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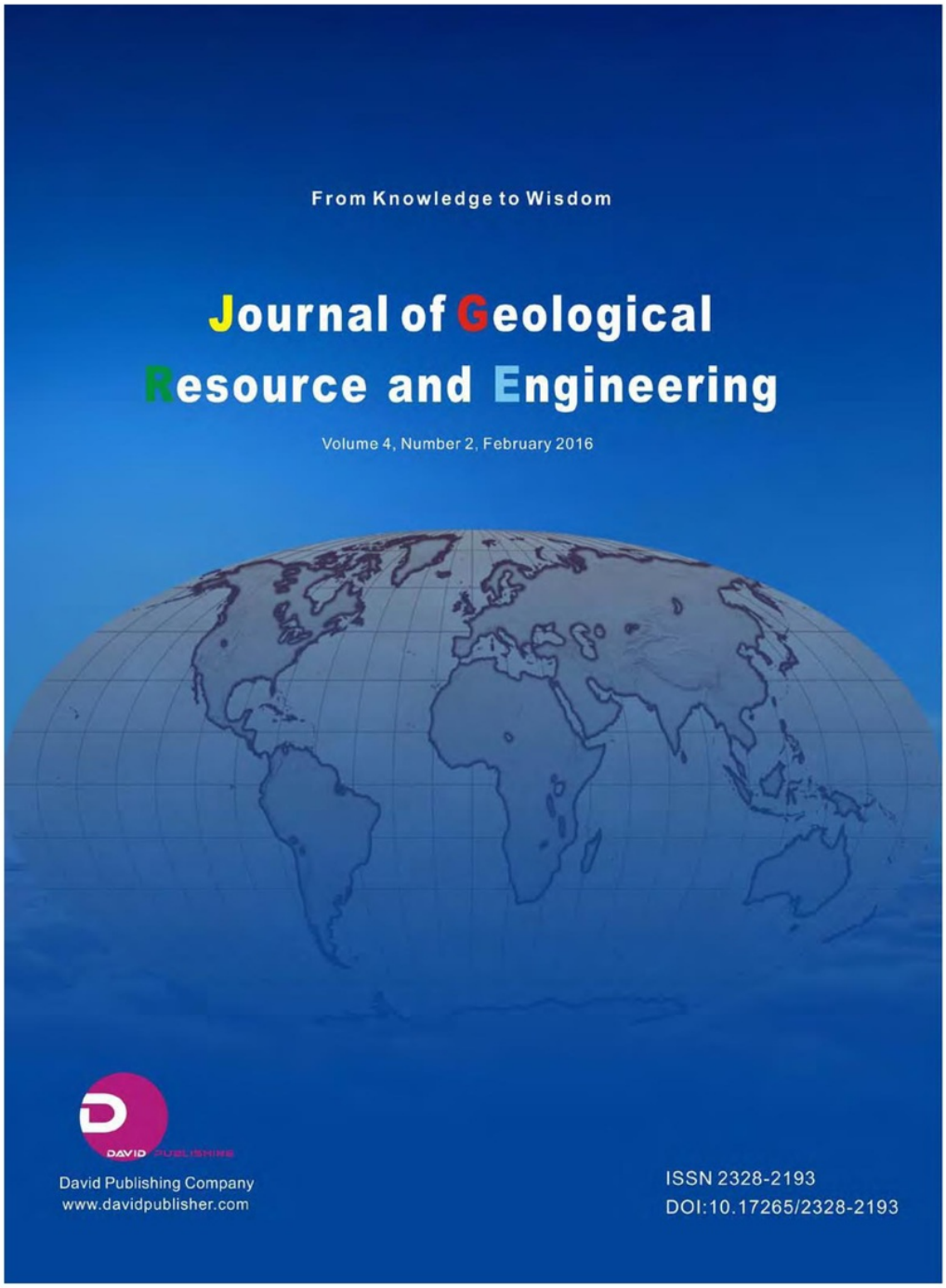
by Sari B Kusumayudha

Submission date: 23-Jan-2018 09:39AM (UTC+0700)
Submission ID: 905604360
File name: 8._JGRE_tectonic_environment_and_landslide.pdf (1,003.8K)
Word count: 5486
Character count: 30723


From Knowledge to Wisdom
Journal of Geological Resource and Engineering
Volume 4, Number 2, February 2016
David Publishing Company
www.davidpublisher.com
ISSN 2328-2193
DOI:10.17265/2328-2193

Journal of Geological Resource and Engineering

Volume 4, Number 2, February 2016 (Serial Number 11)

David Publishing Company
www.davidpublisher.com
Publishing

Publication Information:
Journal of Geological Resource and Engineering is published monthly in hard copy (ISSN 2328-2193) by David Publishing Company located at 616 Corporate Way, Suite 2-4876 Valley Cottage, NY 10989, USA.

Aims and Scope:
Journal of Geological Resource and Engineering, a monthly professional academic journal. Its aim is to achieve the advancement and dissemination of information in the fields of geology, geotechnics, geological engineering, geological resource and so on. And articles interpreting successful policies, programs or cases are also welcome.

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Editorial Office:
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Tel: 1-323-984-7526, 323-410-1082, 607-4416220; Fax: 1-323-984-7374, 323-908-0457
E-mail: geology@davidpublishing.com, geology_davidpublishing@hotmail.com

Abstracted / Indexed in:
Chinese Database of CEPS, CNKI, China
Chinese Scientific Journals Database, VIP Corporation, Chongqing, China
CiteFactor (USA), Ulrich's International Periodicals Directory, USA
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Subscription Information:
Price (per year): Print $520; Online $360; Print and Online $680
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Tel: 1-323-984-7526, 323-410-1082, 607-4416220; Fax: 1-323-984-7374, 323-908-0457
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Journal of Geological Resource and Engineering

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Contents

4

Correlation between Tectonic Environment and Chracteristics of Mass Movement (Landslides): A Case Study from Java, Indonesia

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Abstract: In Central Java and Yogyakarta Special Region, there are several zones, which potential of landslide disaster. The zones are in general located at uplifted and or folded mountains, such as North Serayu Mountains, South Serayu Mountains, Menoreh Mountains, Southern Mountains and slopes of young volcanic area, including Ungaran-Merbabu-Merapi area, and Slamet-Sundoro-Sumbing area. Besides morphology, another main factor influencing vulnerability of the terrain is physical properties of the composing lithology. The geologic formations in the study area are predominantly composed of clayey and volcanic rocks. The cohesion force of clayey rock ranges 0.4 – 0.7 kg/cm2, the internal friction angle ranges 20° – 35°, while the cohesion force of volcanic rock (weathered) ranges 0.25 – 0.27 kg/cm2, and the friction angle ranges 20° – 35°. In general, rocks occupying the area are collectively dissected by joints and active faults, with soil of more than 5 m thick. Local rainfall belongs to high category (>2500 mm/y). However, landslides that occur in each physiographic zone mentioned above show different characterizations.

Key words: tectonic environment, mass movement characteristic

Introduction

Indonesia is a country consisting of about 17,000 islands, controlled by dynamic tectonic environment, generating it rich of active volcanoes, potential of earthquake, and plenty of uplifted mountainous area. In fact, mountainous areas with their slopes mostly play as the main factor for mass movement occurrence. Fig. 1 shows the study area.

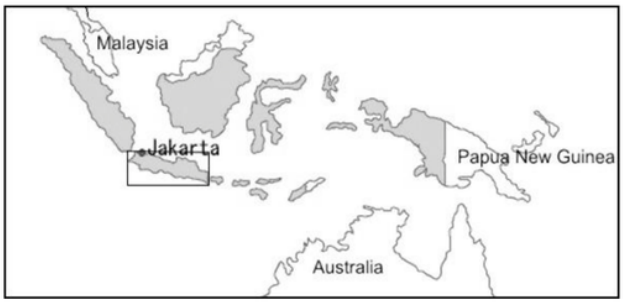


Fig. 1 Indonesia Archipelago and case study area

At some areas of Indonesia, such as North Sumatra, West Sumatra, Nias Island, North Sulawesi, West Java, Central Java, Yogyakarta Special Region, Sangihe, and Nusa Tenggara, landslides occur almost every year in the rainy season, sometimes causes loss of life and property. Places in Java where landslides mostly happen including Bogor and Cianjur regencies of West Java, Banjar Negara, Magelang, Kebumen, and Purworejo regencies of Central Java, and Kulon Progo Regency of Yogyakarta Special Region.

Objectives of the study are to analyze and develop a model on the influence of tectonic environment and physiographic zones to mass movement characteristics. The study was done based on literatures reviews, assessments and analyses, and field surveying.

Tectonic Environments

Indonesia archipelago is formed by the collision among Eurasian continental plate, India - Australia oceanic plate, and Pacific oceanic plate (Fig2). The implication of the plates meeting in Indonesia is formations of active volcanic chains, folded mountain lines, vigorous faults and tectonic zones.

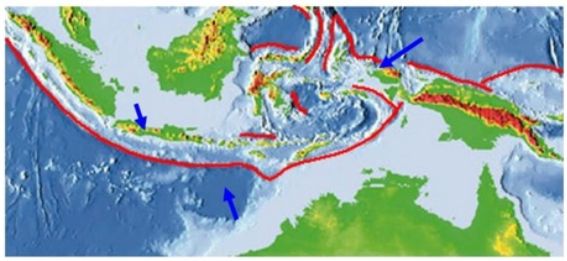


Fig. 2 Tectonic Setting of Indonesia Archipelago.
Red line: plate boundary; blue arrow: plate movement

In the western part of Indonesia, the interaction of Eurasia and India-Australia plates brings about subduction of the oceanic plate beneath the continental plate [3]. In a certain depth, when the environment related to temperature and pressure is condusive, there will be partial melting of the subducted oceanic plate producing magma. Due to diaphiric force and density difference between the magma and surrounding material, the new magma arise to reach earth surface forming active volcanoes. In general the tectonic component of West Indonesia area includes trench, accreted wedge, fore arc basin, volcanic arc, and back arc basin. Figure 3 sows tectonic component of western Indonesia.

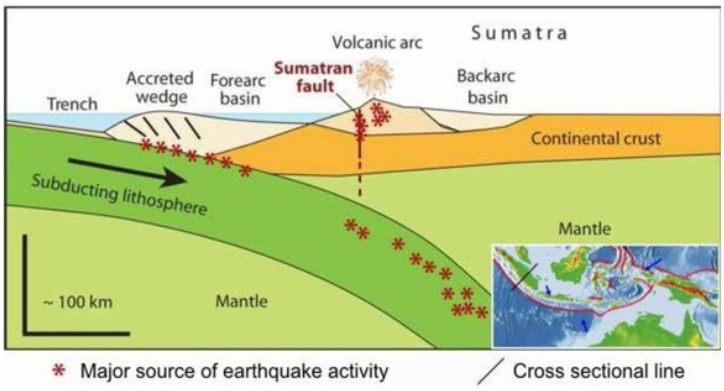


Fig. 3 Tectonic Component of West Indonesia [15]

In spite of tectonically active, Indonesia has wet Tropical climate with relatively high rain fall, approximately more than 250 mm/year [5], [7]. This condition is very conducive for mass movement occurrence, due to physical factors such as mountainous areas with steep slopes, intensive weathering to create thick soil, and frequent tectonic earthquakes. Mass movement occurrences in Java Island are displayed in Table 1.

Table 1 Mass Movements of Java, 2000 – 2015 [1, 5, 7, 8, 9, 11, 13, 14, 15, 16 ,17]

Year	Type	Location (Village/District)	Regency/Province	Casualties
2000	Landslide	Kemanukan / Bagelen District	Purworejo/ Central Java	54 died, houses, properties
2000	Landslide	Penusupan / Sruweng District	Kebumen/ Central Java	9 died, 4 houses damage
2001	Subsidence and creep	Seling / Sadang District	Kebumen/ Central Java	12 houses damage
2001	Landslide	Kedungrong / Samigaluh District	Kulonprogo/ Yogyakarta	8 died, 5 houses damage
2001	Soil & debris slide	Cipanas	Lebak / Banten	12 died, houses damage
2002	Landslide	Suwidak / Wanayasa District	Banjar Negara/ Central Java	8 houses damage, 51 people evacuated
2006	Large landslide	Gunungraja, Sijeruk, Banjarmangu District	Banjarnegara/ Central Java	76 died, tens houses damage
2006	Landslide	Ciloto/ Pacet District	Cianjur/ West Java	Road damage
2007	Large landslide	Margorejo, Jatiyoso District	Karanganyar/ Central Java	62 died, economic lost reaches 137 billions rupiah.
2011	Landslide	Dusun Mundon, Tancep Village, Ngawen District	Gunung Kidul / Yogyakarta	1 died, 4 houses damage
2012	Soil slide, mud flow	Soreang, Ciwidey	Bandung/ West Java	1 died, 100 m road damage
2013	Landslide	Semin village, Semin District	Gunung Kidul Regency/ Yogyakarta	2 houses damage
2014	Landslide	Jemblung Village, Sampang Karangkobar District	Banjar Negara Regency / Central Java	51 died, 35 houses damage
2015	Landslide	Dusun Ngroto, Pendoworejo Girimulyo District	Kulonprogo/ Yogyakarta	1 school building damage

Geologic Condition and Mass Movement Characteristic of Java

As other islands of western Indonesia, tectonic components of Java Island include volcanic arc and back arc basin. Recent geologic configuration of Indonesia has been under the responsibility of tectonic regime since Tertiary to Quaternary periods [4]. The tectonic regime controlling geologic condition of western Indonesia, especially Java Island also can be divided into Tertiary and Quaternary periods. Tectonic of Tertiary period created some volcanic arcs and back arc basins. Back arc basins of Tertiary tectonic period have already

uplifted, slightly folded, faulted, and exposed as mountainous areas. Lithology composing this arc is generally classic sedimentary rocks of relatively fine grain sized of clay, silt, sand to coarse sand, and limestone. As they exist in Java, there is back arc basin environment that associated with magmatic activity of Quaternary period marked by the existence of igneous rocks; and back arc basin that is not associated with igneous rocks. On the other hand the volcanic arc of Tertiary period exists as volcanic complex environment, composed of intrusive, extrusive igneous rocks, and pyroclastics as well as epiclastic breccias [10].

On going Quaternary tectonic creates modern volcanic arc with active volcanoes, such as Mount Talang, Mount Sinabung of Sumatra, Mount Galunggung, Mount Gede, Mount Slamet, Mount Merapi, Mount Semeru, and Mount Bromo of Java. Both fore arc and back arc basins of resent tectonic regime are not uplifted and exposed yet. The tectonic environment and physiographic zones of western Indonesia especially Java can be described in Table 2.

Table 2 Tectonic Environment of Physiographic Zones in Java Island

Epoch	Tectonic Environment
Tertiary (old)	Volcanic Arc Back Arc: - With magmatic activity association - Without magmatic activity
Quaternary (new)	Volcanic Arc

There are several mountainous areas in Java Island where mass movements often take place, such as North Serayu Mountains, South Serayu Mountains, Menoreh Hills, and Southern Mountains [7]. Map showing distribution of the physiographic zones in Java has been figured by van Bemmelen (1949), as can be seen in Fig. 4.

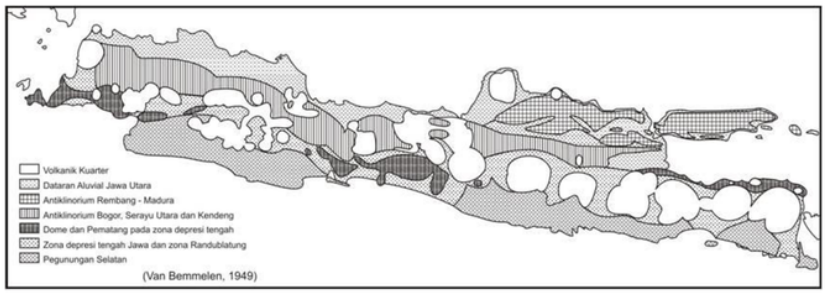


Fig.4 Physiographic Map expressing the Geologic Environments of Java Island [12]

1. Tertiary Volcanic Arc Zones

Tertiary Volcanic Arc of Java Island is represented by several physiographic zones, namely Kumbang Zone of West Java, Menoreh Hills of Central Java, and Southern Mountains of West Java and East Java. In general they have been exposed since Early Pliocene to Pleistocene epoch [10]. In this discussion, the Tertiary Volcanic Arc Zone will be represented by Menoreh Hills and Southern Mountains.

1.1. Menoreh Hills

Examples of Tertiary Volcanic Arc in Java are Menoreh Hills and Southern Mountains. Menoreh Hills is a raised and further strongly denudated dome [12]. It shows hilly morphology with slopes inclination generally more than 40% or 20^o [11]. Rock constituent successively starting from the bottom is marl and sandstone of Eocene, volcanic breccias, and lava deposits; of Early Miocene; reefs limestone of middle Miocene; layered limestone, tuffaceous-calcareous sandstone of middle to late Miocene; and alluvial deposits. Faults pattern is relatively radial on the wings, while some ancient eruption centers are found at the top of the dome [12]. Volcanic rocks of Menoreh Hills are in general highly fractured and weathered, forming soil that the thickness can be more than 5 m to 10 m [7].

Mass movements occur in this area can be classified into landslide (soil slide / landslide). The boundary between fresh rock and soil usually plays as the sliding plane. Shape of the sliding plane is often not purely circular or planar, but rather a combination of both [5]. Their occurrence is always triggered by rain water that seep into soil to reaches the boundary between fresh rock and soil. Further it will extend pore water pressure, reducing the rock strength. Landslide generally happens with high speed, and or a combination of sliding and flowing, as happened in Kemanukan Purworejo [5], Panusupan village, and Ngelo, Purwodadi. The sketch of mass movement typology at Ngelo and Purwodadi villages is shown in Fig.5.

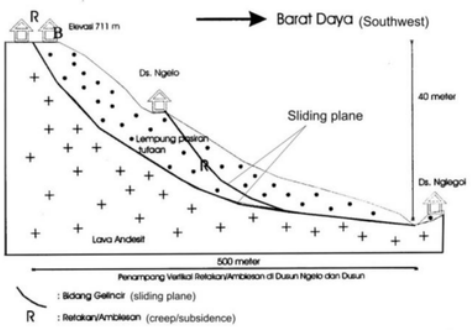


Fig. 5 Typology of Slope Movements in Ngelo and Purwodadi [5]

1.2. Southern Mountains

Southern Mountains of Java performs a chain of old volcanic complex, with its lineament relatively parallel to the length axis and the southern coast of the island. This mountain was the volcanic arc of Java trench, during Tertiary period [10]. Starting from the bottom to the upper parts, it comprises the Besole Group composed of volcanic breccias, sandstone and andesite lava, dacitic tuffs, sandstones, pumice, volcanic breccias, agglomerates and tuffaceous sandstones of Oligocene to Middle Miocene epoch. On the top, there is Wonosari Group consists of marl, calcareous sandstones, sandy limestones, calcarenite, marly-tuffaceous sandstones, bedded limestones, massive limestone and reef limestone of Middle Miocene to Late Pliocene epoch [10]. The youngest lithology of this zone is terrarosa,

alluvial deposits, and sediment of Mount Merapi. Due to the rain fall intensity that is relatively high, thick soil is commonly formed as the result of weathering process, with thickness ranges 0.3 m to 2 m.

Ground motion in the Southern Mountains is relatively not intensive to occur compared to that of Menoreh Hills. The mass involved in the movement is generally soil as the product of volcanic breccias weathering. Border of fresh rock and soil plays the role as the avalanches sliding plane can be a common thing in this area.

There was a landslide at River Widara, involving soil-rock that moved over the sliding plane in the form of marl layer. Even though rarely to occur, there is a planar gliding type of motion. This kind of mass movement happened in the south Patuk in the year 1995 [7]. In the year 2011 such a landslide happened at Ngawen District, Gunung Kidul Regency (Fig 6). Some mass movements in Patuk of Southern Mountains often affect the disturbance of Yogyakarta - Wonosari traffic.

Fig. 6 Landslide of Ngawen, Southern Mountains [13]

2. Tertiary Back Arc Zones

Back Arc Zones of Java Island is represented by Bogor Zone in the west, North and South Serayu Mountains in the middle part, and Rembang – Kendeng Zones in the east. The zones in general perform as folded mountainous and hilly areas, composed of clastic sedimentary rocks of fine to coarse grained, from clay to coarse sand. Geologic structures perform as syncline and anticline.

In the study area, the back arc basin environment can be differentiated between back arc associated with magmatic activity and back arc without magmatic activity.

2.1. Bogor Zone

Bogor zone is an anticlinoria with west-east fold axis. The anticlinoria core is composed of Miocene epoch rocks, while the wings are occupied by younger rocks of Pliocene - Pleistocene [2], consisting of sandstone, mudstone and breccias. There are some hypabisal intrusions, conglomerates and volcanic sediments, and limestone lenses [2]. In Middle Eocene-Oligocene epoch Bogor Basin was the front of magmatic arc, it changed into a basin behind the magmatic arc on Early Miocene-Pliocene epoch. [2].

Bogor is specified by very high rain falls, therefore weathering process is strongly control the existence of thick soil. Mass movement in this Zone generally occurs in the area

that geologically composed of volcanic formation, involving soil and debris of weathered rocks. The moving materials commonly develop from sliding to flowing, because the soil is very saturated by water in the rainy season [5]. This kind of mass movement happened in February 2001 at Cipanas District, Lebak Regency, Banten Province. In this incident, the material had been involved were thick soil of weathered rock, moved on the sliding plane of the boundary between the fresh rock and the soil, with high speed of movement [5].

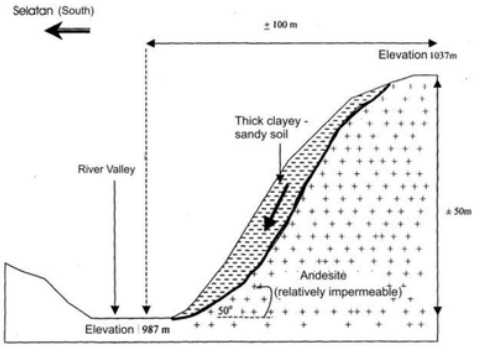


Fig.7 Typology of Mass Movement in Cipanas District, Lebak Regency, West Java [5]

2.2. North Serayu Mountains

North Serayu Mountains is located southward of the North Coast of Java. The mountains are strongly folded. In the west, the mountains are separated from Bogor Mountains by Mount Slamet volcano, and in the east, separated from Kendeng Ranges by Mount Ungaran volcano. Anticline, syncline, reverse as well as horizontal faults are often found in this area.

Lithology composing North Serayu Mountains can be grouped into two categories, namely clayey rocks and volcanic rocks. Clayey rock groups are composed of silty marly sandstone, interbedded of claystone and sandstones, shale and marl of Tertiary period. There also exist a group of volcanic rocks of Quaternary period consisting of breccias, agglomerates and lava of Jembangan formations. Volcanic group is conformably lies over the clayey group. The volcanic rocks of North Serayu Mountains are from the Quaternary tectonic period [6]. The clayey group is strongly folded, while the volcanic group in general is not folded, but only relatively low inclined (less than 15°) [6].

The volcanic rock group has a thickness of more than 100 m, with a thick soil (reaches 5m). Thick and heavy rock is resting on the sedimentary rock formation which is soft, plastic, and slippery in wet condition. Supported by the orographic terrain sloping to the south, it tends to create mass sliding, gliding, avalanches, subsidence, and creeping. Mount Telagalele, Mount Pawinihan, and Mount Lumbung, crept to the south [6]. The illustration showing various typologies of mass movements in North Serayu Mountains displays in Fig. 8.

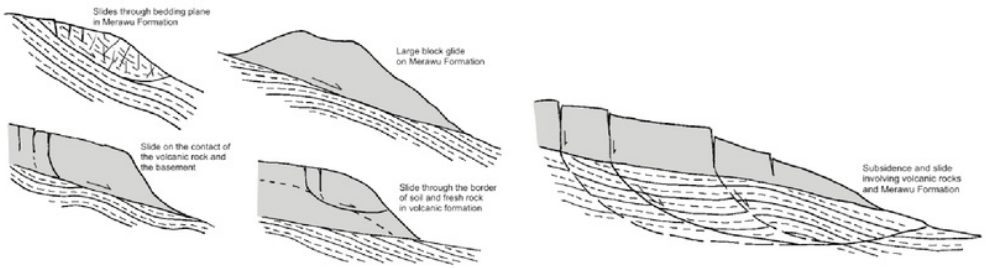


Fig. 8 Various typologies of mass movements in Karangkobar, Central Java [6]

In this area, not just volcanic rock that move, but the clay rock of Merawu formations also particularly prone to avalanches, as influenced by geological structure (bedding, joints, and faults). The type of motion that involves all of the formations among others is landslides, avalanches of debris, soil creep, land subsidence, and debris flow. Tectonic symptom in North Serayu Mountains is known as gravity tectonic [12], because it is influenced by gravitational force. Because it is expressed in the form of sliding and gliding of large-scale rock mass (body hills, mountains), then this phenomenon is also called gliding tectonic [6]. According to Van Bemmelen [12], the average velocity of creep is 24 cm to 40 cm every year.

In the year 2010, a large scale of landslide occur involving thick soil apart of Mount Pawinihan foot slope, killing tens people of Sijeruk village, Banjarmangu, Banjar Negara Regency. The type of mass movement is landslide with rotational movement. Such a similar accident was repeated to happen in the year 2014. In this moment mass which was sliding is soil of Mount Telagalele foot slope at Jemblung village. The accident belongs to land slide of circular plane failure and rotational movement, killing peoples of Karangkobar district, Banjar Negara Regency (Fig 9).

Fig. 9 Landslide of Gunung Telagalele, Karangkobar, Banjar Negara regency [16]

2.3. South Serayu Mountains

South Serayu is folded and mountainous area, compiled by various types of rocks. The stratigraphic setting from the bottom is rock with complex structures, known as Melange of Late Cretaceous, scaly clay olistostrome of Eocene, clay breccias olistostrome of Oligocene, turbidite volcanic breccias of Miocene, tuffaceous sandstones, marl, tuffs, and breccias of the Middle to Late Miocene, marl, tuffaceous sandstone and breccias of Pliocene epoch, and

alluvial deposits. The last two units have Quaternary age. Geologic structures exist in the Melange Complex are reverse faults and lateral slip faults. In the upper stratigraphic formation, the geological structures are also complex. South Serayu Mountains can be classified to back arc zone without magmatic activity association [3].

There was a landslide occurred in Kebumen Regency, involving volcanic clastic rocks. In this incident, geologic structures such as bedding plane, cracks and joints are usually very influential. Some events have been driven by layering structures that the dip is in line with the slope, as happened in Seling village. While in Panusupan, avalanches trend is in line to the direction of the joint plane orientation [8].

Rock layering structure in landslide-prone areas generally has a relative movement parallel and the inclination direction of the slope. The slope of bedding ranges 17^{O} - 23^{o}. While the slope is usually incline more than 20^{o}. The mean inclination of bedding planes is smaller than the inclination of the slope. This makes dangerous conditions, because it will easy to avalanches through the discontinuity planes. Clayey and silty sedimentary rocks are classified into impermeable. They are easily to become slipper, and forming mud when they are in water-saturated condition. When such soil mass lay on bedding system, it will be able to function as the sliding plane of the mass failures [8].

In Seling village, Kebumen Regency there has been a soil creep involving more or less 2 x 1.5 kilometers area with thickness of the moving mass is between 0.5 meters to more than 9 meters. Boundaries of the moving land forms horseshoe. The soil creeps over a formation consisting of tuffaceous mudstone and tuffaceous sandstone, northwest - southeast (N310oE) direction and tilted to the northeast of more or less 15 ° [8]. There were cracks found in the area that floats on the sliding plane, striking relatively parallel to the slope. The speed of creep is 2 cm - 4 cm / day, moved to northwest - southeast (N305oE), toward the river valley [8]. Thus mass movement of soil/rock in South Serayu Mountains can be broadly grouped into two, namely the movement at high speed such as happen in Penusupan, and movement with low speed such as in Seling (Fig 10). Mass movement at high speed occurs at the slope more than 20^{o}, in contrary motion at low speed happens on slopes of less than 20^{o}. The model of land slide at Penusupan village, Sruweng, Kebumen Regency is as shown in Fig. 11.

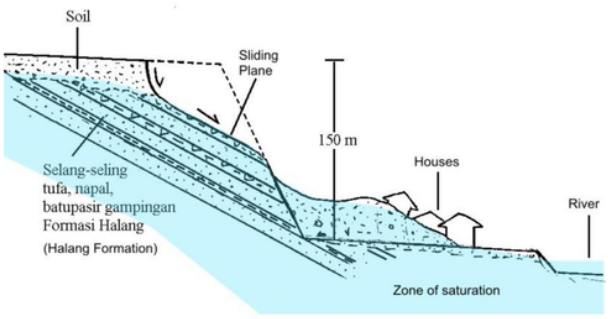


Fig. 10 Type of Landslide at Seling Village. The sliding plane is bedding plane or joints [9].

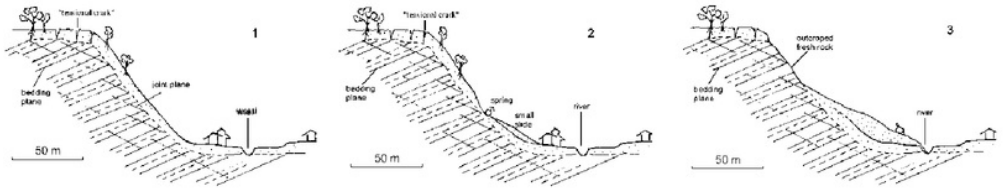


Fig. 11 Type of Slope Movement in Penusupan Area, Kebumen Regency [9].

3. Quaternary Volcanic Arc

The volcanic arc of Quaternary period in Java Island is specified by the existence of active volcanoes that belong to strato and composite type with activity producing the combination of pyroclastics deposits consist of breccias, loose sand, lava, and lahar deposits. The petrological composition of the volcanic deposits are mainly andesitic with low quartz content, therefore the deposits are relatively easier to be weathered. The thickness of soil ranges from 2 m to more than 10 m [7]. Landslides commonly occur within thick soil, which is inclined of more than 20°.

On such active volcanoes as Mount Merapi and Mount Semeru, valleys which are positioned on the upper slope commonly fully filled with pyroclastic materials. When these materials are mixed with rain water, the density will to become higher. In the very saturated condition, lead by gravity, the pyroclastic materials will flow down slope as lahar. On the foot slopes of Quaternary volcanoes, landslides also frequently occurr, for example on the foot slopes of Mount Lawu and Mount Merbabu (Central Java), at Karanganyar area (Fig. 12)

Landslides on the foot slopes of Mount Merapi frequently occur near the flow stream. Common types of movement are soil slides (landslides) involving weathered rock or soil, or loose sand. Another factor that often functions as the driving force of mass movement is the presence of clay layers at a depth of about 50 - 60 m below the surface. Avalanches caused by human activities is also common in places where sand and stone are mined, such as might occur in River Krasak (Magelang, Central Java), River Gendol (Sleman, Yogyakarta), and River Woro (Klaten, Central Java).

Figure 12 Landslide of Karanganyar on the foot slope of Mount Lawu [14]

In the year 2005 a soil avalanches occurred in Ciloto, West Java involving the zone of ± 40 acres on the slopes of a hill [1]. Ciloto landslide included weathered volcanic rocks as breccias, clay, silt, and sand. Infiltration of surface water into the ground making the material is easy to slide. Kind of the sliding material is categorized as gravel or a mixture of debris [1].

Discussion

In the areas prone to landslides of Java Island, rocks easiest to move are clayey stones and weathered volcanic rocks. In the North Serayu Mountains, mass movement occurrence mostly involves claystone (Merawu Formation) and volcanic rocks (Jembangan Formation). In the South Serayu Mountains, mass movements generally only involve clayey rocks (Panosogan Formation and Halang Formation). In the Menoreh Hills, landslides usually involve only weathered volcanic rocks (Kaligesing Formation).

Rock units that are widely available in mountainous areas prone to landslides in general tend to form advanced argillic below the soil layer which is rich in clay minerals. Weathered volcanic rocks are capable of producing kinds of clay minerals including montmorillonite, occurs from alteration of plagioclase, known to be impermeable mudstone, plastic, soft, easily to be eroded, the specific gravity varies 2.0 to 2.25, cohesive force 0.4 to 0.7 kg / cm2 and, the friction angle (ϕ) ranges 2° - 15°, and easy to silt up when submerged in water [4].

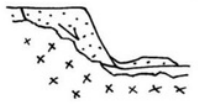
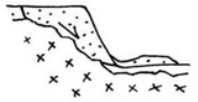
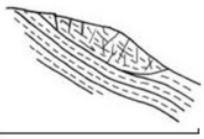
Tertiary volcanic deposits in Yogyakarta and Central Java is composed of andesitic, commonly thick (over 300 m), weight (specific gravity between 2.6 to 2.75), hard, brittle, with cohesion (c) = 0.3 to 0.75 kg/cm2, friction angle (ϕ) between 25° - 35°. A fairly intensive weathering forms thick soil (5 m to 10 m). Laboratory testings indicate that at several locations of the slopes of Mount Sumbing, the impermeable rock has a coefficient of permeability less than 1 x 10-7 m/s, and the coefficient of water in the soil is higher than 1 x 10-6 m/s [5]. The cohesive forces in the sliding plane ranges between 0.08 kg/cm2 up to 11 kg/cm2, the friction angle (ϕ) between 30° to 36° [5]. Due to weathering, the surface of volcanic rocks is commonly decomposed into clay. Physical properties that are relatively tight, causes the rocks become cracked and splited apart, iniciating rainwater to seeping. In saturated condition, pore water preasure will increase breaking the ground to easier sliding.

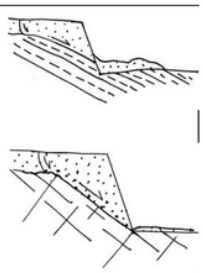
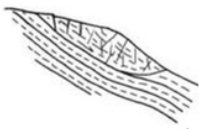
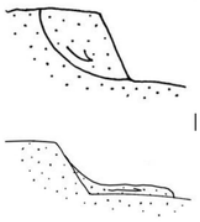
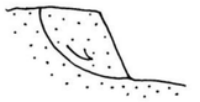
Although mass movement in some physiographic zones shows different characteristics, but in general it can be defined that the places where landslide occurs perform mountainous or hilly topography with slopes of more than 20°. Rainfall in the area in general is high, it is more than 2500 mm/year [5].

Model of Correlation between Tectonic Setting and Mass Movement Characteristic

The result of reviews, analysis, and discussion written in the previous chapters can be put as a model of the correlation between tectonic setting and mass movement characteristics in Indonesia especially Java as the following:

Table 3 Model of Correlation between Tectonic Setting and Mass Movement Characteristic of Java Island

Tectonic Enviro-nment	Physiographic Zone	Geologic Structures	Main Lithology	Mass Movement Model	Figure
Tertiary Volcanic Arc	Menoreh Hills	Fissure System: jointed, faulted	Volcanic rocks: intrusive and extrusive igneous rocks, breccias, sandstones	**Type**: Complex soil & debris slide **Sliding Plane**: the contact between soil and the bed rock	
	Southern Mountains	Slightly inclined and fissured	Volcanic rocks: intrusive and extrusive rocks, breccias, sandstones, tuffaceous sandstones	**Type**: Complex soil & debris slide **Sliding Plane**: the contact of soil and the bed rock	
Tertiary Back Arc with Quaternary Magmatic Activity Association	Bogor Zone	Massive in the upper part; folded in the lower part	Volcanic rocks in the upper parts; clastic sedimentary rocks in the lower parts	**Type**: Rotational thick soil & debris slide **Sliding Plane**: Circular shaped of weathered volcanic rock	
	North Serayu Mountains	Massive in the upper part; strongly folded in the lower part	Volcanic rocks in the upper parts; plastic, clayey sedimentary rocks in the lower parts	**Type**: Translational large block glide **Sliding plane**: the contact of volcanic rock and the plastic rock	
				Type: Rotational thick soil & debris slide **Sliding plane**: Circular shaped of weathered volcanic rock	
				Type: Rotational deep rock block slide (slump) **Sliding plane:** Circular shaped	
				Type: Combination of rotational and translational debris & rock slide **Sliding plane:** Bedding plane	

Tertiary back Arc without Quaternary Magmatic Activity Association	South Serayu Mountains	Slightly folded, jointed, faulted	Plastic sedimentary rocks, calcareous, marly, and volcanic sedimentary rocks	**Type:** Translational soil & debris slide **Sliding plane:** bedding, layering plane **Type:** Translational soil & debris slide **Sliding plane:** Joint plane	
	Kendeng Mountains	Strongly folded, jointed, and faulted		**Type**: Combination of rotational and translational rock & debris slide **Sliding plane:** bedding plane	
Quaternary Volcanic Arc	Quaternary active volcanoes (Type A)	Radial cracks	Old and new volcanic activity products: lava, pyroclastic, and lahar deposits, fine to very coarse grain sized	**Type:** Rotational soil slide **Sliding plane:** Circular shaped of soil or weathered rock **Type:** Mud/ debris flow (lahar)	
	Quaternary inactive volcanoes (Type B & C)	Fissures, cracks, joints, faults	Old volcanic products: lava deposit, pyroclastic breccias, laharic breccias, sandstones	**Type:** Rotational soil slide **Sliding Plane:** Circular shaped of soil or weathered rock	

Conclusions

The conclusions of this study are as follows:

1. Plate tectonic boundary of western Indonesia is subduction convergent, with components of trench, accretionary wedge, fore arc basin, volcanic arc, and back arc basin. Especially for Java Island, the tectonic components already exposed can be divided into 4 (four) physiographic environments, including Volcanic Arc of Tertiary period, Back Arc of Tertiary period associated with magmatic activity of Quaternary period, Back Arc of Tertiary period without magmatic activity association, and Volcanic Arc of Quaternary period.
2. The tectonic regime of Java which is compressional brings about the development of rising mountains and areas with sloping that play as the main factor of mass movement occurrence. The potential of mass movement is supported by high rainfall of Wet Tropical climate, thick weathered rock and soil, and triggered by earthquake.
3. Tertiary Volcanic Arc predominantly consists of andesitic volcanic deposits. The geologic structures are joints and faults. Weathering process is very intensive, thus there thick soil is common to exist. The characteristic of mass movement in this environment is soil slide, debris slide with the contact between soil and bed rock function as the sliding plane.

4. Tertiary Back Arc with Quaternary magmatic activity association is predominantly composed of massive volcanic rocks underlain by folded, plastic, clayey sedimentary rocks. The characteristic of mass movement, especially North Serayu Mountains is known as the gliding tectonic, expressed as soil slide, debris slide; rock block glide, and deep rotational rock slide.
5. Tertiary Back Arc without magmatic association is predominantly composed of plastic sedimentary rocks, calcareous, marly, and volcanic sedimentary rocks. The geologic structures are folds, and faults. Mass movement characteristics are translational soil & debris slide with bedding plane, or joint as the sliding planes; and combination of rotational and translational debris & rock slide with bedding as the sliding plane.
6. Quaternary Volcanic Arc is mainly built of old and new volcanic products such as lava, pyroclastic breccias, and laharic deposits of andesitic composition. The characteristic of mass movements are rotational soil slide exists in non active Volcanic Arc; and rotational soil slide and mud flow occur in active Volcanic Arc.

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