GEOLOGICAL INPUTS FOR LANDSLIDE HAZARD IDENTIFICATION (LHI) IN THE TRUSMADI FORMATION SLOPES, SABAH, MALAYSIA

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ABSTRACT. *This paper describes the importance of geological engineering inputs to landslide hazard occurrences in the Trusmadi Formation slopes, Sabah, Malaysia. The Trusmadi Formation regionally consists of two major structural orientations NW-SE and NE-SW. It consists mostly of dark grey shale with thin bedded sandstone, typical of a turbidite deposit. This unit has been subjected to low grade metamorphism, producing slate, phyllite and meta-sediment as well as intense tectonic deformation producing disrupted or brecciated beds. Quartz veins are quite widespread within the joints on sandstone beds. The shale is dark grey when fresh but changes to light grey and brown when weathered. The weathered materials are unstable and may experience sliding due to high pore water pressure, steep, hummocky or rugged slopes and intensively geomorphologic processes. Engineering properties of fifty five (55) soil samples indicated that the failure materials mainly consist of poorly graded materials of silty clay soils and and are characterized by low to intermediate plasticity content (12 % to 23 %), containing inactive to normal clay (0.43 to 1.47), very high to medium swelling (7.98 to 9.28), low to high water content (5 % to 25 %), specific gravity from 2.61 to 2.69, low permeability (8.78 X 10^{-3} to 3.28 X 10^{-3} cm/s), friction angle (ϕ)from 7.72˚ to 26.65˚ and cohesion (C) from 5.11 KPa to 15.34 KPa. The rock properties of twenty five (25) samples indicated that the point load strength index and the uniaxial compressive strength range were moderately weak. The geological influence had transformed the Trusmadi Formation slopes to be highly unstable and susceptible to landslide occurrences. Six (6) related main parameters were attributed: 1) local and regional geology, 2) hydrological and geohydrological, 3) mineralogical and micro structures, 4) local discontinuities structures, 5) physical and engineering properties of soil and rock, and 6) geomorphological processes which can help in evaluating landslide problems in Trusmadi Formation slopes. In conclusion, the geological factor evaluation should be prioritised and take into consideration in the initial step in all infrastructure programmes and may play a vital role in landslide hazard and risk assessment to ensure public safety.*

KEYWORDS. Geological Factors, Landslide Hazard Identification (LHI), Trusmadi Formation

INTRODUCTION

Landslide is among the major geohazard occurrences in Sabah, Malaysia. As with flooding, tsunami, siltation and coastal erosion, landslides repeatedly occurred in the region with disastrous effect. Landslide is a general term for a variety of earth processes by which large masses of rock and earth materials spontaneously move downward, either slowly or quickly by gravitation (Varnes, 1978). Such earth processes become natural hazard when their direct interaction with the material environment is capable of causing significant negative impact on a property and human's well being.

Landslide hazard identification (LHI) requires an understanding of the slope processes (e.g. factors causes, types, mechanism etc.) relationship of those processes to geomorphology, geology, hydrogeology, failure and slide mechanics, climate and vegetation. From this understanding it will be possible to: 1) classify the types of potential landsliding, 2) assess the physical extent of each potential landslide, including the location, areal extent and volume involved, 3) assess the likely initiating event(s), the physical characteristics of the materials involved, such as shear strength, pore pressures; and the slide mechanics, 4) estimate the resulting anticipated travel distance, travel path, depth and velocity of movement if failure occurs, and 5) identify possible pre-failure warning signs which may be monitored (Fell *et al.* 2005).

This paper discusses the contribution of geological factors to the LHI. Among the earlier research on landslide hazard occurrences which taking into account the geological inputs was prepared by Cruden & Krahn (1973) and Varnes (1978). Apart from that, a few researchers also found have discussed the similar matter might be referred worldwide for examples the geotechnical properties (Hutchinson, 1988), slope instability (Abdul Ghani Rafek *et al.*, 1989; Tsidzi, 1997; Hermanns & Strecker, 1999; Steven *et al.*, 2003), engineering seismology (Zhang & Wu, 1989; Chigira *et al.*, 2003) and geological risk (Miguel *et al.*, 2007).

According to the local research view, there was some research conducted and published in documented research reports, international proceeding or manuscript close to the study area such as Mineral and Geosciences Department of Malaysia (MGDM) (1994), Faisal *et al.* (1998), Komoo & Salleh (2003), Komoo *et al.* (2004), Rodeano & Sanudin (2004; 2005), Adong & Rodeano (2005), Rodeano *et al.* (2006; 2007; 2008), Tating (2006) and Tongkul (2007). MGDM (1994) and Adong & Rodeano (2005) with their documented research report projects have mapped some potential or active landslide areas in the consideration and evaluation of geological contributions factors along the Tamparuli to Ranau highways of Sabah, Malaysia. Faisal *et al.* (1998), Rodeano & Sanudin (2004; 2005) and Rodeano *et al.* (2006; 2007; 2008) more discussing of physical characterization with their engineering materials, slope stability analysis and design or repairing the slopes along the Ranau to Tambunan and Kundasang to Ranau highways, Sabah, Malaysia. Komoo & Salleh (2003) and Komoo *et al.* (2004) have conducted detail study on eight (8) systems landslide hazard complex in Kundasang's town area, Ranau, Malaysia. Tongkul (2007) described the geological background on landslide occurrence in the mountainous areas of west Sabah, Malaysia. Tating (2006) studied the geological contribution to the landslide hazard along the Tamparuli to Ranau highways of Sabah, Malaysia with the case study of landslide at KM 82.2.

However, all the above studies need more comprehensive and intensive clarifications on the geological contribution in the slope design of the Trusmadi Formation especially cut and filled slopes. This paper is hoped to give an information and idea how the geological contributions can be taken into account as guideline in landslide investigation method in Sabah. Thus, the awareness of the geological inputs is necessary for the appropriate idealization of ground conditions and the subsequent model for LHI and future mitigation measures. Detailed and comprehensive discussion would be given further in this paper.

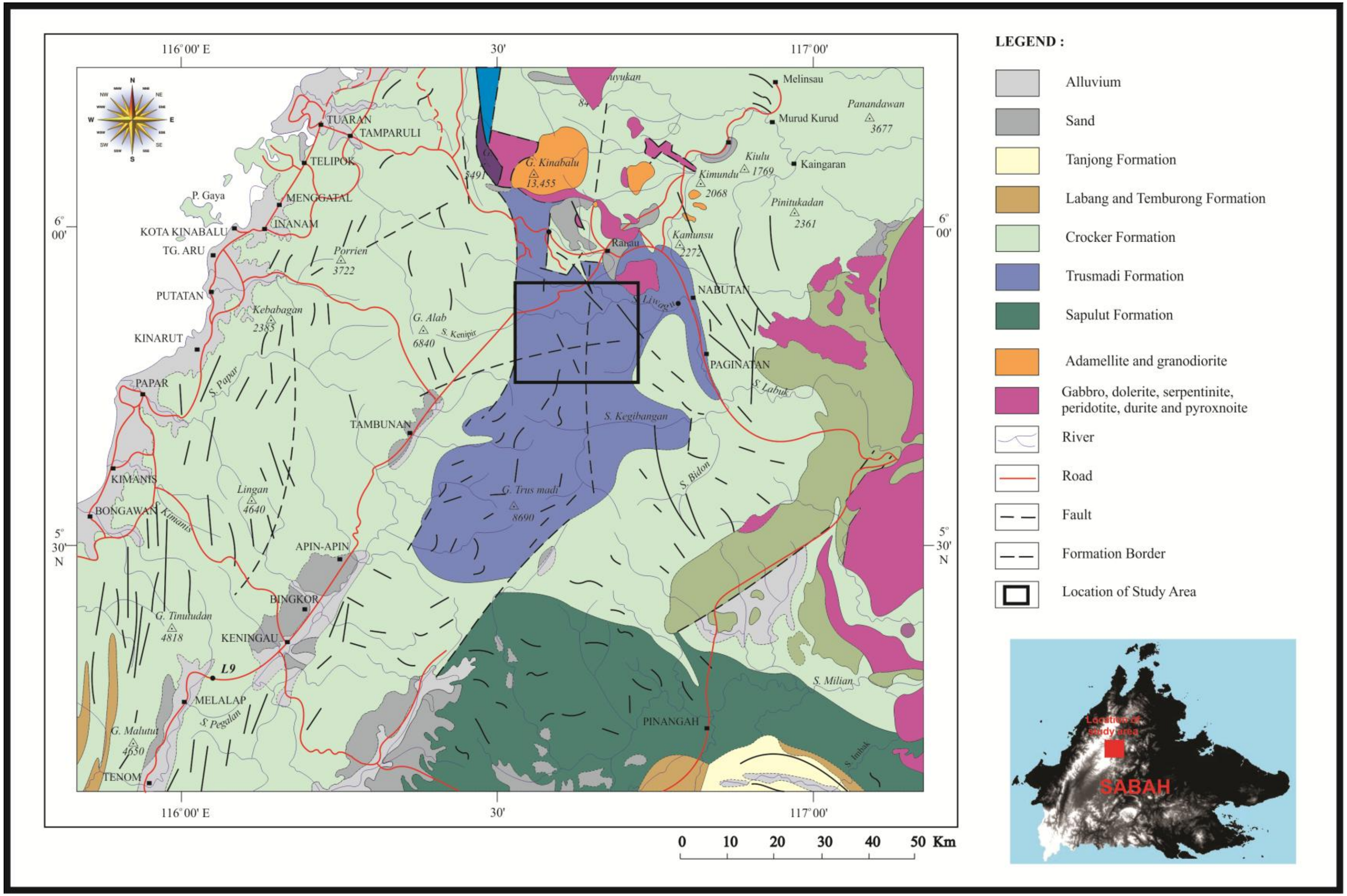

Figure 1. Location of study area

MATERIAL AND METHOD

The study area lies centrally on the western coast of Sabah pass through the Crocker Range roughly about longitude line E 116^{o} 30’ to E 116^{o} 40’ and latitude line N 06^{o} 09’ to N 06^{o}15’ (Figure 1). The mainland part of the study area is the most accessible. Good networks of sealed and unsealed roads connecting most of the prime villages around it. However most of the roads passing in the study area were designed and constructed without taking into account the local geology setting. It is therefore not surprising to see that some of these roads were built on geologically unstable areas, such as located on the major fault zones or old landslide areas, across the steep of hummocky and rugged slopes and facing the intensively of geomorphological processes. As a consequence of this, the recurrence of landslide hazard at these unstable sites is quite frequent and costly to maintain.

Several classifications can be used to describe LHI. The types of landslide were classified according to the proposals of Varnes (1978). In this system, landslides are classified into falls, topples, slides, spreads, flows and complex with their different materials such rock, debris and earth (soil). In this study, only failures with volume exceeding 50 m^3 were considered, since failures involving smaller volume did not generally affect the road users. The landslide was divided into three groups: small (50 – 100 m^3), Medium (100 – 500 m^3) and Large (> 500 m^3) (Abdul Ghani Rafek *et al.*, 1989). For each landslide, the geometry of the slope, local and regional geology background, hydrological and hydrogeological, mineralogical and micro structures, local discontinuities, physical and engineering properties of soil and rock and geomorphological processes an interpretation of the factors causes based on field observations were recorded. Besides of those, intensive literature review was carried out in order to obtain the useful reference and additional information of the study area. Undisturbed soil and rock samples were collected during field mapping for detailed laboratory analysis. The laboratory works such as classification tests (grain size, atterberg limit, shrinkage limit, specific gravity and water content), permeability test, consolidated isotropically undrained (CIU) test, rock uniaxial compressive strength and point load test were carried out in compliance and accordance to British Standard Code of Practice BS 5930-1981 (Site Investigation), British Standard Code of Practice BS 1377-1990 (Method of Test for Soils for Civil Engineering Purposes) and ISRM (1979a; 1979b; 1985).

GEOLOGICAL INPUTS FOR LANDSLIDE HAZARD IDENTIFICATION (LHI)

Local and Regional Geology

The local geology of the study area is underlined by the Trusmadi Formation (Palaeocene to Eocene age), Crocker Formation (Late Eocene to Early Miocene age) and the Quaternary Alluvium Deposits (Table 1 and Figure 2). However in this paper, the study based on landslides formed in the Trusmadi Formation and the slopes found in Trusmadi Formation. Jacobson (1970) divided the Trusmadi Formation rock sequence into four main lithological units; argillaceous rocks, interbedded sequences (turbidites), cataclasites and massive sandstones. Trusmadi Formation is characterized by dark colour argillaceous rocks, siltstone and thin-bedded turbidite in well-stratified sequence. Some of the Trusmadi Formation rocks have been metamorphosed to low grade of the greenish-schist facies; the sediment has become slate, phyllite and metarenite. Cataclastic rocks are widespread and occur as black phyllonite enclosing arenitic and lutitic boudins with diameter up to a meter or demarcating thin to thicker fault zones or as flaser zones with hard and finer grain matrix or as zones of closely spaced fractures (Tjia, 1974). Quartz and calcite veins are quite widespread within the crack deformed on sandstone beds. The shale is dark grey when fresh but changes light grey to brownish when weathered. The Trusmadi Formation generally shows two major structural orientations NW-SE and NE-SW (Tongkul, 2007).

Table 1. Local Stratigraphic Column and their Water Bearing and Engineering Remarks for the Trusmadi Formation

Age	Unit	General Character	Water-Bearing Properties	Engineering Remarks
Paleocene to Eocene	Trusmadi Slate and Trusmadi Phyllite	Comprise of dark colour argillaceous rock either in thick bedded or interbedded with thin sandstone beds and siltstone.	Fractured sandstone has significant to groundwater.	Dangerous site for heavy structure. Improvement should be conducted before any project.

In terms of the regional geologic setting, the effect of faulting activity can be observed in the study area. This was confirmed by the existence of transformed faulted material consisting of angular to sub angular sandstone fragments, with fine recrystallined quartz along the joint planes, poorly sorted sheared materials and marked by the occurrence of fault gouge with fragments of slate, subphyllite and slickensided surfaces (Figure 3). Highly fractured and sheared of the Trusmadi Formation indicates the result from long history of tectonic activities; most of faulting shears exist within the interbedded sandstone-shale and sandstone-slate-phyllite. Breaks and fractures were developed by shearing stresses were caused the rapid disintegration and weathering of the rocks into relatively thick soil deposit (Figure 4). As a corollary to this, in rock bodies, the surface roughness of joint are generally smooth to rough planar (Figure 3). A relatively smooth surface decreases the frictional resistance then increasing possibility of landslide hazard occurrences in the study area. Apart from that, field observation indicated that too many cut and filled slopes were designed without taking account input of geological interest. For example most of the slopes were designed too steep (> 60^{o}) (Figure 5), lack of monitoring on proper drainage system and slope physical state (Figure 6) and most of the slope cutting surface is parallel to the strike direction of the slate bedding orientation (Figure 7).

The trend of strike and dip of the sandstone and slate bedding and cleavage orientations in the Trusmadi Formation can be observed in different patterns such low (030-100/10-20); medium (220-280/30-50) and high dip angles (320-345/60-70). Besides of that, the slope surface orientation range from 210-330 (dip-direction) and 35-80 (dip). Hence, the main factors of landslide hazard occurrences in Trusmadi Formation slopes are sourced from the relationship between the factors of dip-direction slope cutting surfaces with the strike direction of the sandstone and slate bedding and cleavage orientations. That is why there were some landslide found in the variable potential of falls, slides and topples mode types (in Rodeano & Sanudin, 2004; Rodeano et al., 2008) as well as the combination of more than one mode of aforementioned in the form of the landslide hazard complex due to this design negligence described to the above aided by the discontinuities nature complex very often encountered at study area.

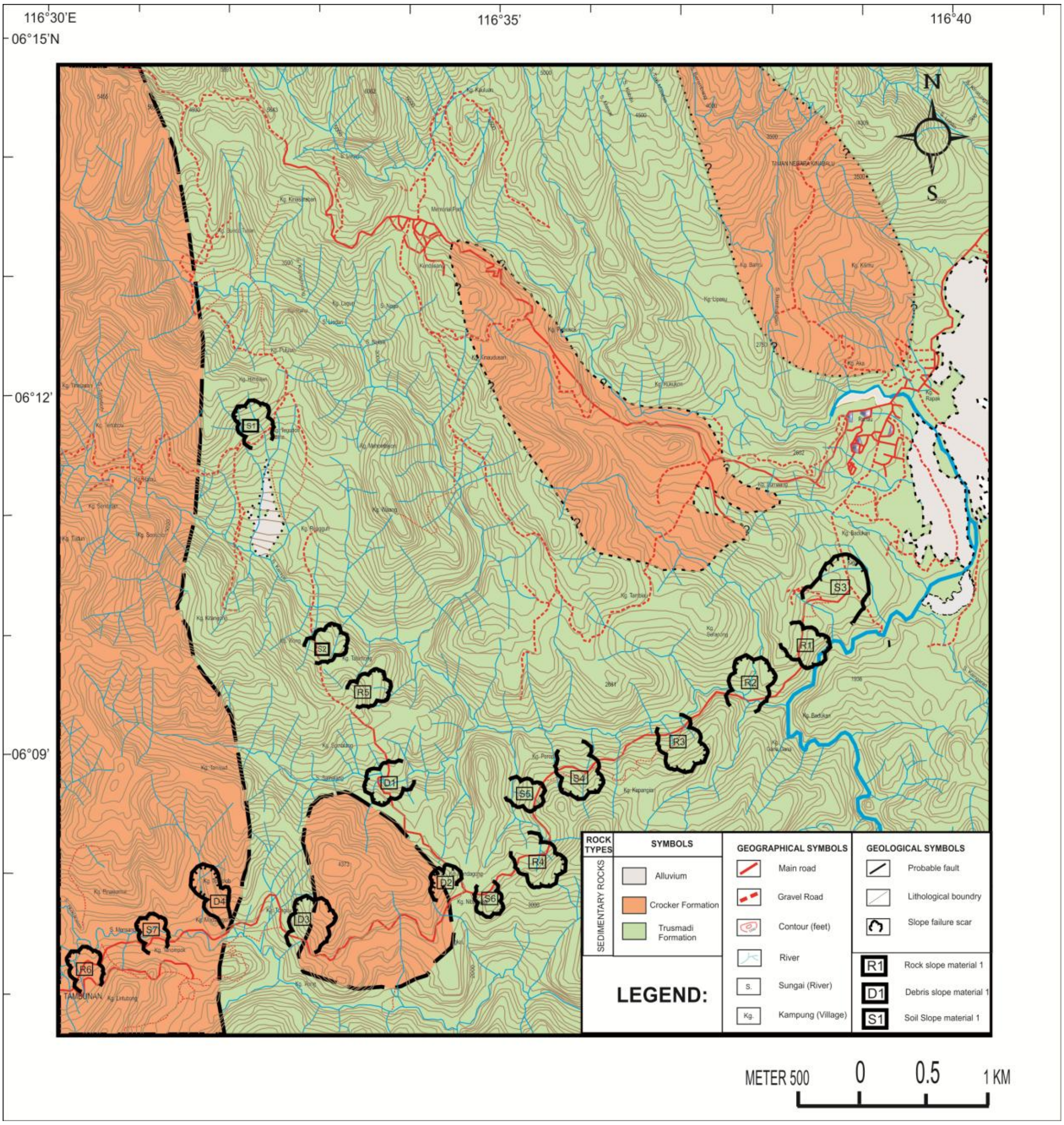

Figure 2. Local engineering geological map of the study area (Modified from Jacobson, 1970; Rodeano, 2004)

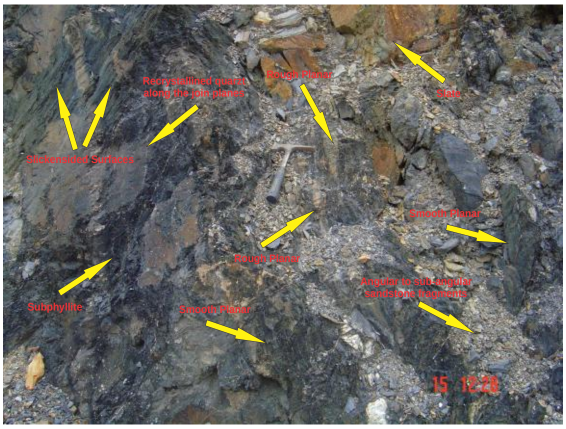

Figure 3. Photograph showing the form of discontinuities provides intersecting sheets to form yield stepped and slickensided surfaces or boundary vertical joints

Figure 4. Photograph showing the settling soil block suffers from fracturing, stumping or flowing considerable lateral movement along the slip plane of the down slope (Location: KM 140 (S3))

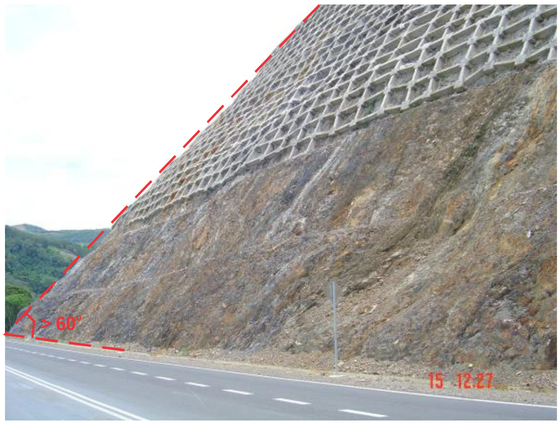

Figure 5. The very steep cut slope (> 60^{o}) enable to the occurrences of landslide hazard

Figure 6. Damaged of slope physical state due to improper monitoring system

Figure 7. Slopes cut parallel to the strike and steeper than the dip of the day lighting planes then lead to landslide

Figure 8. Water seepage/spring on the slope area. Intermittent sliding from this spot will lead to the major slope failure

Geomorphological Processes

The formation of hilly terrain and ridges with an elevation of more than 1,500 meters a.m.s.l with the combination of steep to very steep slopes was the result of violent tectonic activities in the past (Tating, 2006). The steep and hummocky terrain, regional and unstable local geology, presence of the old landslide areas and intensively geomorphological processes in the study area is naturally landslide prone areas. Intense water runoff systems in the steep rugged terrain are characterised by short and rapid flowing streams. These fast moving bodies of water, causes surface erosion and gulling on the slope faces (Figure 8). Surface erosion removes the necessary top soil to sustain vegetation cover. This further exposes the slope and weakens the strength of the slope materials (Figures 4 & 6). In term of weathering grades, the materials that underwent landslide were in the ranges from grade III to VI (Figures 3 & 4). Surface water runoff and groundwater seepage are the main factors causing landslide with the depth of weathering influencing the volume of material that fails. It appears that grade IV to grade V materials actually failed with the overlying grade VI material sliding or slumping down together with this material during failure.

Hydrological and Geohydrological

The study area and its surrounding shows dense drainage with trellis, annular and parallel paths (Fig. 2). Structurally, a number of linear river segments belong to different watershed systems indicate the existence of major tectonic fractures. The structural control of the river tributaries are the physical characteristics of sedimentary and meta-sedimentary rocks; highly fractured areas and less competent shale beds. The sedimentary and meta-sedimentary rocks are more intensely dissected by fault zones than the ultrabasic rocks.

Groundwater occurs and moves through interstices or secondary pore openings in the rock formations. Such openings can be the pore spaces between individual sedimentary and meta-sediment grains, open joints and fractures or solution and cavernous opening in brecciated layers and cataclasites. The direction of groundwater movement is generally under the influence of gravity. The rock formations exhibit a high degree of weathering and covered by thick residual soil that extends to more than 25 meters in thickness. Evaluation of more than 60 boreholes in the study area indicated that the groundwater table is shallow and ranges from 2 meters to about 15 meters (Rodeano & Sanudin, 2004). It's also seen that the water table follows the topography from highland toward the road and the valley side. The weathered materials are weak due to high fractures porosity and high pore-water pressures that generated by both shallow and deep groundwater.

The layered nature of the argillaceous rocks, interbedded sequences (turbidites), cataclasites and massive sandstones of the Trusmadi Formation may constitute possible sliding surfaces. For examples the interbedded sandstone-shale and sandstone-slate-phyllite contacts are easily accessible by water and such contact seepage may weaken the shale surface and cause slides and falls within the formation (Figure 8). This condition may also present problems of settlement and rebound due to shale and subphyllite unit characters nature contains high porosity and low permeability. The magnitude, however, depends on the character and extent of shearing in the shale or subphyllite units. The strength of the sandstone or slate will also depend on the amount and type of cement-matrix material occupying the voids. Instead of chemical cement (vein) or matrix, the pores are filled with finer-grained sands to silt-sized materials or squeezed rock fragments. The absence of chemical cement reduces the strength of the sandstone or slate physically especially when it is weathered or structurally disturbed. The shale and subphyllite units have an adequate strength under dry conditions but lose this strength when wet. During the rainy season, the shale or subphyllite units becomes highly saturated with water which increases the water pressure and reduces resistances to sliding and falling especially within the interbedded sandstone-shale and sandstone-slate-phyllite contacts (Rodeano *et al.*, 2008). This condition, in addition to varying levels of degradation, makes shale and subphyllite units unpredictable and unsuitable for road construction sites. Its unstable nature can be remedied by proper management of soaking and draining of water from the rock or along the interbedded sandstone-shale and sandstone-slate-phyllite contacts.

Mineralogical and Micro Structures

In terms of lithological background of the Trusmadi Formation rocks, argillaceous rock consists of fine grained quartz with a high percentage of matrixes. Trusmadi phyllites consist of fine grained minerals, some of which are showing aligned parallel to the bedding. Shales unit is often found as laminated with dark carbonaceous materials or lignitic clay, aligned parallel to the bedding. Apart of that, mylonites are confined only to fault zones. Mylonites consist of sandstone fragments, which are made up of polycrystalline quartz in a sericite matrix. The sandstone fragments are seen to be deformed tectonically. Mineralogical analysis indicated that about 95% (by volume) of interlocking calcite minerals showing two sets of cleavages and other than about 5% is made up of chert, quartz, mica and pyrite crystals. Recrystallization of calcite grains takes places because of low grade metamorphism.

Micro structures analysis of the soil samples was examined with JEOL JSM – 5610LV scanning electron microscope (SEM) and was coated with Titanium using JEOL JFC – 1600 auto fine coater. This SEM purpose is to study the condition of micro fabrics for the clay mineral in the Trusmadi Formation slopes. It is customary clay mineral plays a deleterious effect on rock’s durability and it’s mechanically weak past may change their structure through the water absorption and dehydration. XRD and SEM studies on this clay mineral showed that it is kaolinite (Figure 9). Kaolinite is relatively stable or inactive clay due to low water or material adsorption because it is limited to the surface of the particles (planes and edges). If perceived, this kind of inactive clay is abundant mostly in weathered rocks such as shale or phyllite units. Shale or phyllite units in the Trusmadi Formation slopes is characterized by fine-grained sedimentary and meta-sedimentary rocks having fissile, laminated, foliated or thinly stratified structures and disintegrated faster when exposed to water as a result of expansion of clay materials that will lead to landslide. The shaly rocks sequence also provides the main decollement horizon (major sites of fault zones) for the development of thrust slices in the western part of Sabah (Tongkul, 1989). Apart from that, the porosity percentage of the Trusmadi Formation rock samples ranged from 15% to 40% and was determined as partial dissolution, grain corrode, trace and grains fracture (Figure 10). Porosity is directly related to moisture content of the rock. Moisture exchange will occur between different porous materials. Due to the higher suction force in finer pores, water capillary transport is much easier from coarse porous to fine porous materials. Study on the porosity revealed that any small changes in porosity may give major impacts to landslide occurrences due to presence of the cracks, clay materials or quartz vein in the Trusmadi Formation rocks (Rodeano *et al.*, 2008).

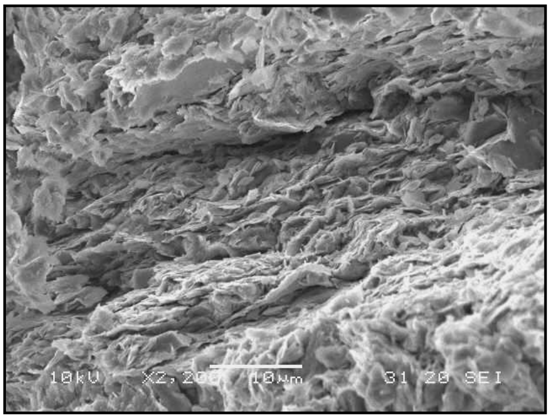

Figure 9. Structured layer of kaolinite found in Trusmadi Formation's soils

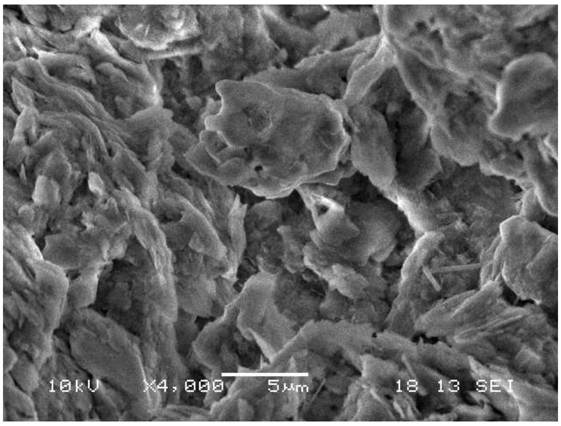

Figure 10. Photograph showing the pores found in Trusmadi Formation's rocks

Local Discontinuities Structures

Several regional tectonic events have occurred in Sabah since early Tertiary, contributing to the diverse structural and depositional framework of Sabah. Mapping by previous researchers have revealed three major periods of deformation in the study area (Jacobson, 1970; Tjia, 1974). The earliest recognizable deformation is the folded and metamorphosed rocks of the Crystalline Basement. The second period, which culminated in Middle of Miocene, resulted in intense folding and fracturing of the Tertiary sediments and the intrusion of the Kinabalu Adamellite. The latest deformation during the Quaternary caused regional uplift and raised many parts of Sabah, including the study area. As the consequent effect of these tectonic activities, the Trusmadi Formation's rocks sequence in the study area have been faulted, folded, jointed and sheared. These local discontinuities structures will let water infiltrate into the slope, thus accelerating the weathering process that will lead to landslide occurrences.

The beds in the Trusmadi Formation regionally show NW-SE and NE-SW structural orientations. The dip of bedding planes in the Trusmadi Formation are steep (> 35^o) and often found parallel to the slope faces. Associated with folds are thrust faults and overturned beds. The Trusmadi Formation in the study area is closely folded. Faulted materials presence in the Trusmadi Formation slopes are accompanied by distinctive features of fault zone area such as slickenside, breccias and mylonite. These features are conclusive proof of faulting activities by tectonic deformation. Slickenside is found with polished and striated surfaces and more common in the highly sheared rocks. Fault breccias consisting of angular to sub angular fragments of mainly sandstone-shale and sandstone-slate-phyllite of various sizes in a finely crushed matrix, which are formed mainly along shear planes (Figures 3 & 7). While mylonites found comprises of fine-grained foliated matrix with highly recrystallized sandstone-slate-phyllite clasts of few cm in diameter. Joint structure is a fracture without movement. Joints are well developed in the interbedded sandstone-shale and sandstone-slate-phyllite. Intensive fracturing weathering causes difficulty in tracing any pattern of joints during the field observation. They cut across the rocks in various directions causing the rocks to break off in irregular shaped blocks and being highly friable and smaller size.

Other than local discontinuities structures described above, slaty cleavage and boudinage structures are commonly developed from the sandstone-slate-phyllite beds in argillaceous sequences. Slaty cleavage is commonly developed in the axial zones of folds while boudinage is a structure that formed by the segmentation of pre-existing bodies that is generally more competent than the surrounding rock. If scrutinized, the boudinage structure in the Trusmadi Formation is more rounded than the Crocker Formation (for examples) and the deformed beds grade into cataclastics. The difference in types of the boudins probably reflects the different lithologic units of the sandstone beds of the Trusmadi Formation. They are much thinner and suffered more rotation when deformed. The boudinage zones are difficult to distinguish from primary slumped zones and in places are superimposed on primary slumped zones. Kinematics slope discontinuities survey conducted by Rodeano *et al.* (2008) indicates that the potential of circular, planar, wedges and toppling as well as the combination of more than one mode of aforementioned failures.

Physical and Engineering Properties of Soil and Rock

Results of a detailed analysis for the physical and engineering properties of the Trusmadi Formation's soil and rock are presented in Table 2. Physical and engineering properties of fifty five (55) soil samples indicated that the landslide materials mainly consist of poorly graded materials of silty clay soils, which characterized by low to intermediate plasticity content (12 % to 23 %), containing of inactive clay (0.43 to 0.70), very high to medium degree of swelling (7.98 to 9.28), low to high water content (5 % to 25 %), specific gravity ranges from 2.61 to 2.69, low permeability (8.78 X 10^{-3} to 3.28 X 10^{-3} cm/s), friction angle (ϕ) ranges from 7.72˚ to 26.65˚ and cohesion (C) ranges from 5.11 KPa to 15.34 KPa. The rock properties characterization for twenty five (25) samples indicates that point load strength index ranges from 0.35 MPa to 0.48 MPa (moderately week). Fractured rock masses have much lower shear strength compared to the original fresh rock. The complex nature of tectonic and intensive weathering activity were affected the Trusmadi Formation's lithological background and lead to the landslide occurrences.

Table 2. Analysis results of physical and engineering properties of soils and rocks

Lithology	**Sub-Phyllite**	**Slate**
Weathering grade	IV to VI	IV to VI
Volume (1)	Medium	Small
Sand (%)	22 – 25	40 – 42
Silt (%)	54 – 57	18 – 25
Clay (%)	22 – 24	38 – 43
Liquid limit (%)	25 – 29	41 – 45
Plastic limit (%)	12 – 14	23 – 27
Plasticity index (%)	14 – 18	18 – 23
Liquidity index (%)	- 0.36 to - 0.31	- 0.81 to - 0.79
Clay activity	0.49 – 0.70	0.43 – 0.50
Shrinkage limit (%)	8.67 – 9.28	7.98 – 8.68
Moisture content (%)	12 – 25	5 – 20
Specific gravity	2.61– 2.64	2.63 – 2.69
Permeability (cm/s) (X 10^{-3})	8.78 – 7.55	4.35 – 3.28
Cohesion, C (kN/m^2)	5.11 – 12.55	12.45 – 15.34
Friction angle (^{o})	7.72 – 8.20	21.55 – 26.65
Point load strength index, $_{IS (50)}$ (MPa)	0.35 – 0.38	0.45 – 0.48

DISCUSSION

Human ignorance and negligence that does not taking into account the geological contribution and inputs in slopes design or road construction were caused landslide occurrences in the study area. There were six (6) parameters can be attributed into the local and regional geology, hydrological and geohydrological, mineralogical and micro structures, local discontinuities structures, geomorphological processes and, physical and engineering properties of soil and rock. All six parameters mentioned above can help in evaluating landslide problems in Trusmadi Formation slopes.

Interbedded sandstone-shale and sandstone-slate-phyllite units of the Trusmadi Formation rock found highly fractured, faulted, folded and sheared then lead to landslide occurrences. For examples, the orientation of the discontinuities and its relation to the geometry and strike of the slope, have a direct influence on the slope stability. Due to the influence of the regional tectonic forces the rock bedding/cleavage in the study area are predominantly orientated at a Northeast - Southwest and Northwest – Southeast directions. It has been determined that slopes that strike northward, westward and South – Southeast show a higher probability to landslide (Edward Voo, 1999). Therefore as a matter of precaution, cutting slopes at these strike directions, if possible should be avoided.

The way groundwater flows; its pressure and gradient at any point within a slope depend on the local geology. Water plays a very important role in landslide study. Water can influence the strength of slope forming material by chemical and hydrothermal alteration and solution (Zhang & Wu, 1989; Chigira *et al.*, 2003), increase in pore water pressures and subsequent decrease in shear strength (Hutchinson, 1988), reduction of apparent cohesion due to capillary forces (soil suction) upon saturation and softening of stiff fissured clays (Tsidzi, 1997; Hermanns & Strecker, 1999), shale (Hermanns & Strecker, 1999; Steven *et al.*, 2003) and phyllite (Abdul Ghani Rafek *et al.,* 1989). All slope forming materials are subject to initial stresses as a result of gravitational loading, tectonic setting activity, weathering, erosion and other processes (Rodeano & Sanudin, 2004; 2005). Stresses produced by these processes are embodied in the materials themselves, remaining there after the stimulus that generated them has been removed (residual stresses). Stress relief many structural features and stress release activity is an important feature in many rock formations. High lateral stresses have played a crucial role in initiating in over consolidated of the slope materials.

Weathering changes the phyllite and shale into fine clayey materials. Direct identification of clay (XRD and SEM) and indirect determination of clay activity values shows that some of the clay minerals are suspected to be inactive clay (kaolinite). These types of clay minerals when interacting with water would expand and lubricate rock joints and other discontinuities. The fine particles in soils are composed of clay minerals that exhibit plasticity when mixed with water. Water is strongly absorbed by clay minerals. The structure and behaviour of clay minerals are different from those of normal clay and it plays an important role in soil behaviour (Rodeano *et al.*, 2008). This kind of clay mineral has the highest swelling potential and the most troublesome in terms of landslide occurrences. Due to intensively weathering processes, chemical and hydrothermal alteration or clay minerals are often found in joints, shears and faults in the interbedded sandstone-shale and sandstone-slate-phyllite units of the Trusmadi Formation rock. Therefore, clay minerals have a significant influence on the behaviour of rock masses. Features such the presence of ground up materials near fault zones are often remoulded, which may result in less resistance to landslide because of loss in shear strength. Groundwater is attracted to a fault zone due to the greater conductivity of the fractured and loosened rock to be found. Faults can act as conduits for water flow. Replacement of original minerals by clays as well as precipitation of these minerals in void spaces grossly changes the character of the rocks near the fault zones, as a result of which stability problem would ensue. In the case of brecciated rocks, a fault usually localizes solution in them, leading to fault gouge and crushed rock developed along the fault zone. Fault gouge and crushed rock may developed along faults even in non – soluble rocks as a result of washing out of gouge and crushed rock and the opening of extension fractures oblique to the fault plane as a by product movement along the fault (Rodeano & Sanudin, 2004; 2005; Rodeano *et al.*, 2008).

CONCLUSIONS

The geological inputs transformed the Trusmadi Formation slopes to be highly unstable and susceptible to landslide occurrences. Much of the findings could not be ascertained without sound understanding of the site geological evolution, inherited unfavourable geological relics and the peculiar but hazardous engineering properties. There were six (6) parameters can be attributed into the local and regional geology, hydrological and geohydrological, mineralogical and micro structures, local discontinuities structures, geomorphological processes, and physical and engineering properties of soil and rock which can help as much in evaluating landslide problems in Trusmadi Formation slopes. In terms of slope remedial work and slope designs, these geological inputs should be taken into consideration for better assessment of the slope materials, geometry and behaviour characteristics. This study has proven that geological input plays an important role in the understanding the causes of landslide. With this understanding appropriate stabilization work can be carried out immediately and effectively before the unstable slope face deteriorates or landslide. Good knowledge of the useful geological inputs can help avoid such unnecessary expensive slope stabilization option.

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