mount Endut igneous rocks which had been concluded from the petrographic analysis are andesite porphyry, diorite porphyry, and dacite porphyry. Based on geochemical analysis, Mount Endut igneous rocks can be classified as trachyte trachydacite, dacite, trachy andesite, andesite, basaltic trachy-andesite, and basaltic andesite. The samples are included in calc-alkaline magma series which had formed because of island-arc or active continental margin tectonic environment.

Acknowledgments

This work is supported by Hibah PITTA 2018 and funded by DRPM Universitas Indonesia No. 2316/UN2.R3.1/HKP.05.00/2018. We also would like to say thank you to Research Center for Nanosciences and Nanotechnology for helping the researcher to obtain the geochemical data.

References

[1] Darman H and Sidi F H 2000 An Outline of the Geology of Indonesia (Bandung: Ikatan Ahli Geologi Indonesia)
[2] Parfitt E A and Wilson L 2008 Fundamentals of Physical Volcanology (Oxford: Blackwell Publishing)
[3] Beccaluva L, Bianchini G and Wilson B M 2007 Cenozoic Volcanism in the Mediterranean Area (Colorado: Geological Society of America)
[4] Sujatmiko and Santosa S 1992 Peta Geologi Lembar Leuwidamar, Jawa (Bandung: Direktorat Geologi)
[5] Kusnadi D, Rezky Y, Supeno and Raharja B 2006 Penyelidikan Geologi dan Geokimia Panas Bumi Daerah Mount Endut Kabupaten Lebak, Banten available at http://psdg.bgl.esdm.go.id/kolokium%202006/panas%20bumi/Makalah%20%20Geologi%20dan%20Geokimia%20G.%20Endut,%20Banten.pdf
[6] Travis R B 1955 Classification of Rocks (Colorado: Colorado School of Mines)
[7] Philpotts A R 1989 Petrography of Igneous and Metamorphic Rocks (Illnoise: Waveland Press, Inc.)
[8] Whitford D J and Nicholls I A Potassium Variation in Lavas Across the Sunda Arc in Java and Bali In: Volcanism in Australasia ed Johnson R W (Amsterdam: Elsevier) pp 63–75
[9] Le Bas M J, Le Maitre R W, Streickeisen A and Zanettin B 2006 J. Petrol. 27 745-50
[10] Peccerillo A and Taylor S R 1976 Contributions Mineral. Petrol. 58 63-81
[11] Irvine T N and Baragar W R A 1970 Can. J. Earth Sci. 8 523-48
[12] Miyashiro A 1974 *Am. J. Sci.* **274** 321-55
[13] Wilson B M 1989 *Igneous Petrogenesis, A Global Tectonic Approach* (London: Unwin Hyman Inc.)
[14] Simandjuntak T O 2004 Tektonika (Bandung: Pusat Penelitian dan Pengembangan Geologi)
[15] Pearce T H, Gorman B E and Birkett T C 1977 *Earth Planet Sci. Lett.* **36** 121-32
[16] Gill J B 1981 *Orogenic Andesite and Plate Tectonics* (Berlin-Heidelberg: Springer-Verlag) p 390
[17] Frost B R and Carol Frost D 2014 *Essentials of Igneous and Metamorphic Petrology* (New York: Cambridge University Press)
[18] Gill R 2010 *Igneous Rocks and Processes: A Practical Guide* (United Kingdom: WileyBlackwell)
[19] Tarbuck E J, Lutgens F K and Tasa D G 2010 *Earth: An Introduction to Physical Geology* (United Stated: Pearson Education)