Journal of Applied Geology, vol. 9(2), 2024, pp. 84–93
DOI: http://dx.doi.org/10.22146/jag.95164

Mineralogical and Geochemical Characteristics of Clays at Godean Hills, Yogyakarta – Indonesia (A Study Case at Gunung Patuk and Gunung Wungkal)

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Received: March 28, 2024 | Accepted: October 31, 2024 | Published online: March 27, 2025

ABSTRACT. Gunung Patuk and Gunung Wungkal are part of the Godean Hills in Yogyakarta, Indonesia. The Godean Hills are isolated hills consisting of a series of hills surrounded by the Young Merapi Volcanics Deposits. A previous study reported that Gunung Patuk and Gunung Wungkal are porphyry andesite – micro diorite intrusions. Both hills are igneous rock intrusions and have almost perfect soil profiles from the source/parent rock to the A horizon. However, another study suggests that Gunung Wungkal has been a hydrothermal alteration process. There is still a debate over the genesis of clay in that area. Therefore, this research needs to be carried out to provide a comprehensive understanding of the mineralogical and geochemical characteristics of the clays in that area. The results of petrographic identification on the source/parent rock sample indicate that the rock sample is classified as andesite rock. Meanwhile, the results of mineralogy identification using the X-ray diffraction (XRD) method show that almost all types of soil profiles contain illite, kaolinite, and smectite. The calculation results of CIW (Chemical Index Weathering) and CIA (Chemical Index Alteration) values based on geochemical data show that CIW and CIA values of the horizons increase steadily as they approach the ground surface. Based on the presence of illite (indicates a product relating to the relatively high temperatures) in A horizon with high values of CIW and CIA, therefore it can be interpreted that clay minerals at Gunung Patuk and Gunung Wungkal were the product of superimpose of hydrothermal alteration and weathering processes.

Keywords: CIA · CIW · Geochemical · Soil profile · Weathered.

1 INTRODUCTION

Indonesia is an archipelagic country with a tropical climate with 2 seasons, which are dry and rainy. This condition causes the weathering process to occur intensely. The intense weathering process can change the source rock into the soil gradually, as indicated by the layers of the soil profile (soil horizons) starting from the source/parent rock, C horizon, B horizon, and A horizon (Velde and Meunier, 2008) with A horizon being the outermost layer and the highest level of weathering. The weathering causes the parent rock's minerals to alter into clay minerals. On the other hand, the Indonesian archipelago is associated with a series of subduction zones with at least seven main magmatic arcs recognized, including the Tertiary Java Magmatic Arc, a part of the Sunda Banda Arc (Soeria-Atmadja *et al.*, 1994). These magmatic arcs are usually associated with hydrothermal alteration processes, which can produce clay minerals. Therefore, clay minerals can also be a product of hydrothermal alter-

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ation processes related to high temperatures and hot fluids. Illite, one of the clay minerals associated with hydrothermal alteration, occurs at approximately 200-250 ˚C (Corbett and Leach, 1996).

Gunung Patuk and Gunung Wungkal, a part of the Godean Hills, Yogyakarta, and a part of the Java volcanic arc, are intrusion hills with abundant clays. Based on the Regional Geological Map of Yogyakarta (Rahardjo *et al.*, 1995), Gunung Patuk is a diorite intrusion and slightly different from Gunung Wungkal which is a porphyry andesite – micro diorite intrusion (Bronto *et al.*, 2014). In addition, Ardiansyah (2021) mentions that Gunung Patuk and Gunung Wungkal are porphyry andesite lava. However, Verdiansyah (2016) suggests that a hydrothermal alteration process has occurred at Gunung Wungkal. Because there is still a debate over the genesis of clay in that area, therefore this research needs to be carried out to provide a comprehensive understanding of the mineralogical and geochemical characteristics of the clays in that area with an approach to the type of clay minerals in soil horizons and calculation of CIW and CIA using Harnois formulation (Harnois, 1988). The mineralogical and geochemical characterization was carried out on the soil profiles divided into source rock, C horizon, B horizon, and A horizon. Physically, each horizon displays a different color and texture, so it is assumed to characterize different mineralogical and geochemical compositions. The mineralogical characteristic was identified using petrographic and the XRD (X-Ray Diffraction) method. Petrographic analysis was conducted at the Geological Optic Laboratory, and XRD analysis using Rigaku Multiflex BD3550N was carried out at the Central Laboratory. Both laboratories are housed in the Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada. The geochemical characteristic is shown by values of the CIW (Chemical Index Weathering) and CIA (Chemical Index Alteration) that were calculated based on the major oxide data from geochemical analysis using the ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy) instrument. The preparation method and analytical procedures of ICP-AES for the samples of this study were conducted in the Laboratory of ALS Canada Ltd., in North Vancouver, Canada.

This study shows that the soil profiles of C horizon to A horizon are dominated by illite, kaolinite, and smectite, where the illite indicates that the mineral formed at relatively high temperatures. Hydrothermal illite is micaceous and fine-grained, with formation temperatures of about 175 °C – 350 °C (i.e., Bove *et al.*, 2002; Park *et al.*, 2022), and illite, which is related to an active geothermal system occurs at approximately 200-250 ˚C (Corbett and Leach, 1996). The values of CIW and CIA show higher values from the source rock to the outermost horizon. Therefore, it can be suggested that the genesis of clay minerals at Gunung Patuk and Gunung Wungkal was the product of superimpose hydrothermal alteration and weathering processes.

2 REGIONAL GEOLOGY

Based on the regional geological map of Yogyakarta, Java (Rahardjo *et al.*, 1995), this study area is an isolated hill known as the Godean Hills, which is surrounded by Quaternary Young Merapi Volcanics Deposits (Qml) (Figure 1). Godean Hills consists of several hills, some of which are Gunung Wungkal and Gunung Patuk, which are the focus of this research. Gunung Wungkal is a hill in the Kebobutak Formation with an Oligocene – Early Miocene age located north of Gunung Patuk. The Kebobutak Formation comprises andesite breccia, tuff, lapilli tuff, agglomerates, and insertion of andesite lava flows (Rahardjo *et al.*, 1995). At the same time, Gunung Patuk is located in the Nanggulan Formation, which is older (the Eocene) than the Kebobutak Formation. This formation comprises sandstone with lignite insertions, sandy marl, claystone with limonite concretions, marl and limestone inserts, and sandstone and tuff (Rahardjo *et al.*, 1995). A more detailed Geological Map of Godean (Bronto *et al.*, 2014) reports that Gunung Patuk and Gunung Wungkal are intrusion rocks (porphyry andesite – micro diorite). This research identifies Gunung Patuk and Gunung Wungkal as andesitic intrusions (Figure 2).

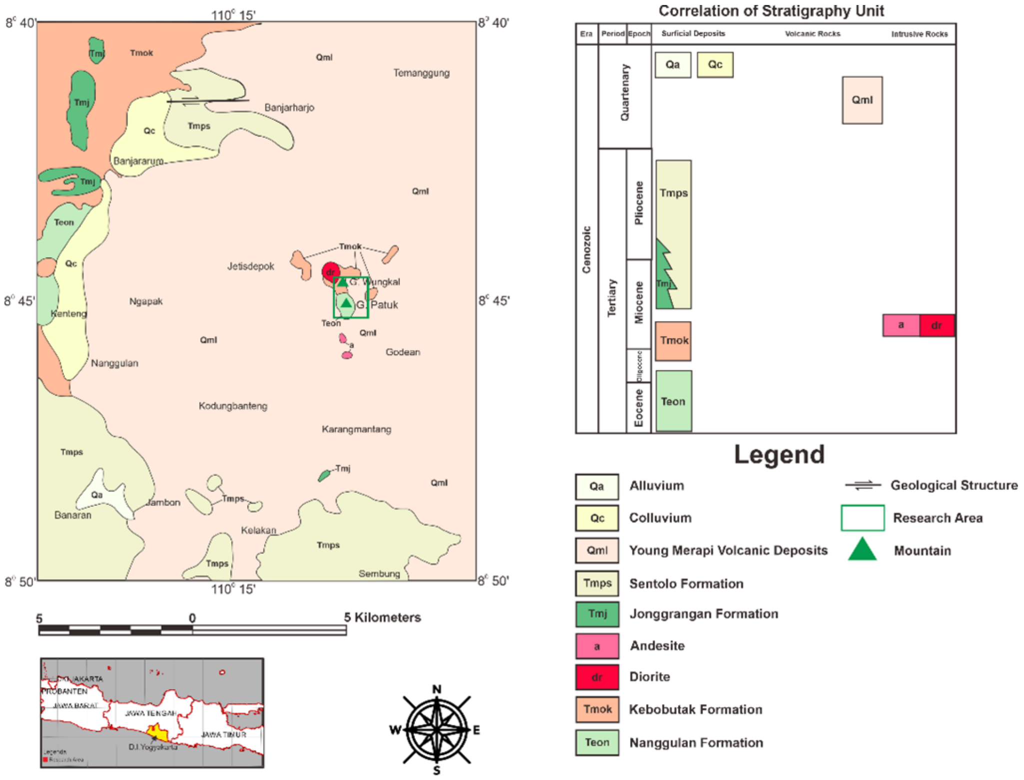

FIGURE 1. Research area based on regional geological map Yogyakarta, Java, simplified from (Rahardjo *et al.*, 1995). A more detailed geological map of the study area can be seen in Figure 2.

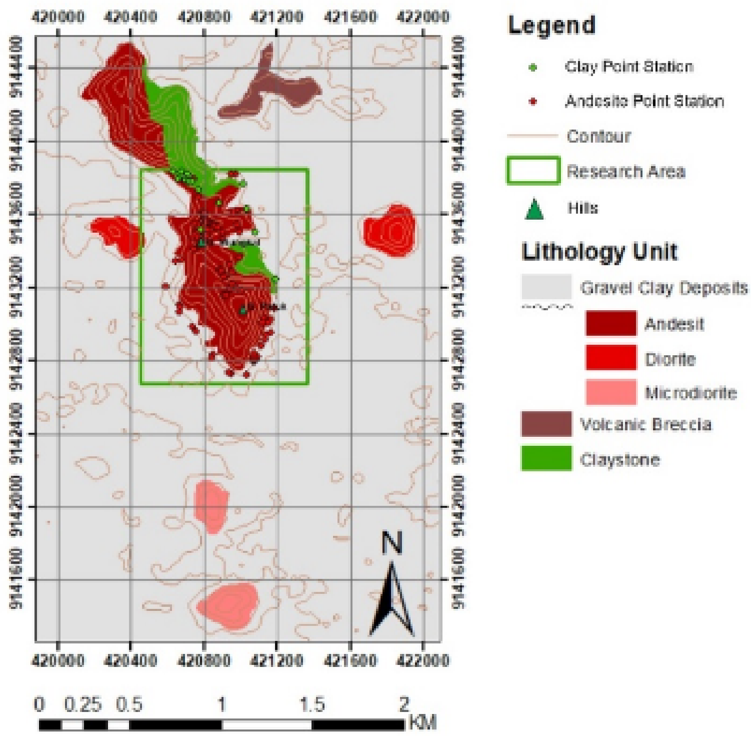

FIGURE 2. Simplified and modified Godean geological map from a previous study (Rahardjo *et al.*, 1995; Bronto *et al.*, 2014; Prabawa, 2020; Akmal, 2021) and the research area of Gunung Patuk and Gunung Wungkal.

3 METHODOLOGY

Measurement sections of the outcrop at Gunung Patuk and Gunung Wungkal were carried out to determine the layers of the soil profiles. Rock sampling was collected at several points representing the study area's horizons. Laboratory analysis was conducted for petrographical observations, XRD, and geochemical analyses. The thin-section analysis was to determine the mineral content of the source/parent rock. It was conducted in the Optical Geology Laboratory at the Geological Engineering Department of Universitas Gadjah Mada. XRD analysis was performed at the Center Laboratory, Geological Engineering Department of Universitas Gadjah Mada, to identify clay mineral content in the study area's C, B, and A horizons. The XRD analysis used a clay-oriented method: air drying, ethylene glycol, and heating at 550º C for 1 hour. The oriented method referred to by Wicaksono *et al.* (2017). ICP – AES analysis was carried out in ALS Laboratory in Canada and is to be used to determine concentrations of major oxide in the samples of Gunung Patuk and Gunung Wungkal in units of wt%. This ICP–AES analysis data is used to calculate the CIW and CIA using equations (1) and (2) (Harnois, 1988).

4 RESULTS

Gunung Patuk and Gunung Wungkal's soil horizons are presented in Figure 3 (Yoellanice, 2022). Gunung Patuk shows the complete soil horizon from source/parent rocks, horizon C, horizon B, A, and O. However, Gunung Wungkal only has an incomplete layer where the source/parent rock is not exposed.

Observation results on thin sections of the source/parent rock of the study area (samples of 22BI, A227BI, and B227BI at Gunung Patuk) show that the source rock is andesite, based on Streckeisen's classification (Streckeisen, 1976). The appearance of thin sections on PPL (Parallel Polarized Light) and XPL (Cross Polarized Light) of the sample 22BI, A227BI, and B227BI showing porphyritic texture with plagioclase (Pl) as phenocryst are set in a groundmass of plagioclase micro-crystalline and opaque minerals (Figure 4).

The major oxide concentration (in wt.%) of the research samples is presented in Table 1 (Yoellanice, 2022). This data is used to calculate the chemical weathering index (CIW) and chemical change index (CIA) using the Harnois formulation (Harnois, 1988).

Calculation of Chemical Index Weathering (CIW) and Chemical Index Alteration (CIA) is carried out based on the concentrations of major oxide data obtained from the results of the ICP-AES analysis according to equation (1) and (2) (Harnois, 1988).

$$\mathrm{CIW} = \left[\frac{\mathrm{Al_2O_3}}{(\mathrm{Al_2O_3} + \mathrm{CaO} + \mathrm{Na_2O})}\right] \times 100 \quad (1)$$

$$\mathrm{CIA} = \left[\frac{\mathrm{Al_2O_3}}{(\mathrm{Al_2O_3} + \mathrm{CaO} + \mathrm{Na_2O} + \mathrm{K_2O})}\right] \times 100 \quad (2)$$

Identification of clay minerals using the XRD method on 7 clay samples. The sample positions at Gunung Patuk profile from the A horizon, B horizon, and C horizon, which are 18A, 13B1, 16B2, and 14C, respectively, are presented in Figure 3A, and the clay minerals identification of XRD analysis result is shown in Figure 5A–D. Almost all soil horizons contain clay minerals of illite, kaolinite, and smectite. The sample positions at Gunung Wungkal profile from the A horizon, B horizon, and C horizon, which are 60A, 47B, and 9C, respectively, are presented in Figure 3B, and the clay minerals identification of XRD analysis result can be seen on Figure 5 (E-G). The XRD result shows that all soil horizons at the Gunung Wungkal contain clay minerals of illite, kaolinite, and smectite.

The results of the identification of clay minerals, calculation of Chemical Index Weathering (CIW), and calculation of Chemical Index Alteration (CIA) of Gunung Patuk and Gunung Wungkal are summarized in Table 2.

The results of the CIW and CIA calculations in Table 2 are then visualized in Figure 6

5 DISCUSSION

Andesite is suggested as the source/parent rock of the soil horizons in the study area. The texture of the andesite that shows porphyritic texture (large crystals of plagioclase are set in finer-grained plagioclase microcrystalline) and does not indicate the trachytic texture (flow lines) so that this andesite is interpreted as part of a shallow intrusion in the study area. This interpre-

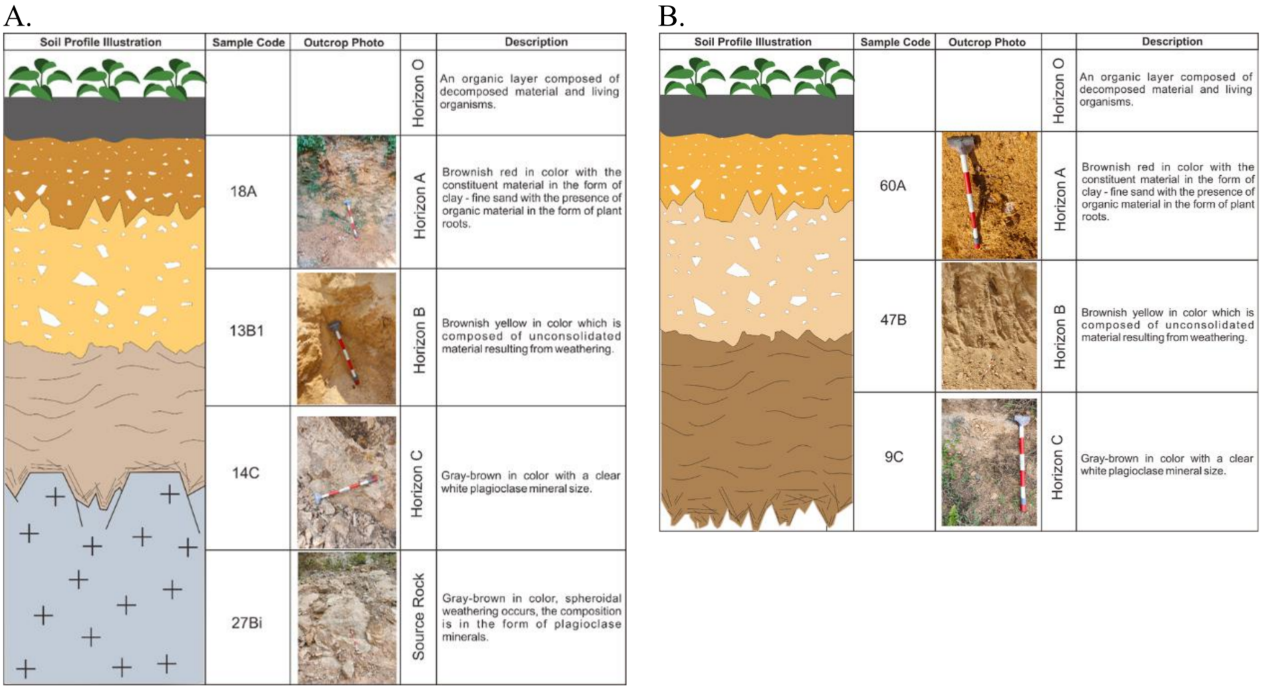

FIGURE 3. Soil profiles of Gunung Patuk (A) and Gunung Wungkal (B) are not in scale, and the sampling positions are on every horizon (Source: Yoellanice, 2022).

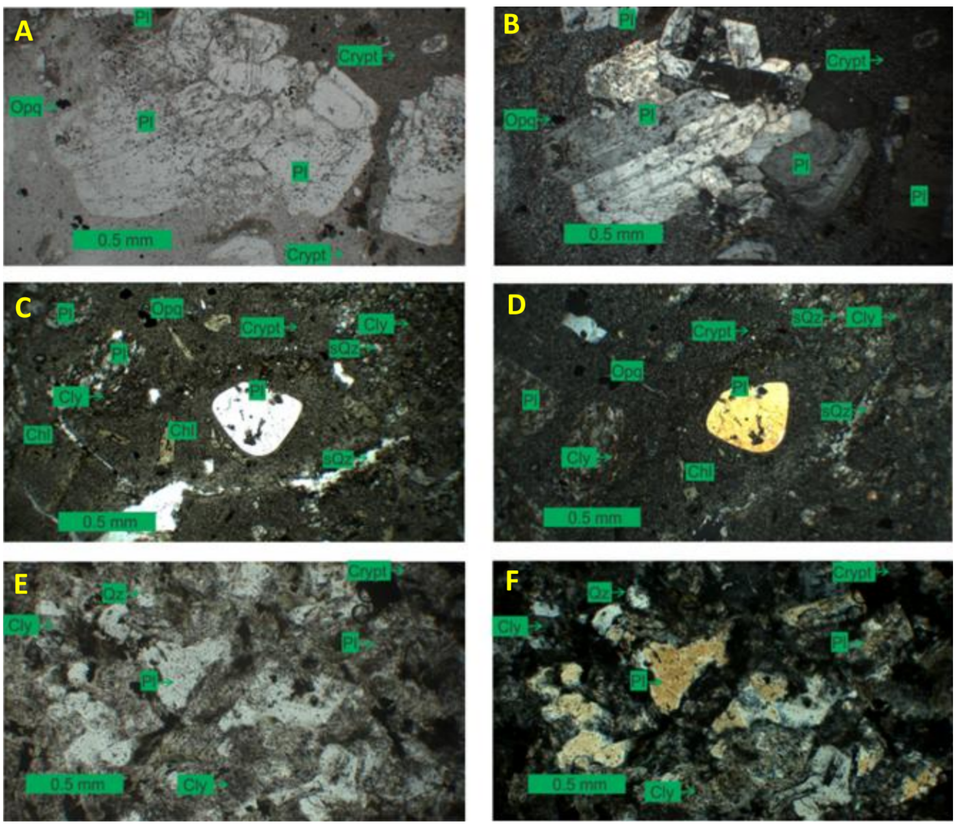

FIGURE 4. (A) Photomicrograph of sample 227BI (PPL); (B) Photomicrograph of sample 227BI (XPL); (C) Photomicrograph of sample A27BI (PPL); (D) Photomicrograph of sample A27BI (XPL); (E) Photomicrograph of sample B27BI (PPL); (F) Photomicrograph of sample B27BI (XPL) (Source: Yoellanice, 2022).

TABLE 1. Major oxide concentration (in wt.%) based on soil profile at Gunung Patuk and Gunung Wungkal (Yoellanice, 2022).

	Gunung Patuk						Gunung Wungkal		
	Horiz A	Horiz B	Horiz B	Horiz C	Source Rock	Source Rock	Horiz A	Horiz B	Horiz C
	18A	13B1	16B2	14C	227Bi	27Bi	60A	47B	9C
SiO_2	52.3	61.8	60.3	69.0	68.7	54.7	77.2	56.1	65.4
Al_2O_3	19.15	16.2	17.7	15.8	15.3	15.05	13.85	19.35	16.8
Fe_2O_3	12.75	6.92	6.78	3.99	4.27	6.6	2.56	7.67	4.19
CaO	0.35	0.65	0.84	1.22	3.1	6.82	0.34	0.66	2.26
MgO	1.77	1.58	1.52	0.81	1.66	2.31	0.32	1.1	0.86
Na_2O	2.98	2.74	2.92	4.42	4.29	4.9	0.25	3.54	4.13
K_2O	2.02	1.85	3.92	1.5	1.56	0.98	2.18	1.2	2.23
TiO_2	0.87	0.81	0.79	0.41	0.39	0.72	0.69	0.97	0.37
MnO	0.06	0.07	0.05	0.08	0.09	0.14	0.01	0.04	0.08
P_2O_5	0.19	0.16	0.21	0.14	0.15	0.2	0.02	0.08	0.15
SrO	0.01	0.01	0.01	0.03	0.03	0.02	0.01	0.01	0.03
BaO	0.02	0.01	0.08	0.04	0.03	0.01	0.03	0.02	0.05
LOI	8.31	5.93	5.95	3.67	1.72	8.02	4.43	8.53	3.87
Total	100.78	98.73	101.07	101.11	101.29	100.47	101.9	99.27	100.42

TABLE 2. The results of the identification of clay minerals, calculation of CIW, and calculation of CIA of Gunung Patuk and Gunung Wungkal.

Location	Stop Site Code	Soil Profile	Minerals Identification (XRD identification)	CIW	CIA
Gunung Patuk	18A	Horizon A	Illite, Kaolinite, and Smectite	85.19%	78.16%
	13B1	Horizon B	Illite and Smectite	82.70%	75.56%
	16B2	Horizon B	Illite, Kaolinite, and Smectite	82.48%	69.74%
	14C	Horizon C	Illite, Kaolinite, and Smectite	73.69%	68.88%
	227Bi	Source Rock	-	67.43%	63.09%
	27Bi	Source Rock	-	56.22%	54.23%
Gunung Wungkal	60A	Horizon A	Illite, Kaolinite, and Smectite	95.91%	83.33%
	47B	Horizon B	Illite, Kaolinite, and Smectite	82.17%	78.18%
	9C	Horizon C	Kaolinite and Smectite	72.45%	66.09%

tation supports the type of rocks suggested by Rahardjo *et al.* (1995) and Bronto *et al.* (2014), which reported that the igneous rocks of Gunung Patuk and Gunung Wungkal are intrusions.

The results of XRD analysis show that horizons C to horizons A in the study area are dominated by clay minerals, which are illite, kaolinite, and smectite, except horizon C of Gunung Wungkal, which shows no presence of the illite (Table 2). The CIW and CIA calculation values show a similar trend of Gunung Patuk and Gunung Wungkal, which is getting higher from the source/parent rock up to horizon A (Figure 6).

The CIW and CIA values , which are increasingly higher towards the horizon approaching the earth's surface, indicate a supergene enrichment process of the Al_2O_3 compound in comparison to other elements such as CaO, Na_2O, and K_2O, which are more mobile compounds, where these elements act as divisors (denominators) in the formulation of CIW and CIA. These more mobile elements will leave the nearest horizon from the ground surface by rainwater or groundwater, which dissolves them and carries them along with their flow. Therefore, the higher CIW and CIA values at the horizon closer to the ground surface indicate that the weathering process, which causes Al_2O_3 enrichment, is becoming more intensive. The formation of soil horizons characterizes the enrichment of Al_2O_3 with different contents. Therefore, soil horizons indicate that the weathering process in the research area is running intensively and further suggest that it occurs at atmospheric temperature. On the other hand, the surprising thing is the presence of illite on both A horizon, which are the closest horizon to the earth's surface (characterized by the highest value of the CIW and CIA), even though the illite indicates the mineral forming at the

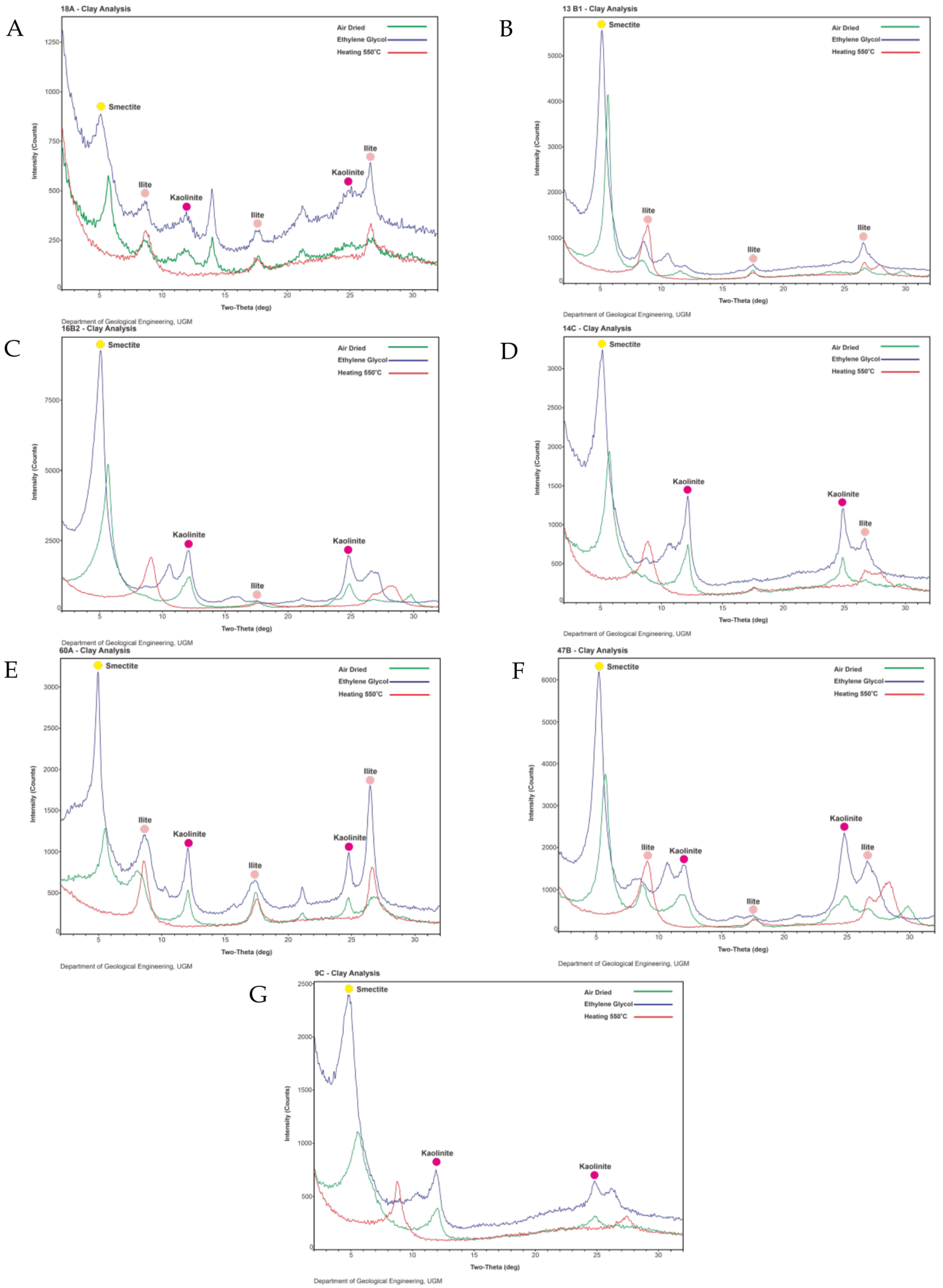

FIGURE 5. Identification of clay minerals at Gunung Patuk (A-D) and Gunung Wungkal (E-G) as a result of XRD analysis (clay-oriented method) (Source: Yoellanice, 2022).

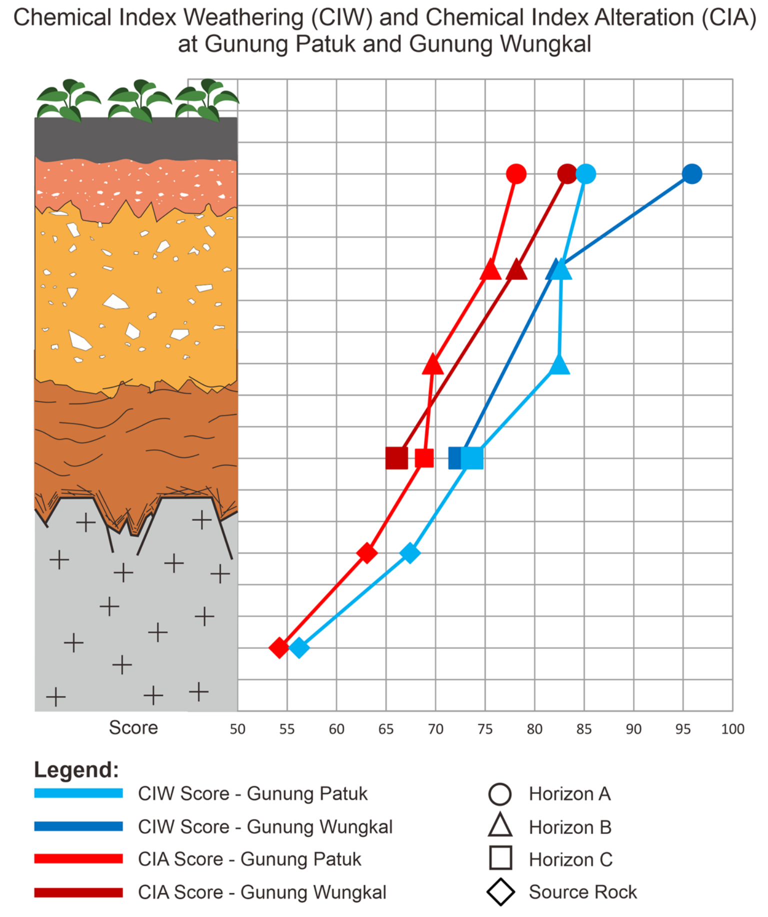

FIGURE 6. The illustration of soil horizons and results of the CIW and CIA calculations (Source: Yoellanice, 2022).

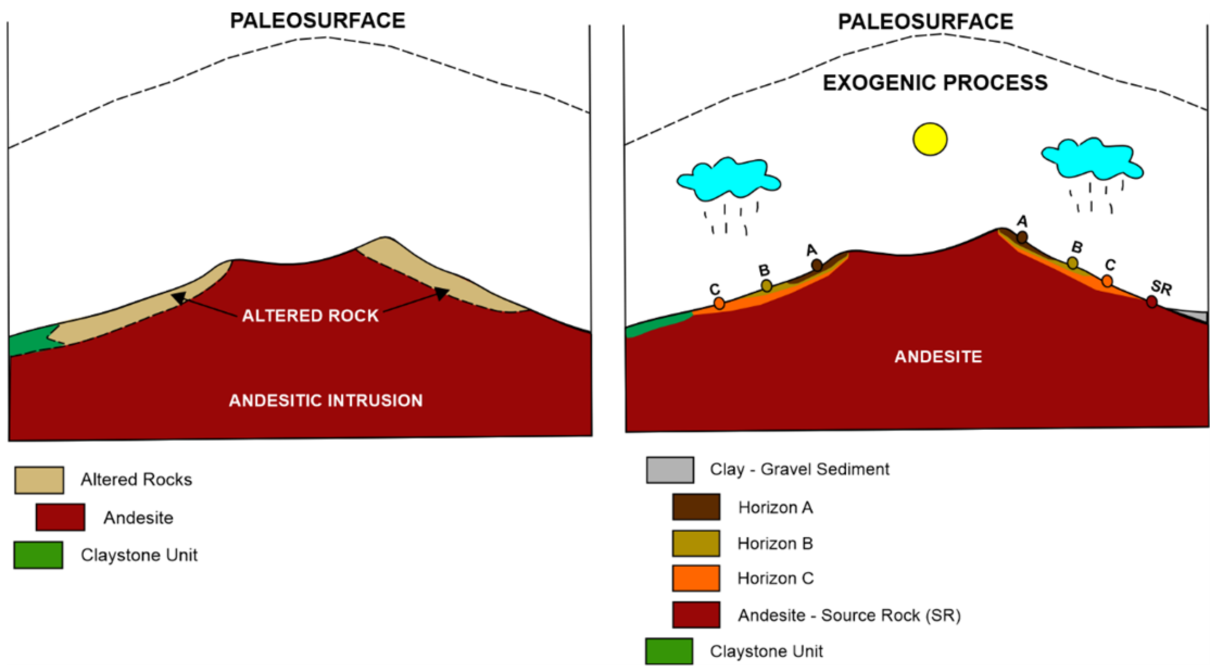

FIGURE 7. A simple cartoon figure illustrating the process of forming soil horizons containing clay minerals.

relatively high temperatures (associated to hydrothermal fluids). As mentioned before, the presence of illite is related to formation temperatures of about 175 °C – 350 °C (i.e., Bove *et al.*, 2002; Park *et al.*, 2022) and approximately 200-250 °C (Corbett and Leach, 1996). For that reason, it can be suggested that clay minerals at Gunung Patuk and Gunung Wungkal were formed by hydrothermal alteration processes and then superimposed by weathering processes. This suggestion can be explained as follows: The geological process in the research area was preceded by the alteration of part of the andesite formation (as parent rock) due to the andesite intrusion process, where the altered rock formed the mineral illite as a marker of a high-temperature environment. After the modified rock is exposed to the earth's surface, the altered rock undergoes a weathering process due to the influence of exogenic processes. These exogenic processes include weathering forming soil horizons, where the illite mineral remains in these horizons. A simple cartoon drawing that illustrates the process of creating soil horizons containing clay minerals is shown in Figure 7

6 CONCLUSION

The least altered igneous rock in the Gunung Patuk and Gunung Wungkal study area is andesite, which is suggested as the source/parent rocks of the soil horizons. The soil horizons C to A are dominated by clay minerals such as illite, kaolinite, and smectite. Geochemical characteristics of the horizons, shown by CIW and CIA values, increase steadily from the source rock up to horizon A. The presence of the illite on both horizon A and having the highest value of the CIW and CIA suggests that the genesis of clay minerals at Gunung Patuk and Gunung Wungkal was the product of the superimpose of hydrothermal alteration and weathering processes.

Acknowledgements This research is part of the first author's undergraduate thesis, which has never been published. The authors thank the Geological Engineering Department, Faculty of Engineering Universitas Gadjah Mada, for providing grants to finance this research in FY 2022.

REFERENCES

Akmal, M.F. (2021). Studi Geokimia Material Hasil Lapukan Batuan Beku Daerah Godean Kabupaten Sleman, D.I. Yogyakarta. Yogyakarta: Bachelor's Thesis, Geological Engineering, Universitas Gadjah Mada (in Indonesian), unpublished.

Ardiansah, T. (2021). Studi Petrologi Batuan Beku di Daerah Godean - Seyegan, Kabupaten Sleman, Daerah Istimewa Yogyakarta. Yogyakarta: Bachelor's Thesis, Geological Engineering, Universitas Gadjah Mada (in Indonesian), unpublished.

Bove, D., Eberl, D., McCarty, D., & Meeker, G. (2002). Characterization and modeling of illite crystal particles and growth mechanisms in a zoned hydrothermal deposit, Lake City, Colorado. Am. Mineral. 87 (11-12), 1546–1556.

Bronto, S., Ratdomopurbo, A., Asmoro, P., & Adityarani, M. (2014). Longsoran Raksasa Gunung Api Merapi, dimuat dalam Jurnal Geologi dan Sumberdaya Mineral, Volume 15. Bandung: Pusat Survei Geologi (in Indonesian).

Corbett, G.J. & Leach, T.M. (1996). Southwest Pacific Rim Gold-Copper Systems: Structure, Alteration and Mineralization, *in* Manual for an Exploration Short Course, Baguio, Philippines.

Harnois, L. (1988). The CIW Index: A New Chemical Index of Weathering: Sedimentary Geology, v. 55, p. 319-322, doi: 10.1016/00370738(88)90137-6.

Park, C., Chung, D., Park, C., Seo, S., Kim, J.H., Seo, S.M., & Il-Mo, K. (2022). Mineralogical and geochemical characteristics of the hydrothermal illite from Hoam granite, South Korea: Implications for episodic fluid injections in the hydrothermal alteration system. Geochemistry, v.82, 14p. doi: 10.1016/j.chemer.2022.125919.

Prabawa, A. (2020). Geologi dan Karakteristik Lempung Gunung Gedang dan Sekitarnya, Kecamatan Seyegan dan Godean, Kabupaten Sleman, DIY Serta Rekomendasi Pemanfaatannya. Yogyakarta: Bachelor's Thesis, Geological Engineering, Universitas Gadjah Mada (in Indonesian), unpublished.

Rahardjo, W., Sukandarrumidi, & Rosidi, H.M.D. (1995). Peta Geologi Lembar Yogyakarta, Jawa. Bandung: Pusat Penelitian Dan Pengembangan Geologi.

Soeria-Atmadja, R., Maury, R.C., Bellon, H., Pringgoprawiro, H., Polve, M., & Priadi, B. (1994). Tertiary magmatic belts in Java: Journal of Southeast Asian Earth Sciences, v. 9, p. 13–27, doi:10.1016/0743-9547(94)900620.

Streckeisen, A.L. (1976). Classification and Nomenclature of Igneous Rocks. N. Jahrb. Miner. Abh., 107, 144-240.

Velde, B. & Meunier, A. (2008). The Origin of Clay Minerals in Soils and Weathered Rocks. Springer-Verlag Berlin Heidelberg, 426 pp.

Verdiansyah, O. (2016). Perubahan Unsur Geokimia

Batuan Hasil Alterasi Hidrotermal Di Gunung Wungkal, Godean, Yogyakarta. Yogyakarta: KURVATEK, v. 1, No. 1, p. 59 – 67 (in Indonesian).

Wicaksono, D.D., Setiawan, N.I., Wilopo, W., & Harijoko, A. (2017). Teknik Preparasi Sampel Dalam Analisis Mineralogi dengan XRD (X-Ray Diffraction) di Departemen Teknik Geologi, Fakultas Teknik, Universitas Gadjah Mada. Proceeding, Seminar Nasional Kebumian Ke-10, p. 1864 – 1880 (in Indonesian).

Yoellanice, D. (2022). Karakteristik Geokimia Lempung di Gunung Patuk dan Gunung Wungkal, Godean, Kabupaten Sleman, Daerah Istimewa Yogyakarta. Yogyakarta: Bachelor's Thesis, Geological Engineering, Universitas Gadjah Mada (in Indonesian), unpublished.