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Mineralogical and Geochemical Control of Altered Andesitic Tuff upon Debris Slide Occurences at Pelangan Area, Southern Mountain of Lombok Island, Indonesia

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ABSTRACT. Debris slides were recently found in the Pelangan area at Southern Mountain of Lombok Island, Indonesia. Pelangan is well known as the gold mineralization and hydrothermal alteration area. This study is aimed to identify the mineralogy and geochemistry of altered andesitic tuff that controlled slope instability and induced debris slides. For this purpose, it is necessary to prepare the field observation and laboratory analyses. Landslide inventory reveals that the Pelangan debris slides mostly occur in altered andesitic tuff. Based on the outcrop observations in the field, andesitic tuff found around the Pelangan debris slides have been altered in general. The strong intensity of alteration developed by hydrothermal alteration in this study area produces large amount of clay minerals especially montmorillonite, kaolinite, and illite. The abundance of those clay minerals reflect the intermediate argillic alteration. Montmorillonite is a type of clay mineral that easily swells at wet condition and easily shrinkages at dry condition. Swelling of clay mineral destroys intersheet and interlayer bonds, and reduces shear strength. The presence of clay minerals in the altered andesitic tuff of intermediate argillic zone can be considered as one of the factors that induced to the Pelangan debris slides. Further studies on geotechnical and slope stability analysis of the landslide area are crucial to be done for better understanding of the characteristics of the altered rocks inducing hazardous landslides.

Keywords: Clay mineral · Shear strength · Hydrothermal alteration · Debris slide · Lombok Island · Indonesia.

1 INTRODUCTION

Landslide is one of the most common types of natural disaster in tropical countries such as Indonesia, especially on the mountainous and hilly terrain with complex geological condition. Geology, topography, slope hydrology, material properties, climate, landuse condition, infiltration, seismicity, and human activity are several factors which significantly affect landslides (Abramson *et al.*, 1996, Karnawati, 2005, Hardiyatmo, 2006). According to Cruden and Varnes (1993) after Abramson *et al.* (1996) there are five main types of landslide, namely fall, topple, slide, spread, and flow. The first two types are features frequently associated with rock slopes, whereas the latter three are related to soil slopes (Abramson *et al.*, 1996).

Lombok Island is one of areas in Indonesia that experiences landslides. Most landslides frequently occur in areas intensively suffered by mineralization and hydrothermal alteration including Pelangan area at Southern Mountain of Lombok Island. The studied landslide is situated in Pelangan area, Sekotong District, West Lombok, in the southwest part of Lombok Island, Indonesia. Geographically, this area is located in zone 50 S UTM, from 381000 mE –

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386000 mE and 9024000 mN – 9032000 mN, having 40 km² area (Figure 1). The major town close to the study area is Mataram, 54 km to the southwest. Pelangan area is characterized by strongly hydrothermal altered rocks, flat to very steep slopes, complex geological structures, low intensity rainfall, and less density vegetation. This area has different morphologies that the slope degree varies from 0° to 88° and the elevation varies from 0 to 394 meters above sea level. The moderate to very steep slope (15° - 88°) occupy 71,59% of the total area, whereas 28,41% is flat to gentle slope (less than 15°). This condition is prone to landslide.

Winarti *et al.* (2016a) investigated landslides at Pelangan, Sekotong, in West Lombok. Rock falls, debris slides, and a creep have been recognized. Debris slides were the most frequent landslides. These landslides occuring on the periode of September 2013 to January 2014. Debris slide is a down-slope movement of a mass of soil, or soil and rock fragments, moving as a unit or a number of units along a steeply dipping planar surface (Hunt, 2007). In the Pelangan area, the debris slides have close relationship with hydrothermal alteration. The hydrothermal alteration produced clay minerals and reduced the shear strength of rocks. Consequently, it tend to landslide in Pelangan area.

Furthermore, there is no advance studies that describes the mineralogical and geochemical control of altered andesitic tuff upon Pelangan debris slide occurrences. Therefore, this paper focuses on identifying mineralogical and geochemical characteristics of altered andesitic tuff that would be potentially reducted the shear strength and induced the debris slide occurrences at Pelangan area.

2 METHODS

This study was conducted by literature search, field observation, laboratory work, and analyses. Field observation includes landslide inventory, surface geological mapping, hydrothermal alteration mapping, and sampling of altered andesitic tuff. Laboratory work includes petrography, X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and X-Ray Fluorescene (XRF) analyses of a total of 36 samples. Petrography and XRD analyses were conducted at Department of Geological Engineering, Faculty of Engineering, Gadjah Mada University, whereas SEM and XRF analyses were carried out in the tekMIRA laboratory of Research and Development Centre for Mineral and Coal Technology, Bandung, Indonesia.

3 RESULTS AND DISCUSSION

Geology

Lombok Island is located in the central part of the Sunda-Banda magmatic arc. This magmatic arc is a result of three major tectonic plates convergent between the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate in late-Miocene (Hamilton, 1979). Physiographically, Lombok Island can be differentiated into three geologic terrains, namely Northern Mountain Zone, Southern Mountain Zone, and flat terrain in the middle part of the island. Tertiary rocks are exposed in the Southern Mountain Zone.

The regional stratigraphy of the study area comprises the volcanic and sedimentary rocks, which is of Late Oligocene to Late Miocene (Suratno, 1994). The oldest rock unit in this region is Pengulung Formation (Tomp) which composed of breccia, lava, tuff, and limestone lenses containing of sulphide minerals and quartz veins. This formation interfingering by the Kawangan Formation (Tomk), it consists of sandstone, claystone, and breccia. Both of those formations were cross-cut by Middle Miocene andesite porphyry, diorite, and dacite intrusions. The intrusions produces ore mineralization and hydrothermal alteration. The Pengulung and Kawangan Formation unconformably overlain by Late Miocene calcarenite limestone locally crystalized of Ekas Formation (Tme). The youngest deposit of the Pelangan area which is Holocene sedimentation (Qa) has been represented by alluvium and coral reef deposits on coastal and lowland plains.

The stratigraphy of the Pelangan area is consist of andesitic breccia, andesitic tuff, andesite porphyry, diorite, dacite, limestone, and alluvium (Figure 3). Andesitic breccia is the oldest rock in the Pelangan area. Meanwhile, andesitic tuff is the most widespread covered rock and occupied 63,12% of the total study area. Andesitic breccia and andesitic tuff are regarded as the member rock of Pengulung Formation. These rocks suffers intensive hydrothermal alteration. The andesite porphyry,

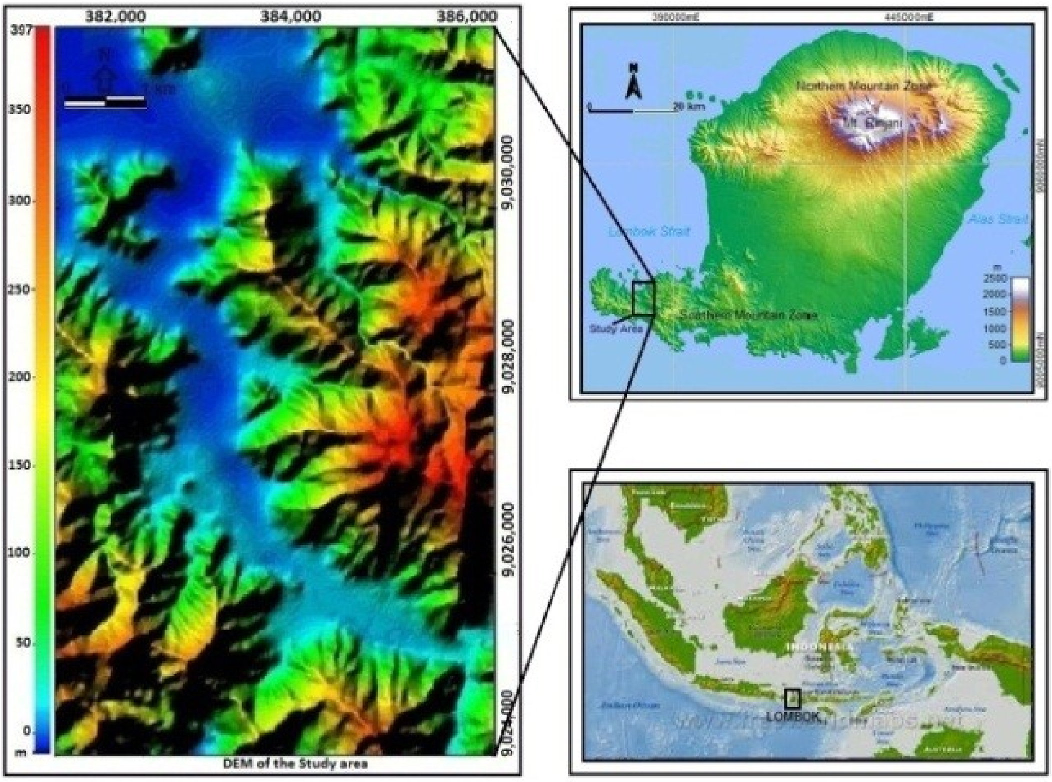

Figure 1: Location map of Pelangan area, Sekotong District, West Lombok, Indonesia.

diorite, and dacite intrusions are interpreted to be source of mineralization and hydrothermal alteration process. Many landslides and vulnerable sites are common to be found in the Pelangan area which composed of hydrothermal altered rocks of Pengulung Formation. According to the AHP analysis, hydrothermal alteration and slope inclination are the most important factor controlling landslide occurrences within Pelangan area (Winarti *et al.*, 2016b).

Hydrothermal alteration

Pelangan has experienced landslides. The landslides generally occur in hydrothermal altered rocks of Pengulung Formation. The andesite porphyry, diorite, and dacite intrusions are interpreted as source of mineralization and hydrothermal alteration process. Andesitic breccia and andesitic tuff were cross-cut by those intrusions produced hydrothermal alteration zones. The types of hydrothermal alteration are well exposed. In this study, the mineral assemblages of Evans (1993) are applied to clasify the hydrothermal alteration type. On the basis of mineral assemblages, two main alteration zones are identified including propylitic and intermediate argillic alteration (Figure **??** and Table 1). Propylitic alteration characterized by chlorite, epidote, albite, dolomite, calcite, ankerite, and accessories minerals include montmorillonite, illite, quartz, pyrite, and magnetite, whereas intermediate argillic alteration typified by montmorillonite, kaolinite, and accessories minerals include illite, quartz, pyrite, and magnetite. The debris slides occured in Pelangan area is related to intermediate argillic alteration (S04, S07, S08, S12, S13, S15, and S16).

Mineralogy

Totally seven debris slides were recognized in the study area. Fieldwork observation shows that the Pelangan debris slides mostly occured in altered andesitic tuff (Figure 4). In megascopic, the altered andesitic tuff is greenish white to yellowish white in colour, very fine to very coarse grain size (0.003 to 64 mm), and composed of andesite, quartz, biotite, clay, and pyrite. Generally, the altered andesitic tuff can easily crushed by hand. Petrographic analysis have done on seven samples of altered andesitic tuff that represent each debris slides. Results show that the altered andesitic tuff consists of plagioclase (10%), clinopyroxene (5%), quartz (10-20%), and secondary minerals (80-95%)

Table 1: Mineral assemblages of hydrothermal alteration zone in the Pelangan area.

Zone	Location	Mineral Assemblage	
		Key Mineral	**Accessory Mineral**
Propylitic	S01	Chlorite, epidote, albite, calcite, ankerite	Montmorillonite, illite, quartz, pyrite, magnetite
	S05	Chlorite, epidote, calcite, ankerite, dolomite	Illite, quartz, pyrite, magnetite
	S11	Chlorite, epidote, albite, calcite, dolomite	Montmorillonite, illite, quartz, pyrite, magnetite
	S17	Chlorite, albite, calcite	Montmorillonite, illite, quartz
Intermediate Argillic	S04	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S07	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S08	Montmorillonite, kaolinite	Illite, quartz, pyrite
	S09	Montmorillonite, kaolinite	Illite, quartz, pyrite
	S10	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S12	Montmorillonite, kaolinite	Illite, quartz, pyrite
	S13	Montmorillonite, kaolinite	Illite, quartz, pyrite
	S15	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S16	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S18	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite
	S20	Montmorillonite, kaolinite	Illite, quartz, pyrite, magnetite

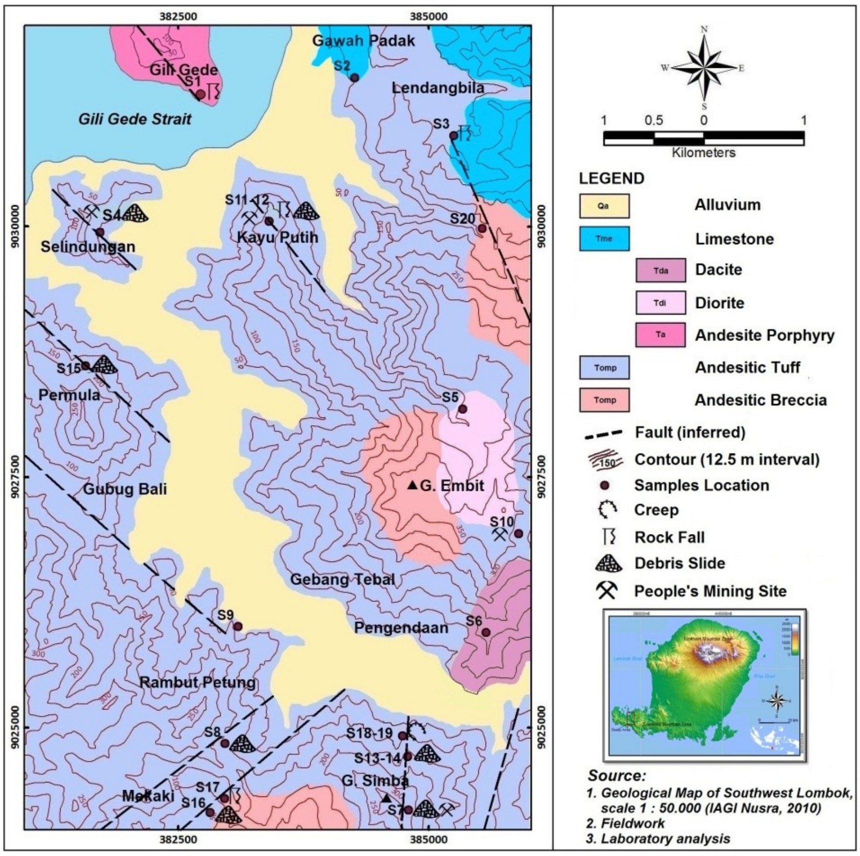

Figure 2: Geological map of Pelangan area (modified from Suratno, 1994, fieldwork observation).

include chlorite, smectite, muscovite, opaque minerals, and iron oxides with size less than 0.1 to 1.0 mm (Figure 5). Based on the classification of alteration intensity of Kingston Morrison (1996) as shown in Table 2, this altered andesitic tuff is classified as strongly altered (more than 75%). SEM images of altered andesitic tuff shows that kaolinite is found in the form of hexagonal and rolled plate, and quartz exist in the form of flake, cube, and rossete (Figure 6). Based on XRD analysis, seven samples of the altered andesitic tuff contain montmorillonite, kaolinite, illite, quartz, pyrite, and magnetite (Figure 7). According to Evans (1993) those minerals are well developed in intermediate argillic alteration.

Geochemistry

Whole-rock geochemistry data were assessed to determine chemical changes associated with the alteration intensity. In this study, major element compositions of the altered andesitic tuff samples were analysed by XRF method. Results of geochemical analyses of altered andesitic tuff are reported in Table 3 and Figure 8. The SiO_2 contents range from 56.68 to 85.11 wt.%, with an average of 67.399 wt.%, and the Al_2O_3 contents range from 8.83 to 22.66 wt.%, averaging 16.126 wt.%. The Fe_2O_3 contents range from 0.97 to 14.62 wt.%, averaging 6.446 wt.%, and the MnO concentrations range from 0.003 to 0.049 wt.%, with an average of 0.014 wt.%. The MgO, CaO, Na_2O, and K_2O contents ranges from 0.029 to 1.42 wt.%, 0.04 to 0.26 wt.%, 0.018 to 0.26 wt.%, and 0.44 to 6.14 wt.%, averaging 0.636 wt.%, 0.117 wt.%, 0.086 wt.%, and 3.006 wt.%, respectively. The TiO_2 concentrations range from 0.22 to 1.04 wt% and averages 0.67 wt%. The P_2O_5 content ranges between 0.013 to 0.18 wt.% and averages 0.089 wt.%, whereas LOI concentrations vary from 2.48 to 8.04 wt.%, with and average 5.296 wt.%. The AI concentrations range from 88.324 to 97.574 and averages 93.688.

Ishikawa *et al.* (1976) quoted by Gifkins (2001) and Large *et al.* (2001) could be used to study alteration intensity of altered volcanic and sedimentary rocks. The alteration intensity (AI) is given by:

$$AI = \frac{100\,(K_2O + MgO)}{(K_2O + MgO + Na_2O + CaO)} \quad (1)$$

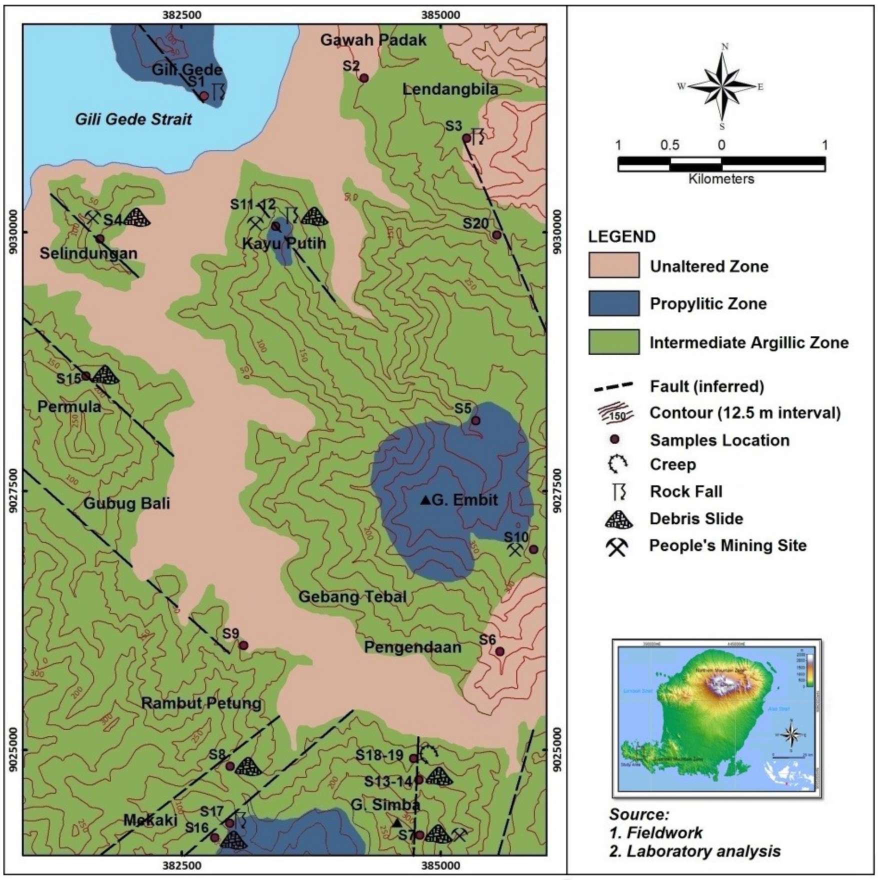

Figure 3: Hydrothermal alteration zone map of Pelangan area.

Figure 4: Outcrop of altered andestic tuff, located on the Pelangan debris slide S8 (left), S13 (middle), and S16 (right).

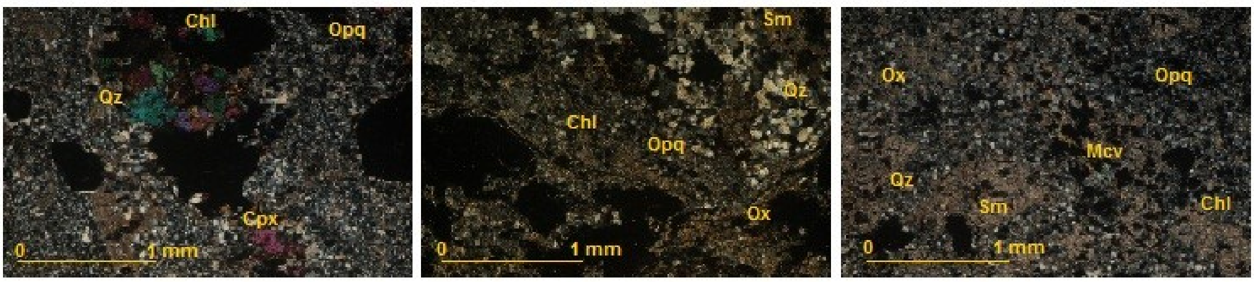

Figure 5: Optical photomicrographs of altered andesitic tuff showing the presence of clinopyroxene (Cpx), quartz (Qz), opaque mineral (Opq), chlorite (Chl), smectite (Sm), iron oxides (Ox), and muscovite (Mcv).

Table 2: Classification of alteration intensity (Kingston Morrison, 1996).

Intensity of alteration	Percentage of secondary mineral
Unaltered	No secondary minerals
Weakly altered	Less than 25 volume % secondary minerals
Moderately altered	25-75 volume % secondary minerals
Strongly altered	More than 75 volume % secondary minerals
Intensely altered	Completely altered (except for primary quartz, zircon, and apatite), but primary textures remain visible
Totally altered	Completely altered (except for primary quartz, zircon, and apatite), but primary textures loss

Figure 6: SEM images of altered andesitic tuff showing the presence of hexagonal plate of kaolinite and rossete of quartz (left), flake of kaolinite (middle), and flake of quartz and rolled plate of kaolinite (right).

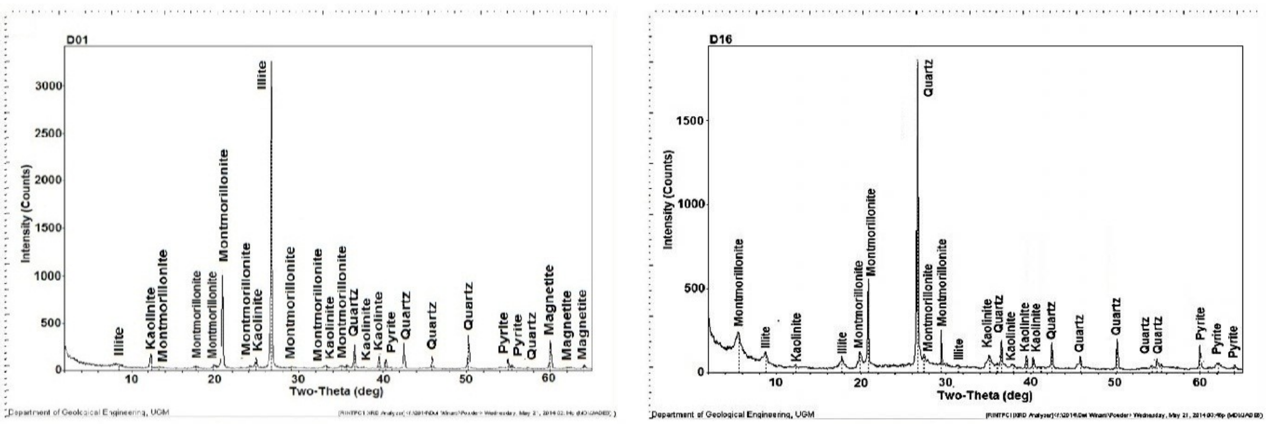

Figure 7: X-Ray Diffraction patterns of altered andesitic tuff from the Pelangan area.

Table 3: Geochemical analyses of altered andesitic tuff for calculating hydrothermal alteration intensity (major elements in weight % and determined by XRF).

Sample	S04/F01	S07/F11	S08/F09	S12/F10	S13/F13	S15/F03	S16/F16	Average
SiO_2	85.110	63.070	59.650	56.720	56.680	80.510	70.050	67.399
Al_2O_3	10.170	22.660	21.650	16.740	20.050	8.830	12.780	16.126
Fe_2O_3	1.380	0.970	6.370	14.620	8.950	4.300	8.530	6.446
MnO	0.003	0.019	0.007	0.008	0.049	0.007	0.008	0.014
MgO	0.029	1.100	0.430	0.470	1.420	0.460	0.540	0.636
CaO	0.044	0.040	0.160	0.260	0.160	0.065	0.087	0.117
Na_2O	0.018	0.140	0.019	0.092	0.260	0.030	0.046	0.086
K_2O	0.440	6.140	3.280	2.580	3.310	2.220	3.070	3.006
TiO_2	0.220	0.010	1.040	0.790	0.780	0.360	0.490	0.670
P_2O_5	0.045	0.013	0.110	0.150	0.180	0.063	0.063	0.089
LOI	2.480	4.770	7.160	7.420	8.040	2.950	4.250	5,296
Total	99.939	99.932	99.876	99.850	99.879	99.795	99.914	99.884
AI	88.324	97.574	95.397	89.653	91.845	96.577	96.447	93.688

LOI = Loss on Ignition, AI = Alteration intensity = $100x(K_2O+MgO)/(K_2O+MgO+Na_2O+CaO)$

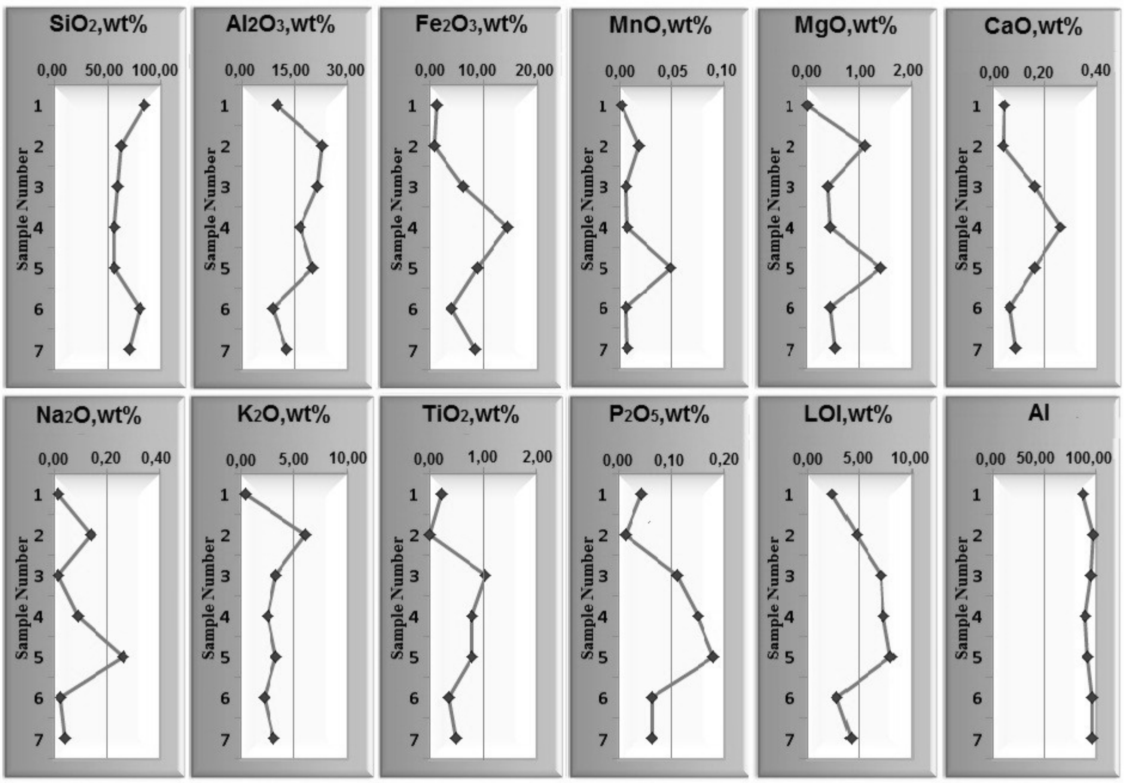

Figure 8: Vertical variations in the geochemical composition and alteration intensity of altered andesitic tuff.

Table 4: Alteration intensity classification (Ishikawa et al., 1976 after Gifkins, 2001).

Intensity of alteration	Values of chemical change
Unaltered	< 25
Weakly altered	25 - 70
Strongly altered	> 70

To classify alteration intensity, this study adopted the classification of alteration intensity (AI) based on chemical changes as shown in Table 4.

The alteration intensity for the majority of the altered andesitic tuff vary from 88.324 to 97.574. Based on the classification of alteration intensity (Table 4), the altered andesitic tuff in the intermediate argillic zone is classified as strongly altered.

Implication for debris slide

Pelangan area, southwestern part of Lombok Island, is well known as the area of gold mineralization and hydrothermal alteration. The study area is consisted of Tertiary volcanic and sedimentary rocks of Pengulung Formation (Tomp) that altered due to hydrothermal alteration. The hydrothermal altered rocks consists of andesitic breccia, andesitic tuff, andesite porphyry, and diorite. Most of the landslides frequently occured in this area is debris slides. And it is mostly due to the altered andesitic tuff.

On the basis of mineral assemblages (Evans, 1993), hydrothermal alteration in Pelangan area was developed by two main alteration zones consisting of propylitic and intermediate argillic alteration. The propylitic alteration zone is developed in the andesitic breccia, andesitic tuff, andesite porphyry, and diorite, whereas the intermediate argillic zone is composed of andesitic breccia and andesitic tuff. The area within intermediate argillic alteration is subjected to an intensive debris slides occurences in the study area. Applying classification of alteration intensity based on percentage of secondary minerals of Kingston Morrison (1996), and chemical changes of Ishikawa *et al.* (1976) quoted by Gifkins (2001), the altered andesitic tuff in the intermediate argillic zone is classified as strongly altered.

The strong intensity of alteration developed by hydrothermal alteration in this study area produces large amount of clay minerals especially montmorillonite and kaolinite, with few illite, quartz, pyrite, and magnetite. Montmorillonite is a type of clay mineral that easily swells at wet condition and easily shrinkages at dry condition (Pusch and Yong, 2006). Swelling of clay mineral destroys intersheet and interlayer bonds, and consequently the shear strength of altered andesitic tuff tend to decrease and prone to landslide. The presence of abundant montmorillonite in the altered andesitic tuff of intermediate argillic zone can be considered as one of the factors that induced to the Pelangan debris slides.

4 CONCLUSION

The Pelangan debris slides generally occur in altered andesitic tuff of Pengulung Formation (Tomp). On the basis of mineral assemblages, percentage of secondary minerals, and chemical changes, and by comparison with existing models of Evans (1993), Kingston Morisson (1996) and Ishikawa et al. (1976) quoted by Gifkins (2001), respectively, it concluded that the debris slides occured in the study area is related to montmorillonite as a product of intermediate argillic alteration with strong intensity. The presence of abundant montmorillonite in the altered andesitic tuff is considered as one of factors that induced the debris slide, because it has the property of swelling and reducing shear strength at wet condition.

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