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Mineralogical Characteristics of Hydrothermally-altered Andesite in Kalirejo Village and The Surrounding Areas, Indonesia

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ABSTRACT. Type and intensity of hydrothermal alterations affect rock engineering properties and slope stability. Identification of mineralogical characteristics of rocks is essential in determination of rock slope failure mechanism in a hydrothermal alteration zone. This research was conducted to identify mineralogical characteristics of hydrothermally-altered andesite in Kalirejo Village and surrounding areas, Indonesia. The research was conducted by field observation and laboratory analyses involving petrographic and X-ray Powder Diffraction (XRD) analyses. The results showed that the research area was dominated by argillic alteration type and high alteration intensity implying high susceptibility to slope failures.

Keywords: Hydrotermal alteration · Mineralogical characteristics · Andesite · Kalirejo Village · Indonesia.

1 INTRODUCTION

The research area was located in Kalirejo Village and the surroundings. It was administratively located in Kulon Progo Regency (Yogyakarta Special Province) and Purworejo Regency (Central Java Province), Indonesia. The regional geological map produced by Rahardjo *et al.* (1995) indicated that the research area was composed of intrusive igneous rock group of andesite. In addition to weathering, the andesite near the research area had also been undergone hydrothermal alteration (Ansori and Hastra, 2013). The 1:100.000 scale map produced by Center of Volcanology and Geological Hazard Mitigation (PVMBG, 2010) indicated that the research area had a medium to high landslide susceptibility level. Although research on landslide susceptibility has been conducted on a regional scale, mechanism of slope failures in the research area was not well understood and required further studies. Better understanding of slope failure mechanism allows more detailed zonation of areas susceptible to slope failures.

Stability of rock slopes in tectonically active and tropical regions is controlled by several factors, such as slope geometry, material properties, groundwater, surface cover, and active factors involving earthquake and rainfall. Previous publications (e.g., Bell, 2007; Pola *et al.*, 2012) have shown that hydrothermal alteration may change engineering properties of rocks, inducing slope failures. As the intrusive igneous rocks in the research area had undergone hydrothermal alteration, the change in their engineering properties due to hydrothermal alteration could partly be responsible for a number of slope failures.

This paper presents preliminary results of a study conducted to investigate factors controlling slope failures in the research area. The geology and mineralogical characteristics of the hydrothermally-altered andesite are described and hydrothermal alteration type and intensity of the intrusive igneous rocks in the research area are highlighted.

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2 GEOLOGIC SETTING

According to Rahardjo *et al.* (1995), Kulon Progo Mountains regional stratigraphy from old to young is composed of Nanggulan Formation, Old Andesite Formation, Jonggrangan Formation, Sentolo Formation, and Alluvial Deposits. In addition there are intrusive rock groups in the form of andesite, diorite and dacite intrusive rocks (Figure 1). The research area belongs to the Andesite Intrusion Rock Group. This group of rocks has a composition ranges from hypersthene andesite to hornblende augite andesite and trachyandesite. Judging from the Regional Geological Structure, according to Van Bemmelen (1949), the Kulon Progo Mountains region has a structure characterized by the existence of ancient volcanic complexes that have undergone several tectonic phases. As a result, geological structures formed in the form of normal faults with dominant shear components and upward faults (Rahardjo *et al.*, 1995). The structures formed relatively have an orientation northeast-southwest and west-east (Figure 1).

3 METHODOLOGY

A 1:25,000-scaled field mapping, which involved observation of lithology, geological structure, and hydrothermal alteration, and laboratory analyses, which included petrographic and X-Ray Diffraction (XRD) analyses, were conducted in this research. Genetic classification of the intrusive igneous rocks in the research area was carried out following the IUGS classification proposed by Streckeisen (1978, in Le Maitre, 2002). Hydrothermal alteration type of the intrusive igneous rocks was determined by natural outcrop observation and detailed petrographic and XRD analyses. Meanwhile, hydrothermal alteration intensity of the intrusive igneous rocks was determined by comparing the amount of secondary minerals to the primary minerals observed in the petrographic analyses of thin sections, following the procedure described in Byers (1990). The percentages of the hydrothermal alteration intensity were then classified following classification proposed by Gillis *et al.* (2014) (Table 1).

Table 1: Classification of hydrothermal alteration intensity (Gillis *et al.*, 2014).

Alteration Intensity	Secondary mineral to primary mineral (%)
Fresh rock	<2
Weak	2 – 9
Moderate	10 – 49
High	50 – 95
Intensive	>90

4 RESULTS AND DISCUSSION

4.1 Lithology

The geological map shown in Figure 2 shows that the research area consisted of andesite. The rock type observed in this research was consistent with that in the Rahardjo et al. (1995). The andesite could be further divided into three rock units, namely hornblende andesite intrusion 1, hornblende andesite intrusion 2, and hornblende andesite intrusion 3. In general, the rock units had similar characteristics and were dominated by secondary mineral group of hornblende (Figure 3). The outcrops showed that the rock units had grey color, weak to high alteration conditions, porphyro aphanitic texture with <1–3 mm crystal size, and jointed structures. In thin sections, the rock units had a porphyritic texture and were composed of phenocrysts of pyroxene, hornblende, plagioclase (labradorite), and opaque minerals and the groundmasses of plagioclase and clay minerals. The rock units were distinguished each other by the weathering degree and relative age. The unit of hornblende andesite intrusion 1 had a slightly to moderately weathering degree, the unit of hornblende andesite intrusion 2 had a moderately weathering degree, and the unit of hornblende andesite intrusion 3 had a highly to completely weathering degree.

The geological structures observed in the research area were shear and tension joints and sinistral strike-slip and normal faults (Figure 4). Generally, shear joints has an orientation direction northeast-southwest and northwest-southeast, while the tension joints generally has a north-south orientation direction. In the tension joints found a filling structure in the form of calcite and quartz veins. This joints structure

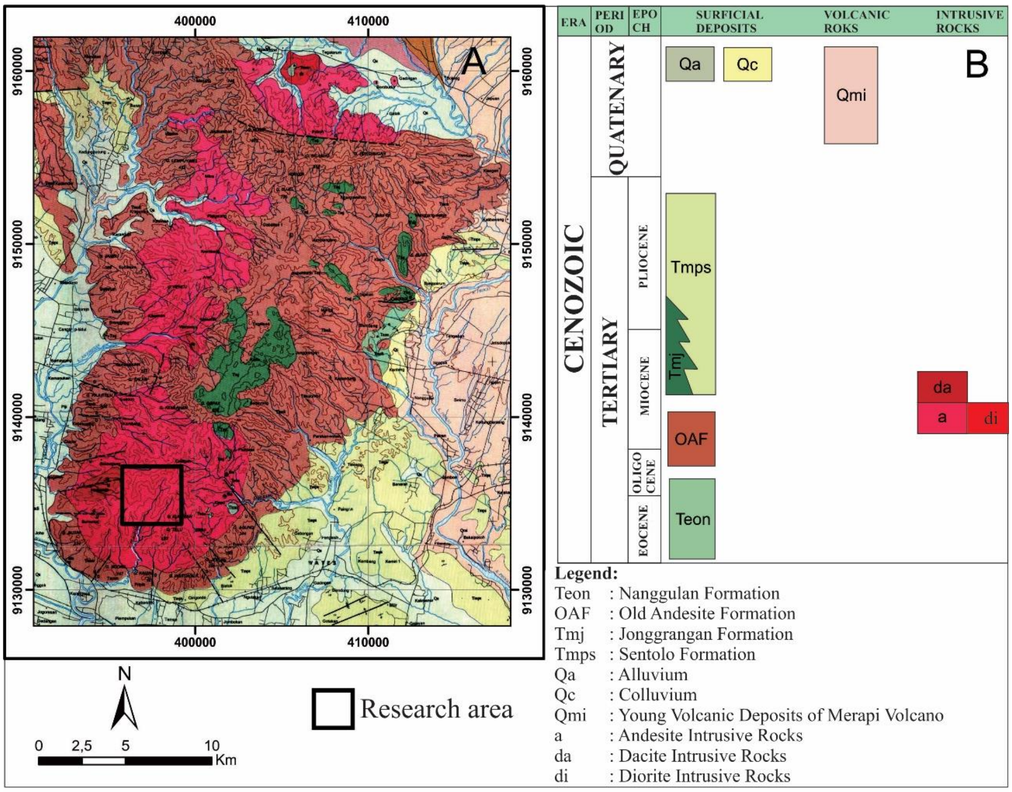

Figure 1: (A) Regional geological map of the Kulon Progo Mountains. (B) Stratigraphic column of the Kulon Progo Mountains area (Rahardjo *et al.*, 1995 with modifications). The research area is marked with a black box that belongs to the Andesite Intrusive Rock Group.

acts as a pathway for hydrothermal fluid to get out to the surface which eventually forms the vein structure. Analyses of fault data (Table 2) indicated that the sinistral strike-slip faults in the research area were estimated to be developed by two main stress, which were northeast east-southwest west and southeast east-northwest west directions (Figure 5).

4.2 Hydrothermal alteration

4.2.1 *Types of hydrothermal alteration*

Determination of hydrothermal alteration type is done by direct outcrop mapping method in the field and supported by petrographic analysis. Based on the composition of the mineral composition in general, alteration types in the study area can be grouped into two, namely: argillic alteration types and propylitic alteration types. The map of hydrothermal alteration types is shown in Figure 6.

Argillic alteration

The argillic alteration was more dominant and developed in almost 70 % of the research area. The XRD analysis results showed that this type of alteration was characterized by the presence of smectite, kaolinite, quartz, illite and illite/montmorillonite mixed layer minerals. According to Pirajno (1992), this type of hydrothermal alteration generally has a low forming temperature (<200–250°C) and forms near the ground surface. In the field, the hydrothermally-altered andesite having argillic alteration appeared to be relatively soft and the rock structures were easily destroyed by fingers. In thin sections, they were characterized by a high content of clay minerals (Figure 7).

Propylitic alteration

The XRD analysis results showed that the propylitic alteration was characterized by the presence of chlorite, epidote, and calcite minerals. This type of hydrothermal alteration has a relatively higher formation temperature as compared to the argillic alteration (about 250°C) and generally forms at a deeper location (Pirajno, 1992). In the field, the hydrothermally-altered andesite having propylitic alteration appeared to be harder than those having argillic alteration. In some places,

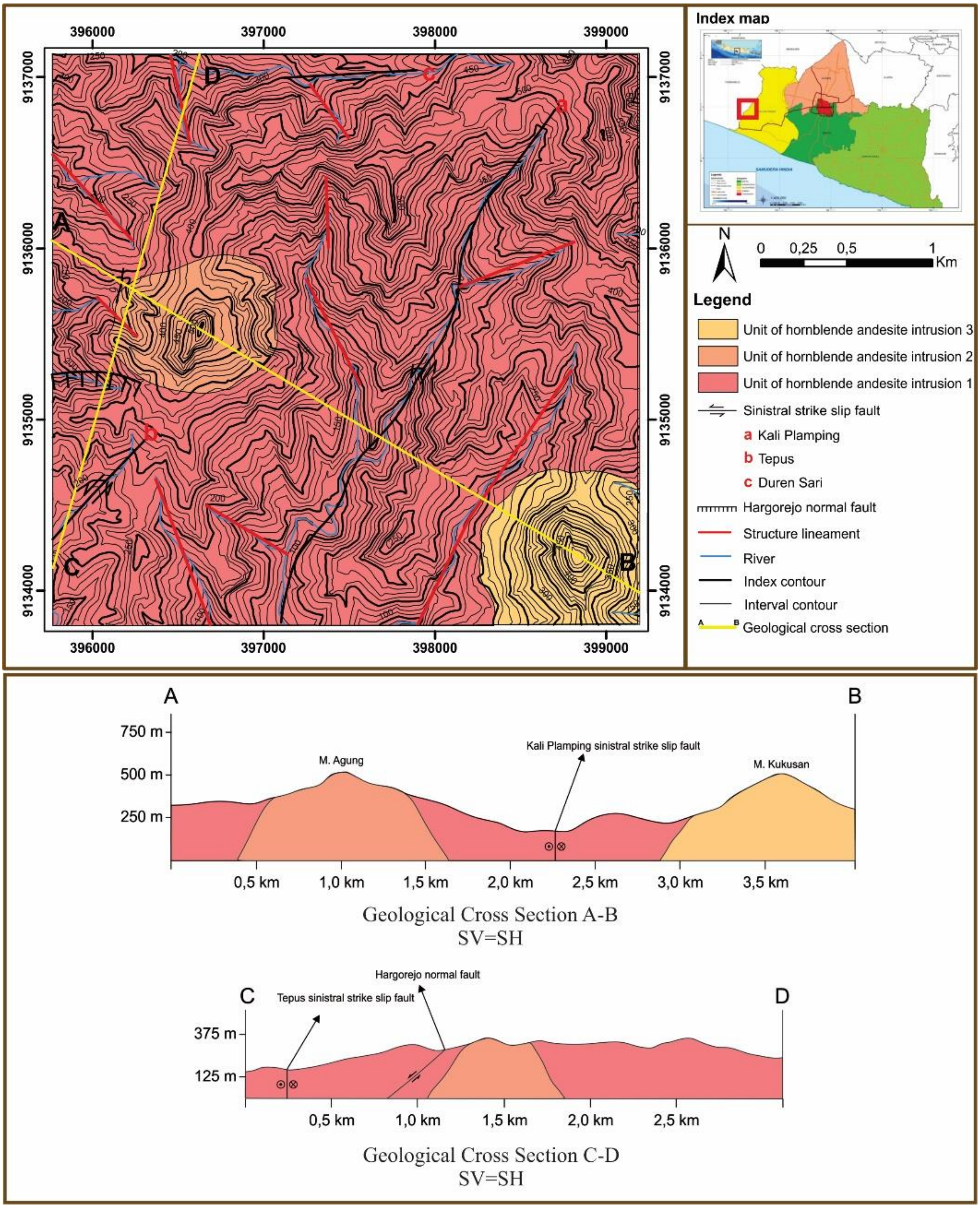

Figure 2: Geological map and cross sections.

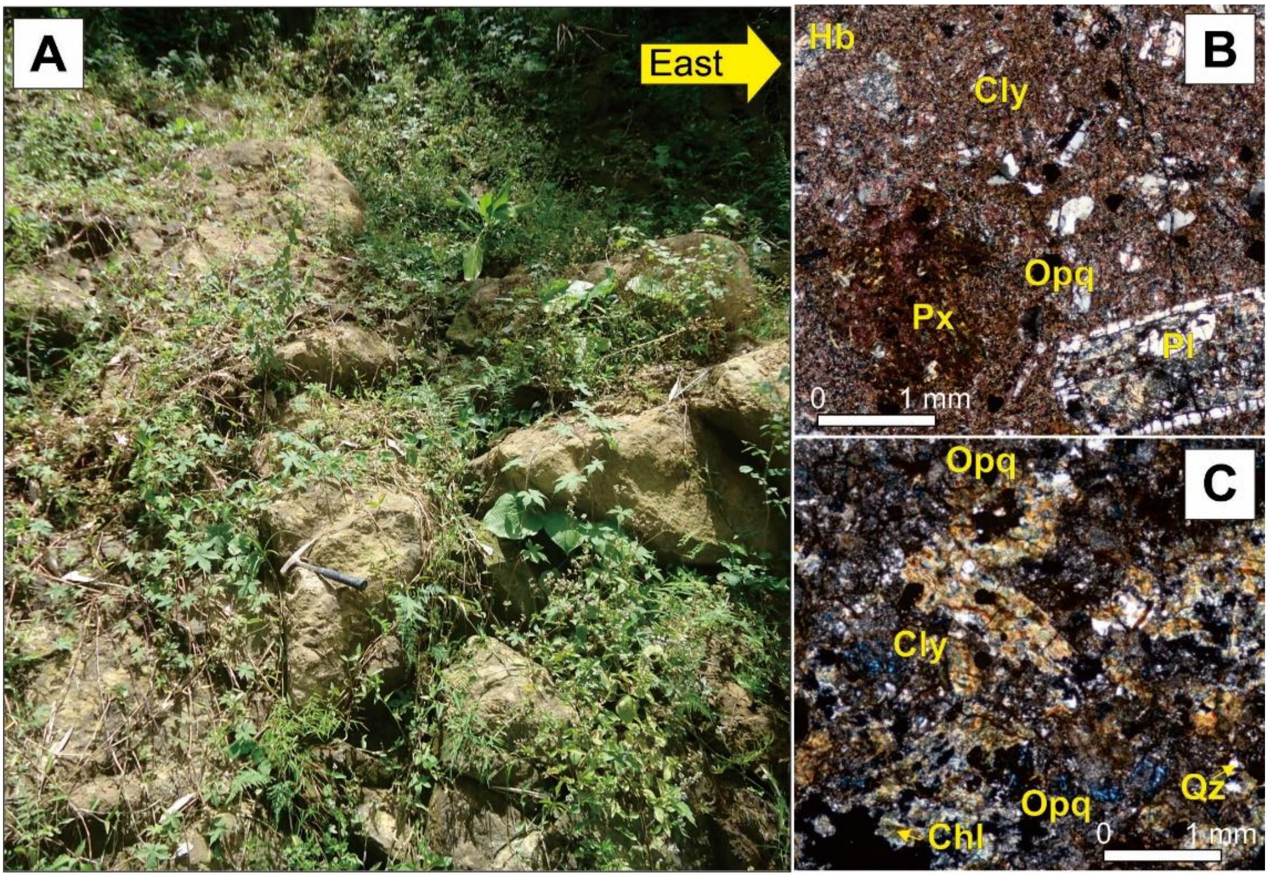

Figure 3: Photographs of the andesite hornblende intrusion unit. (A) Natural outcrop. (B,C) Thin sections (XPL). Hb: hornblende; Cly: clay; Opq: opaque mineral; Px: pyroxene; Pl: plagioclase; Chl: Chlorite; Qz: quartz.

Table 2: Fault measurement data.

Geological Structure	Strike/Dip (N...°E/...°)	Striation (°)
Kali Plamping sinistral strike slip fault	150/72	30 NE
Tepus sinistral strike slip fault	245/78	30 NE
Duren Sari sinistral strike slip fault	75/85	40 W

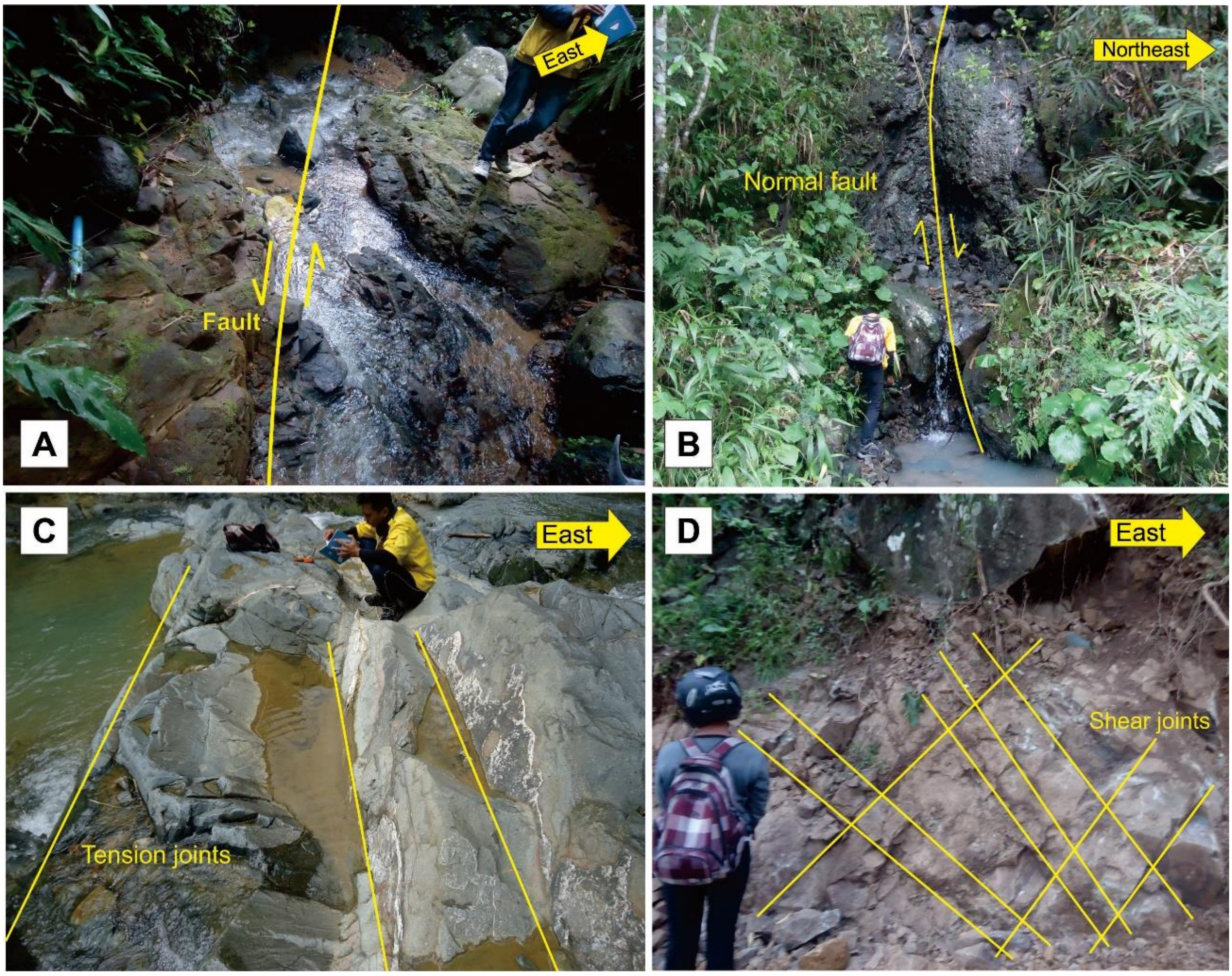

Figure 4: Photographs of geological structures in the research area. (A) Sinistral strike slip fault. (B) Normal fault. (C) Tension joints with north-south orientation. (D) Shear joints with orientation of northeast-southwest and northwest-southeast.

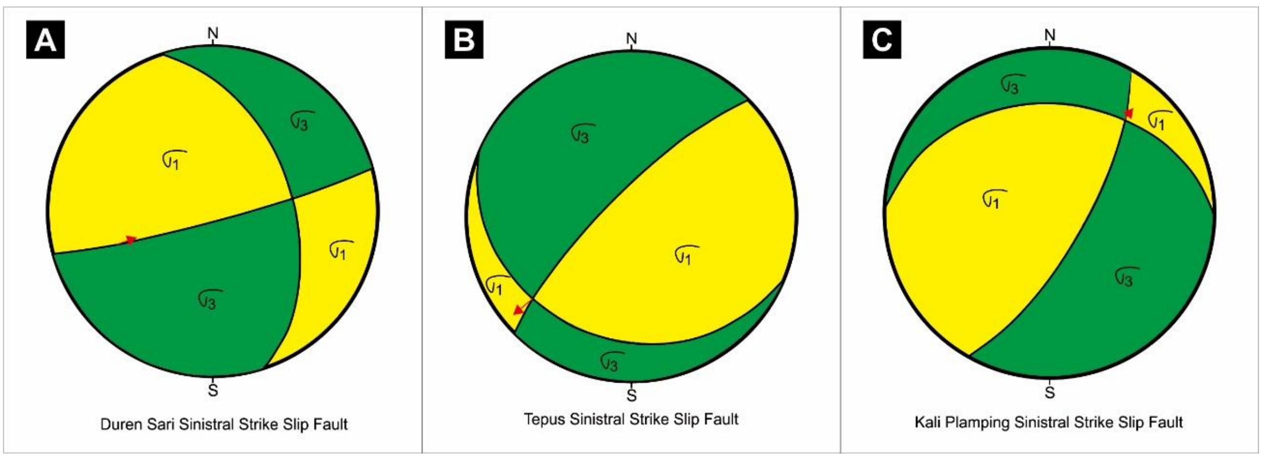

Figure 5: Stress analyses of the sinistral strike-slip faults.

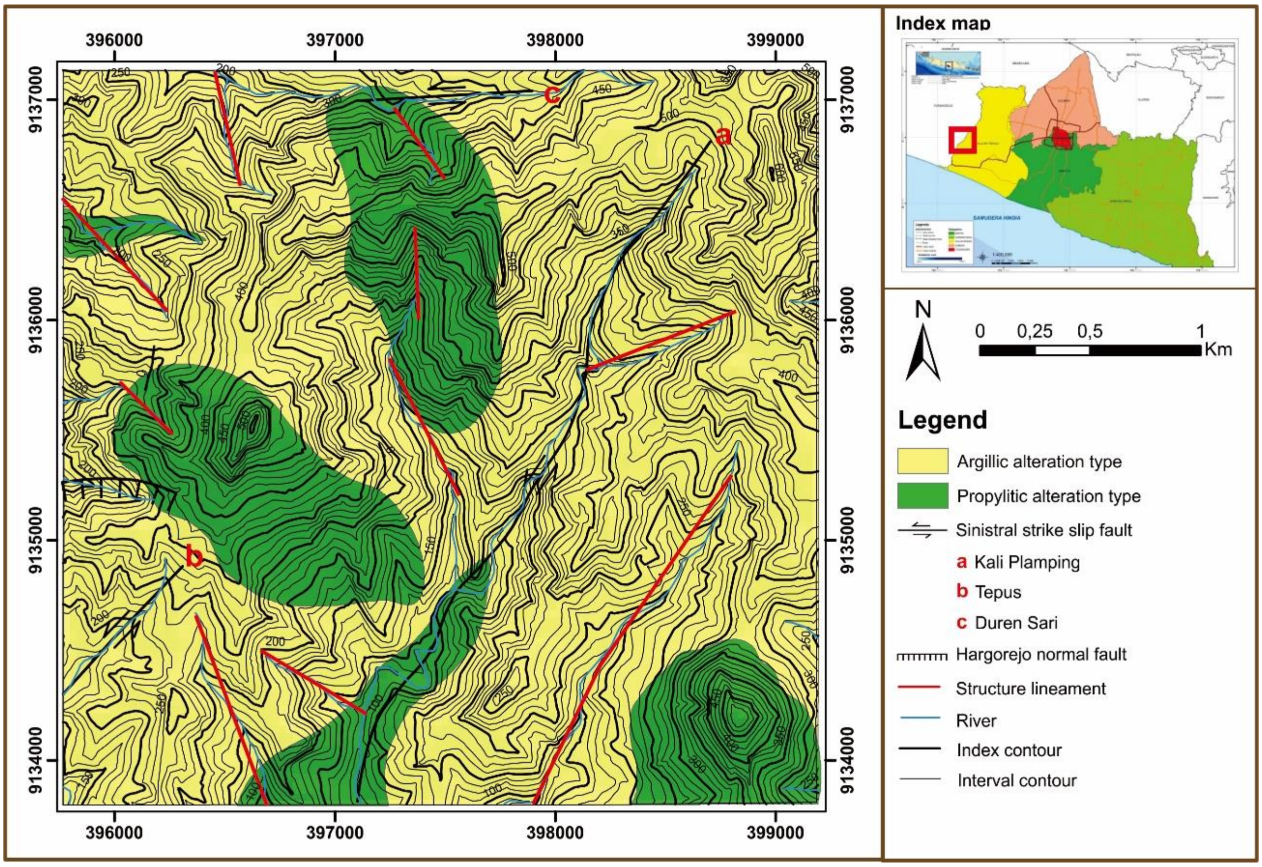

Figure 6: Map of hydrothermal alteration type.

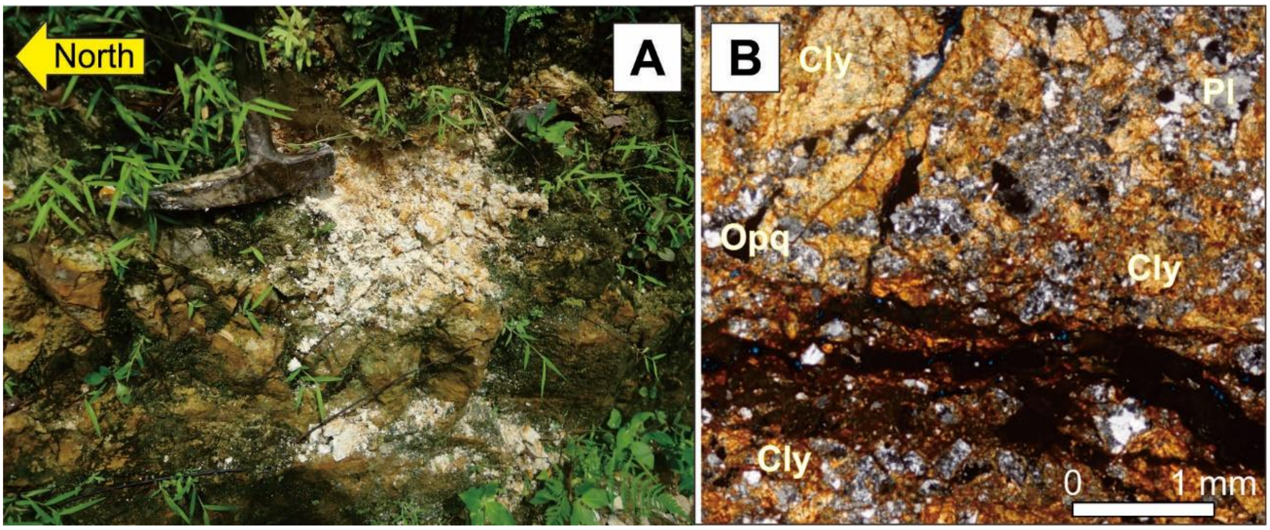

Figure 7: (A) Photograph of argillic alteration in the field. (B) Photograph of argillic alteration in thin section (XPL). Opq: opaque mineral; Pl: plagioclase; Cly: clay.

quartz and calcite-filled veins were observed in the hydrothermally-altered andesite. In thin sections, this type of propylitic alteration was characterized by the presence of chlorite minerals (Figure 8).

4.2.2 *Intensity of hydrothermal alteration*

Petrographic analysis results for measurement of the hydrothermal alteration intensity are presented in Table 3 and the map of hydrothermal alteration intensity is shown in Figure 9. The andesite in the research area had undergone three different hydrothermal alteration intensities, namely weak, moderate, and high alteration intensities. High alteration intensity had dominant spatial distribution and about 75 % of andesite in the research area were highly altered. Aproximately 15 % of the andesite, particularly in the western and northern parts of the research area, were moderately altered, while approximately 10 % of the andesite, particularly located in the southern part of the research area, were weakly altered. Presence of geological structures, particularly faults, allow hydrothermal fluid to flow upward and to alter mineral compositions of the host rock near the ground surface. The more intensive the presence of the geological structures is the higher intensity of hydrothermal alteration will be. The zone of high hydrothermal alteration intensity in the research area appeared to be influenced by presence of the strike-slip and normal faults. Other faults might exist and contribute to the dominant high intensity of hydrothermal alteration in the research area. However, identification of other faults that was hindered because the andesite had also undergone weathering.

The area having argillic type and high intensity of hydrothermal alteration were likely to have high landslide hazard potential. As slope failure was not dictated only by material properties, further study was conducted to determine the mechanism of slope failures in the research area by considering other controlling factors of slope failures, such as slope geometry, groundwater, and land use.

5 CONCLUSION

The research area consisted of andesite that could be divided into three lithological units based on the weathering degree and relative age. The presence of faults, particularly the strike-slip faults, allowed the intrusive igneous rocks in the research area to undergo hydrothermal alteration. Two types of hydrothermal alteration developed in the research area, namely argillic and propylitic alterations. The propylitic alteration was characterized by the presence of calcite, epidote quartz, and chlorite minerals, while the argillic alteration had more dominant spatial distribution and was characterized by the presence of illite/montmorillonite, illite, smectite, quartz, and kaolinite minerals. Three hydrothermal alteration intensities, which were weak, moderate, and high alteration intensities, were developed. However, most of the andesite in the research area had undergone high intensity of hydrothermal alteration.

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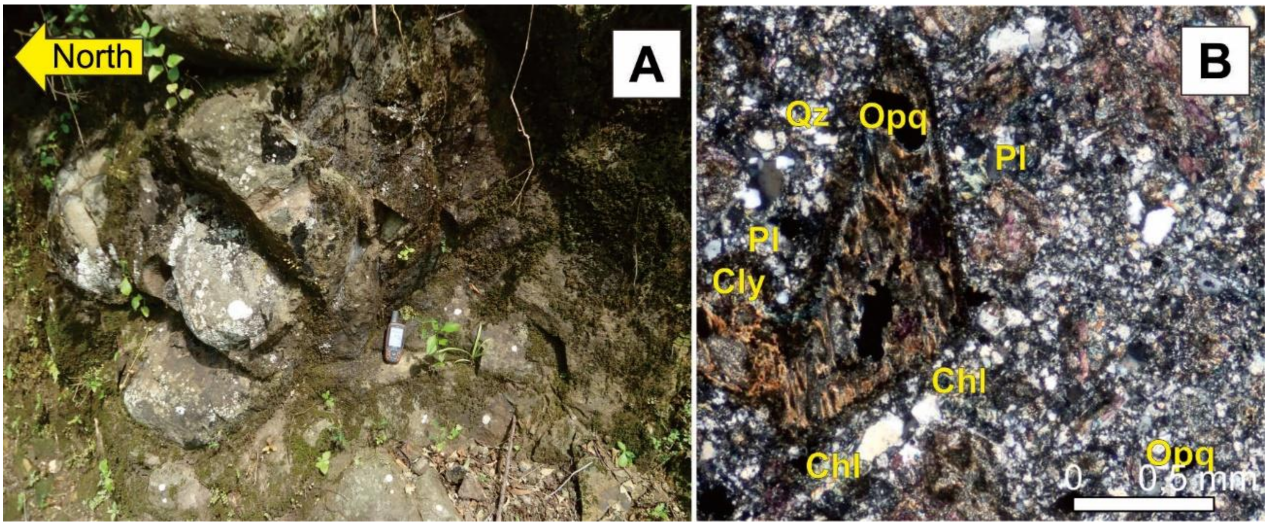

Figure 8: (A) Photograph of propylitic alteration in the field. (B) Photograph of propylitic alteration in thin section (XPL).Cly: clay; Opq: opaque mineral; Pl: plagioclase; Chl: chlorite; Qz: quartz.

Table 3: Measurement of hydrothermal alteration intensity.

No	Mineral (%)								Tot (p)	Tot (s)	AI
	Qz (p)	Qz (s)	Pl	Opq	Px	Hb	Chl	Cly			
1		5.67		3.83				90.50	3.83	96.17	High
2	1.30			5.00				93.70	6.30	93.70	High
3				6.50				93.50	6.50	93.50	High
4	1.53		2.25	5.42			6.95	83.85	9.20	90.80	High
5	4.08		2.67	3.17				90.08	9.92	90.08	High
6			8.50	2.67			8.33	80.50	11.17	88.83	High
7	1.83			10.50				87.67	12.33	87.67	High
8		4.75	0.83	12.25				82.17	13.08	86.92	High
9		7.50	8.58	4.58				79.34	13.16	86.84	High
10		8.08	2.50	17.23				72.19	19.73	80.27	High
11			11.17	14.75				74.08	25.92	74.08	High
12		8.67	9.25	18.00				64.08	27.25	72.75	High
13		9.20	24.70	5.50				60.60	30.20	69.80	High
14			26.30	7.80				65.90	34.10	65.90	High
15		2.25	42.57	2.92	2.44	10.32		39.50	58.25	41.75	Moderate
16			65.71	1.00	4.50	9.87		18.92	81.08	18.92	Moderate
17			71.40	1.25	2.33	10.60		14.42	85.58	14.42	Moderate
18	1.25		76.50	2.00	1.20	10.30		8.75	91.25	8.75	Weak
19			81.44	0.08	2.30	8.60		7.58	92.42	7.58	Weak
20	0.67		63.00	4.58	7.00	17.92		6.83	93.17	6.83	Weak

Qz (p) = primary quartz, Qz (s) = secondary quartz, Pl = plagioclase, Px = pyroxene, Opq = opaque mineral, Chl = chlorite, and Cly = clay mineral; Tot (p) = total of primary minerals, Tot (s) = total of secondary minerals, AI = Alteration intensity according to Gillis *et al.* (2014).

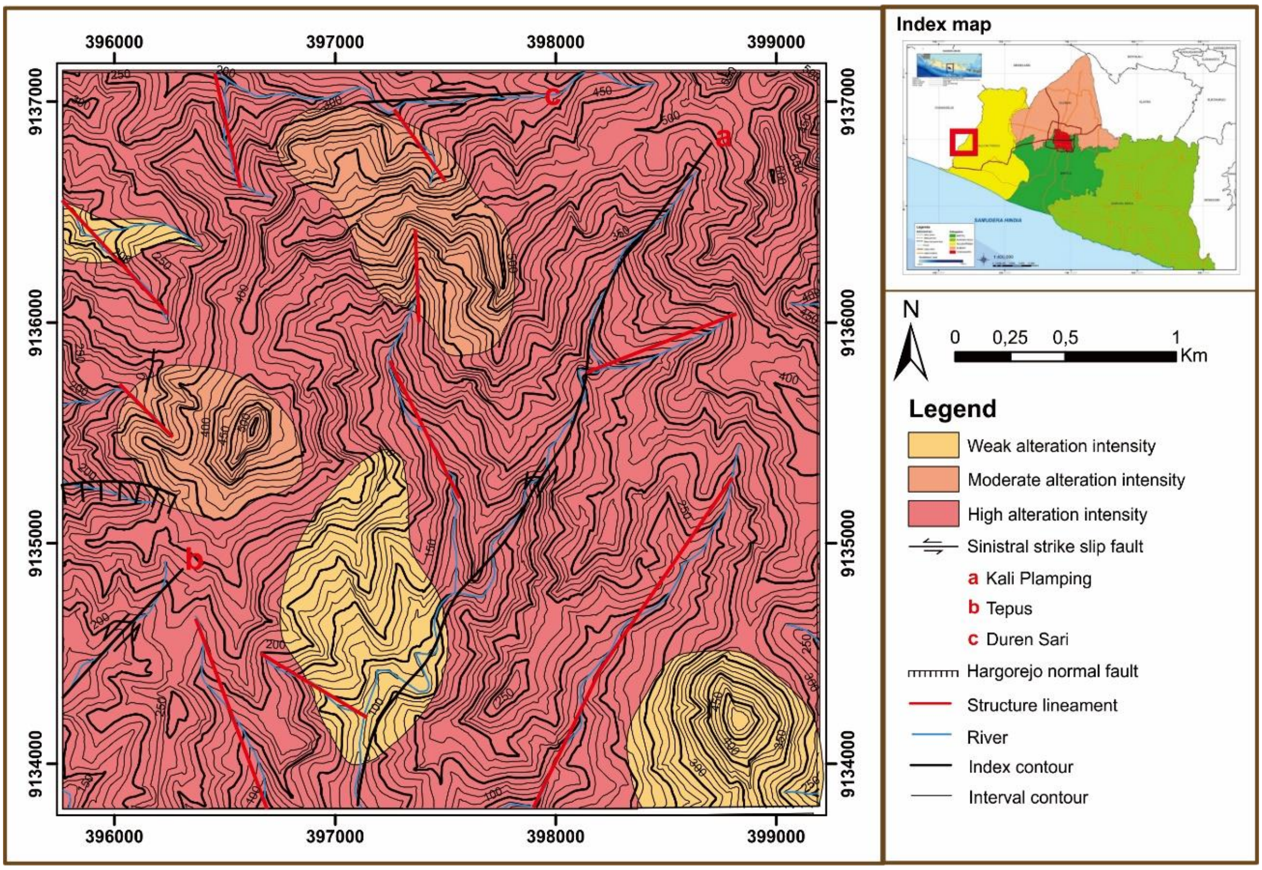

Figure 9: Map of hydrothermal alteration intensity.

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