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THE 2011 ZEN GARDEN LANDSLIDES: TRIGGER AND CAUSAL FACTORS

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ABSTRACT: *The Zen Garden Resort and its surrounding area are part of the "Kundasang Landslide Complex" and were experiencing reactivation of old landslides on 10 April 2011. Consequently, more than 80 room units of the resort, ten buildings, homes, and local roads were destroyed, uplifted, and damaged as well as disrupted day traffic. About 500m in length and 200m in width of the slope area were slides for 25m. The vertical fall movement in the head section of the landslide is 25m. There is no direct relationship between the 2015 Ranau earthquake and with earlier rotational clay slide of the 2011 Zen Garden Resort landslide. The causing and triggering factor for landslides are generally varied and are always characterized as region-specific and site-specific. Thus, this study was conducted to unravel the triggering and causal factors for the rotational clay slide of the 2011 Zen Garden Resort landslide. The methodology consists of desk study, remote sensing study, geological mapping, geodynamic mapping, laboratory, and data analysis. This study found that the landslides were triggered by prolonged moderate to occasional heavy rainfall. The causal factors are divided into natural factors (tectonic uplift, weak materials, weathered materials, sheared or jointed materials, adversely oriented mass discontinuity or structural discontinuity, and contrast in permeability) while the artificial factor consists of excavation of the slope or its toe, cut and fill, subterranean erosion/ piping, irrigation or water leakage from utilities and deforestation or vegetation removal.*

KEYWORDS: Zen Garden Resort, landslides, Kundasang landslide complex, colluvium, geodynamic, trigger and causal factors

INTRODUCTION

A landslide is a downslope movement of the rock, soil, or debris under the influence of gravity. It becomes a major problem in the mountainous region, as well as plain areas. It causes damage to properties and loss of lives. The causing and triggering factors for a landslide are varied by the location, climate, and local geological setting and a landslide is a region-specific and site-specific character.

Many publications have published the landslide-causing factors such as Highland and Bobrowsky's (2008), Cruden & Lan (2015), Taiwan Geoscience portal (2021), Danish et al. (1994), and Jesus et al. (2017), but Novotný (2012) for triggering factor. The causing factors are divided into natural, physical-artificial, and geomorphological factors.

The natural factor includes the earthquake, tectonic or volcanic uplift, geological rebound, geological meltwater outburst, fluvial erosion of slope toe, wave erosion of slope toe, glacial erosion of slope toe, erosion of lateral margin geology, and climate. The physical-artificial factor consists of flawed design, improper construction, and non-maintenance of slopes, subterranean erosion, deposition loading slope or its crest, subterranean erosion, deposition loading slope or its crest, and groundwater, or water table, thawing, freeze and thaw weathering, shrink and swell weathering, and flooding and oscillation vegetation removal). The geomorphological factor is divided into geology, geological rebound, fluvial erosion of slope toe, wave erosion of slope toe, glacial erosion of slope toe, and erosion of lateral margin.

The triggering factor has been divided into internal (earthquake), external weathering (rainfall, rapid snowmelt, prolonged intense rainfall, rapid downthrown), and human (over-steep slope cutting) factors. Based on the above statement the definition of causing and triggering factors are inconsistent and vital to improvement. On 8-10 April 2011, the huge rotational clay slide (Hungr, et al., 2014) hit the Zen Garden Resort, Kg. Dumpiring and Kg. Kundasang Lama areas in southern Kundasang. These areas are located outside the eight (8) system of 'Kundasang Landslides Complex' (Figure 1) and informally label as system number nine (9) by some local researchers.

After more than two (2) decades of the rotational clay slide of the Zen Garden landslide, the causal and triggering factors have never been documented properly. Thus, this study was conducted to unravel the causal and trigger factors for this landslide.

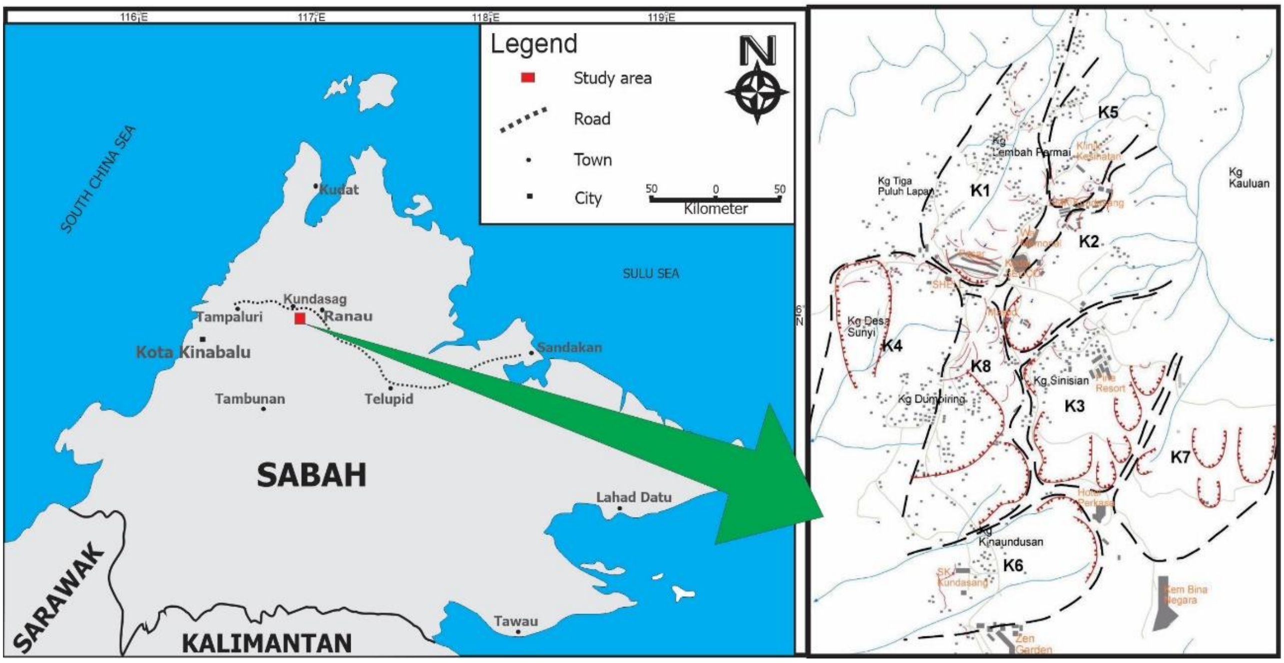

Figure 1 Kundasang landslide complex (Ibrahim Komoo & Lim Sian Choun, 2003).

GEOLOGICAL SETTING

Sabah is currently under a WNW-ESE (west northwest-east southeast) compressive stress which was generated from westward-moving of Philippine-Pacific plate against the southeast moving Eurasian plate. The WNW-ESE compression is being accommodated by northeast-southwest (NE-SW) active thrust faults, active strike-slip faults, and active normal faults of the extensional stress regime all over Sabah. Co-existence has both stress regimes along subduction-accretionary fold-thrust belts may has been attributed to gravitational forces generated by high topography (Sapin *et al*., 2013). The ongoing compressive tectonics, along the northwest (NW) Borneo Trough maybe linked to gravitational forces, collision and gravity sliding (Tongkul, 2017).

The shortening, associated with thrust faults, may have resulted in the thickening of the upper crust as the Dangerous Grounds continental crust is being overthrust by the Sabah ophiolitic oceanic crust. Sabah has been massively uplifted since the Early Miocene, with the Kinabalu pluton emplaced during the early Late Miocene and being exhumed at a rate of 7 mm per year during Late Miocene–Early Pliocene (~ 8–3 Ma ago) as the region continues to rise at a long-term rate of about 0.5 mm each year.

The Kundasang area is underlain by the Paleogene, Neogene, and Quaternary rock units such as Trusmadi formation, Crocker formation, Gravel Pinosuk, and alluvium deposit (including colluvium deposit) (Figure 2). The Trusmadi formation is a deep-sea deposit that metamorphosed to meta-sedimentary rocks. It consists of interbedded sandstone, phyllite, and slate. Some sandstone was metamorphosed into meta-sandstone. The ages of this formation are Paleocene to Late Eocene and overlain the Crocker formation with angular unconformity (Figure 2). This angular unconformity represents a fault line (Jacobson, 1970; Collenette, 1958).

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The Crocker formation is Late Eocene to late Early Miocene ages and represents flysch deposit. This formation consists of sandstone, siltstone and shale inter-bed and can be divided into three (3) units, i.e., thick sandstone unit, interbedded sandstone-shale unit and shale unit. Nondeposition activities from Middle Miocene to Pliocene was showed hiatus zone in the study area (Kundasang) unless the igneous intrusion during Late Miocene to Early Pliocene (Figure 2).

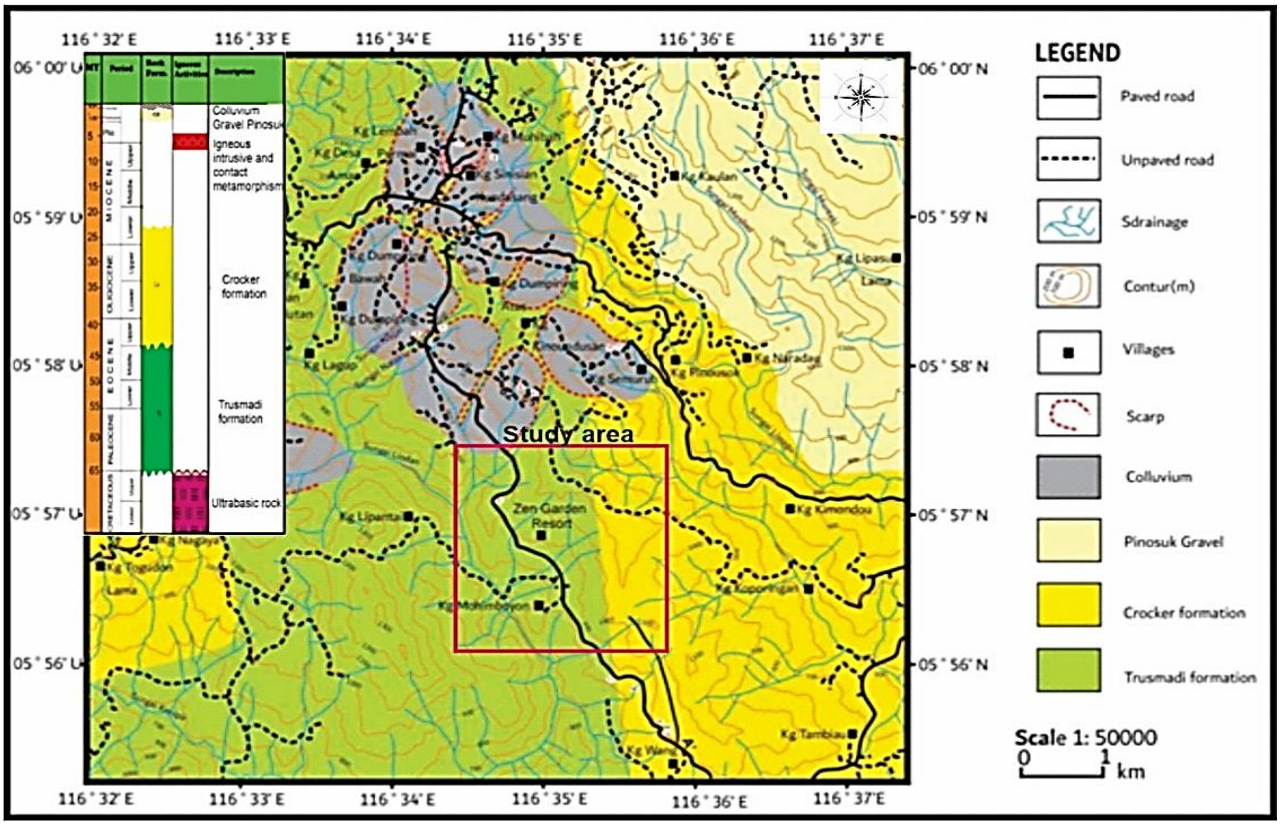

Figure 2 Geological map of the Kundasang area (left) and stratigraphic column (right) (modified from Jacobson, 1970; Immas Jangok, 2021; Amy Natasha Arjali, 2021).

The Pinosuk Gravel of till deposit was deposited during the Pleistocene surrounding Kundasang and Ranau areas. The gravel consists of Mount Kinabalu adamellite, diorite, granodiorite and granite, peridotite, Crocker and Trusmadi sandstone and lesser of basement rock unit which deposited together with/ in a clay matrix.

The alluvium deposit is Quaternary ages and underlain the low land area, along the valley and rivers. It consists of sand, silt, clay, and organic matter. The younger or recent colluvium deposit with Holocene ages locally overlain the alluvium deposit and rock formation of fail slope. This colluvium deposit is considered as in-situ alluvium deposit of the Quaternary ages.

LANDSLIDE MECHANISM

Typical landslide morphology is shown in Figure 3 which is divided into head, body, foot, and toe sections. This landslide is the reactivation of an old dorman landslide (Figure 3) and classified as a rotational clay slide (Hunger et al., 2014). The movement was involving a rotational slide. The materials are colluvium deposits which come from the old landslide and are dominated by matrix material. Then, the slope materials are classified as clay.

Figure 4 shows the chronology of the formation of a rotational clay slide of the 2011 Zen Garden Resort landslide:

A. Natural slope and water table in the Zen Garden Resort area. The slope has been undergoing natural slope equilibrium proses.

B. The morphology of the old Zen Garden landslide but the upper boundary is not found in field investigation and remote sensing study. Interview with surrounding local was made to collect the data. The transverse crack, major and minor scarp, tension crack, 1m down-thrown surface level, undulating resort road, and colluvium deposit of the old landslide are shown in the Photos in Figure 4.

C. Weathering and erosional processes on the slope surface produce smoother slopes but raise the water table. Surface levelling and fertility of secondary plant shows the natural erosional activity, infiltration, and existence of colluvium deposits from an old landslide.

D. After 20 years, the slope becomes smoother due to the natural phenomenon of slope equilibrium. The slide comes once again but moves its position towards the southern part of the study area. The rotational clay slide of the 2011 Zen Garden Resort landslide took place on the transverse crack of the body section of the old dorman landslide. This landslide is caused by about 200 m width, 450 m length, more than 20 m vertical fall, and tens of meter area thrown down the slope as well as the destruction of more than 80 room units, damages of few buildings, roads, homes and a day traffic disruption. The main scarp, tension crack, transverse crack and foot section are clearly shown in the attached Photos in Figure 4.

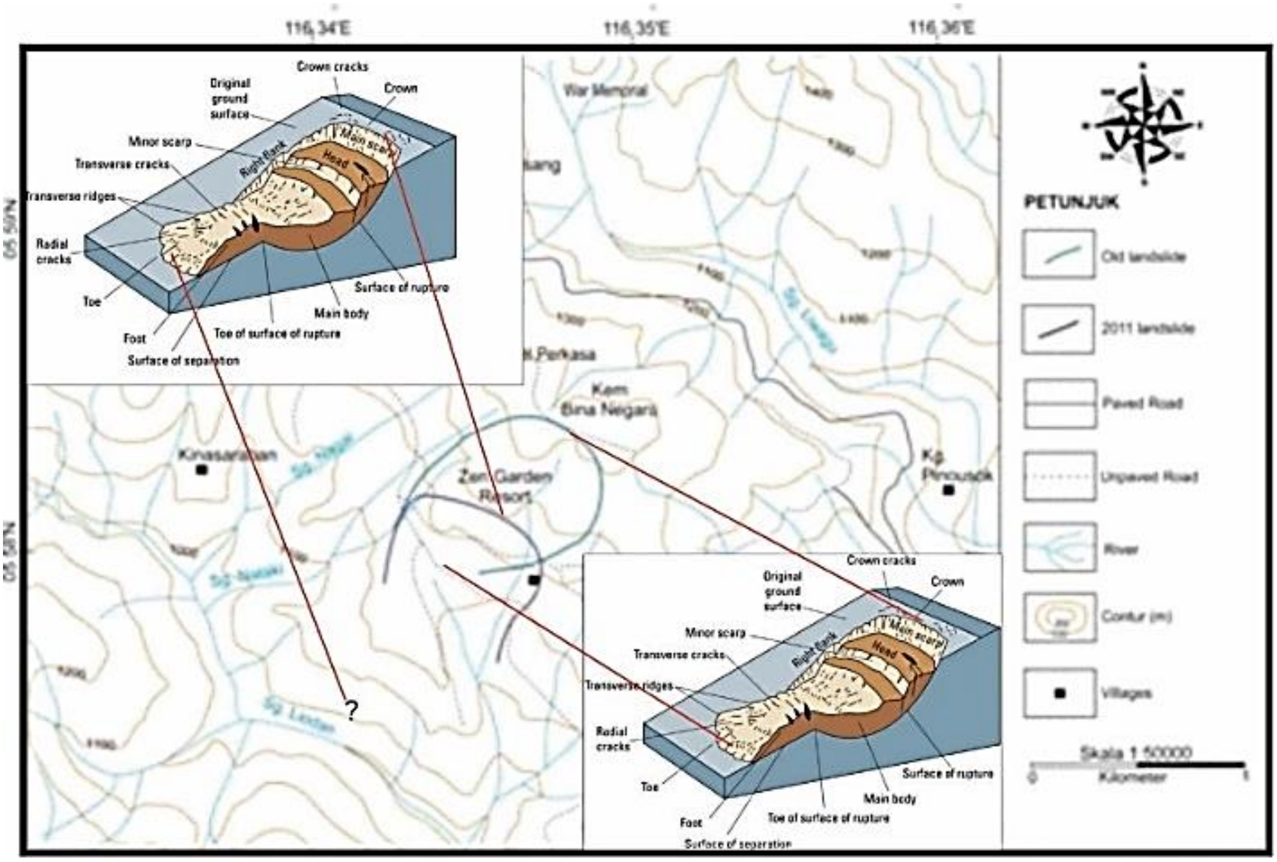

Figure 3 Location and the reactivation on the body (transverse crack) of old landslides. Upper left- old landslide morphology; Lower right- rotational clay slide of the Zen Garden 2011.

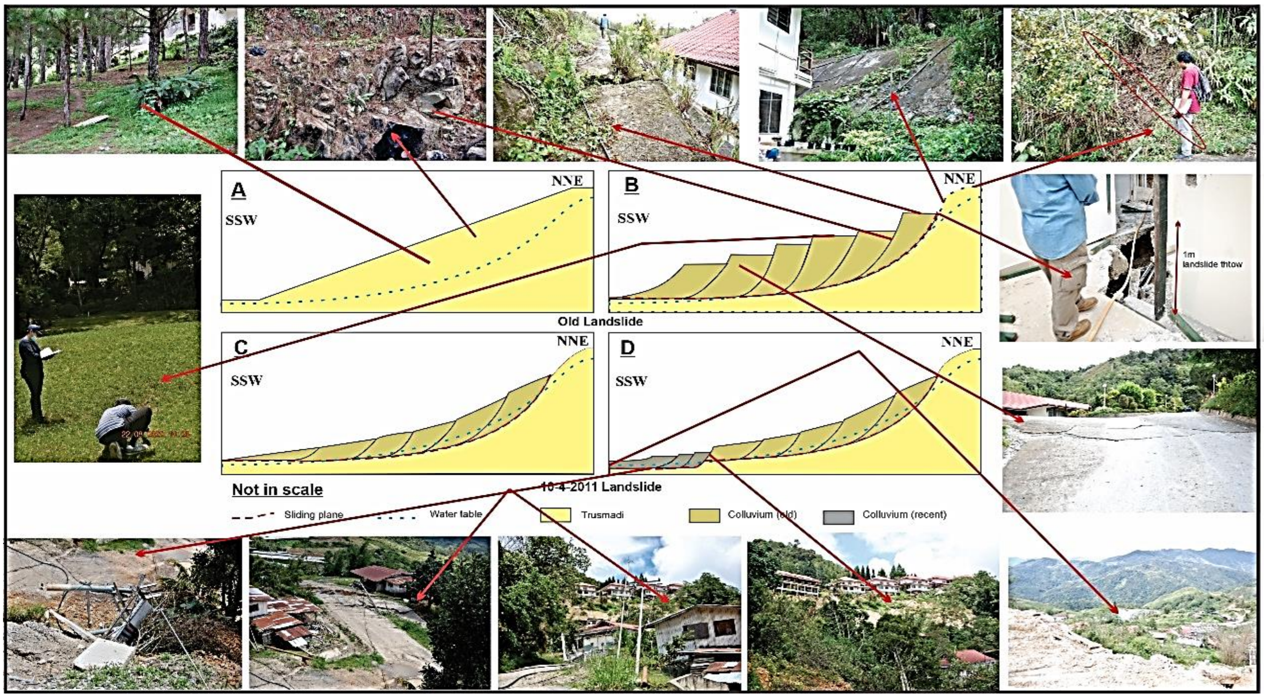

Figure 4 The rotational clay slide of the 2011 Zen Garden Resort Landslide model and the reactivation on the body (transverse crack) of old landslides with attached photos for the selected landslide section. A- Natural slope surface; B- Old landslide mechanism; C- towards natural slope equilibrium; D- rotational clay slide of the 2011 Zen Garden landslide.

TRIGGERING AND CAUSAL FACTORS

The landslides triggering and causing factors for the rotational clay slide of the 2011 Zen Garden landslide were summarized in Table 1. This factor was design base on geological observation and mapping as well as sampling, laboratory, and data analysis studies.

Triggering factors

Triggering factors refer to an event or episode that potentially increases slope instability and is only represented by the prolonged moderate to occasionally heavy rainfall.

Table 1 Summary of the triggering and causal factors for rotational clay slide 2011 of Zen Garden landslide.

Trigger	Causes	
	Natural	**Artificial**
prolonged moderate to occasionally heavy rain	tectonic uplift	excavation of the slope or its toe
	weak material	cut and fill activity
	weathered material	subterranean erosion
	sheared and jointed material	irrigation or water leakage from utilities
	adversely orientated mass discontinuity or structural discontinuity	vegetation removal or deforestation
	contrast in permeability.	
	Water table	

Prolonged moderate to occasionally heavy rainfall

The annual rainfall for the Kundasang area is 2440 mm on average and experienced prolonged light rain type (5-20 mm/days) or moderate with occasional heavy rainfall from January to June 2011. The landslides on 10 April 2011 occured in only 37mm of rainfall but occasional intense rainfall (until 110 mm/day) happened before (Figure 5). That prolonged moderate to occasional heavy rainfall will raise groundwater level rapidly condition to the ground surface and this would result in a sudden increase in pore pressure which would reduce the shearing resistance of geomaterial and finally lead to a failure or landslide.

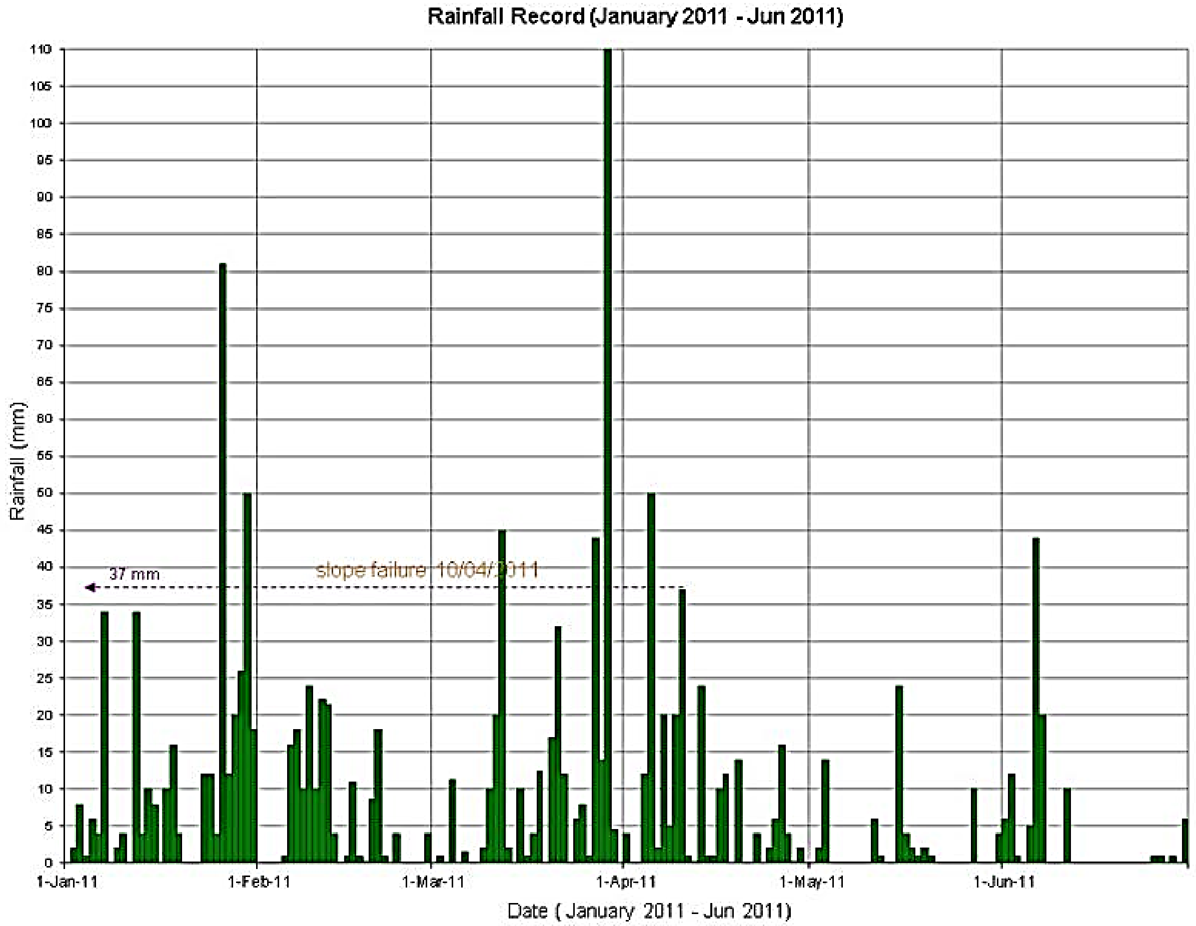

Figure 5 Daily rainfall record from January to June 2011 in the Kundasang area (source from IKRAM, 2011).

Causal factors

The causal factor is "a condition or actions that influence individual assessment of the situation" or refers to an issue, feature, or property that tends to reduce slope stability. The causal factors can be divided into natural and artificial. The natural causal factor consists of tectonic uplift, weak material, weathered material, sheared and jointed material, adversely orientated mass discontinuity or structural discontinuity, contrast in permeability and water level. The artificial causes are related to excavation of the slope or its toe, cut and fill activity, subterranean erosion, irrigation or water leakage from utilities, and vegetation removal or deforestation (Table 1).

Tectonic uplift

The Lobou-lobou fault zone is part of a regional extensional zone trending NW-SE along the west coast of Sabah. The NW-SE trending normal fault appears to be not directly related to the NW-SE compression but is due to gravitational sliding on an uplifted mountain belt. The uplift belt is a tectonic plate collision zone in Sabah, informally referred to as the Sabah Suture Zone (Figure 6). Continued compression in Sabah created differences of roughly around 4000 m in elevation of the upper crust - the Crocker Range is around 2000 m above sea level and the NW Borneo trough around 2000 m below sea level. As mentioned earlier, GPS readings in West Sabah indicate gravity sliding or collapsing the NW in response to significant thickening of the upper crust due to collision (Tongkul, 2015).

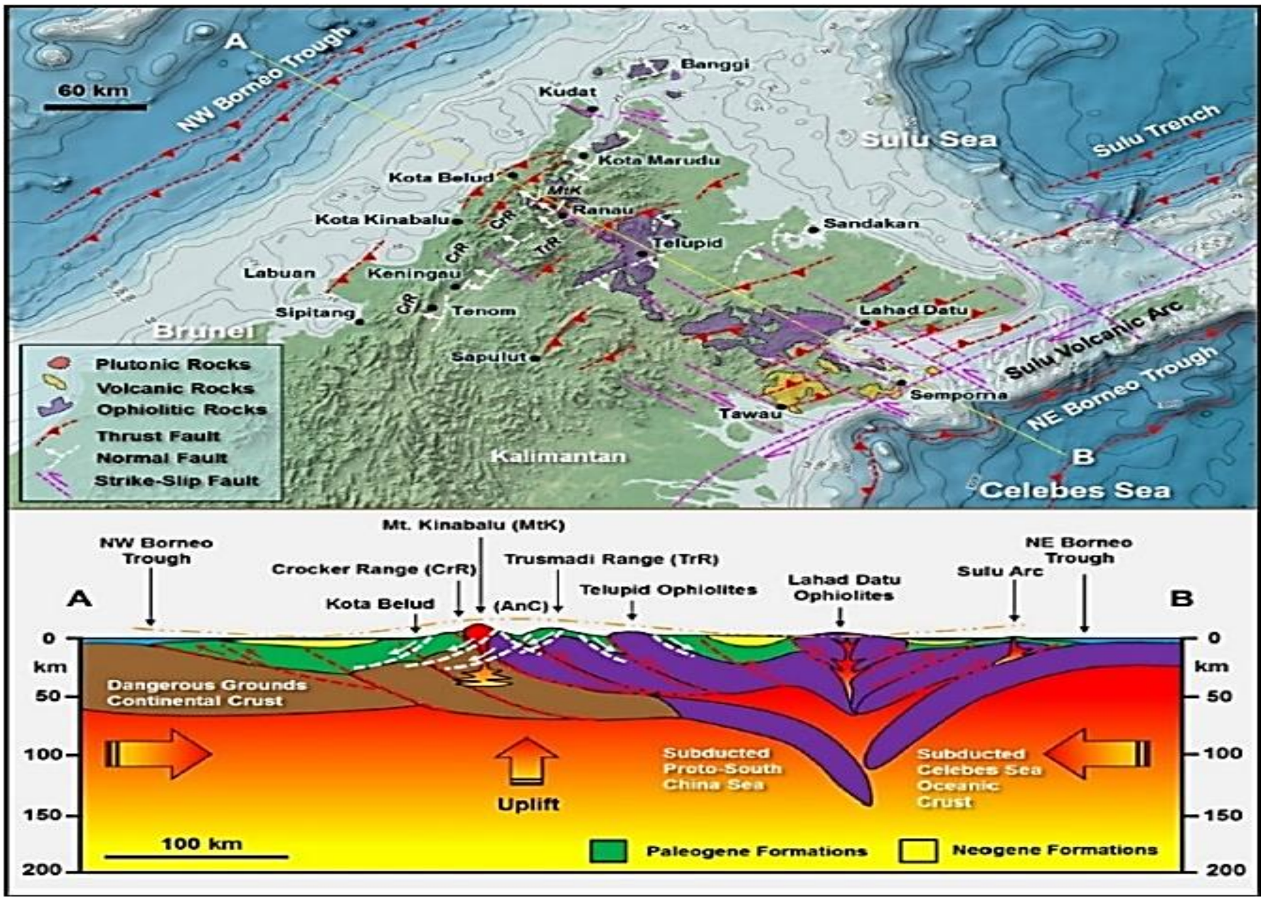

Figure 6 Tectonic cross-section of Sabah showing post-collision collapse due to gravity sliding producing deep-seated normal fault (white line) in response to significant thickening and uplift of the Crocker Range upper crust. A- northwest; B-southeast (adapted from Tongkul, 2015).

The uplift belt or tectonic plate collision zone is continuing to compress and produce high-land areas around Crocker Range including the study area in Kundasang. This high elevation has been reducing the stability of the slopes. The higher the area, the steeper the slope and the less stable the slope. The natural tectonic uplift by collision has caused the slope to decrease in resisting force and become landslide prone.

Weak material

There are four (4) rocks unit underlying the study area namely Trusmadi formation, Crocker formation, Pinosuk Gravel, and Colluvium deposit (alluvium) (Photo 1). Laboratory analysis found that the Colluvium deposit is weak (19.52 MPa) by Lithological Unit Thickness, LUT method (Ismail Abd Rahim et al., 2009). The characteristics of Pinosuk Gravel which is almost like Colluvium (i.e., unconsolidated deposit and consists of rock block and matrix materials) assumed as a ‘weak’ rock unit also. The Uniaxial Compressive Test (UCT) was conducted on Trusmadi and Crocker formations rocks and found the strength to be medium (Table 2). Then, it concludes that the strength of rock units varies from ‘medium to weak’ and is prone to landslides or less resisting force.

Weathered material

Generally, the Kundasang area is experiencing a humid tropical zone of climate with high about 2500 mm of annual rainfall, often seasonal with high temperatures for a longer period. The weathering process is much more progressive due to the abundance of rainfall and moisture, thus accelerating the transformation of homogeneous subsurface material into heterogeneous subsurface materials. The present subsurface materials have suffered from an additional weathering process thus producing another poor rock mass quality. The weathered (class IV) Crocker formation and Trusmadi formation are shown in Figures 7A & 7B, respectively. These weathered rock units are normally characterized as ‘weak’ rocks which have less resisting force and lead to landslides.

Photo 1 Moderately strong to weak rock units’ appearance. A& B- Sheared meta-arenite and meta-argillite (dark) of Trusmadi formation; C- Crocker formation sandstone; D- Pinosuk Gravel; E&F- colluvium deposits.

Table 2 Strength of rocks unit.

<table>
<tr><th rowspan="2">Rock unit</th><th rowspan="2">Strength (MPa)</th><th colspan="2">Classification</th></tr>
<tr><th></th><th>Overall</th></tr>
<tr><td>Crocker formation</td><td>30-40*</td><td>Medium</td><td rowspan="4">Medium to weak</td></tr>
<tr><td>Trusmadi formation</td><td>53.6#</td><td>Medium</td></tr>
<tr><td>Pinosuk Gravel</td><td>-</td><td>Weak (?)</td></tr>
<tr><td>Colluvium (Trusmadi formation)</td><td>19.51#</td><td>Weak</td></tr>
</table>

Note: # - Immas Jangok (2021); Amy Natasha Arjali (2021)
* - Ismail Abd Rahim (2011)

In the weathering process especially for class IV, the old discontinuity plane normally disappears. So, the discontinuity observation during the survey depends on relic structures on the limited outcrop. The effect of the weathering activity on discontinuities is the formation of planar failure in the Markland test (Figure 7C). Highly weathered Trusmadi formations (underlain Zen Garden Resort) are locally potential to produce a high concentration of kaolinite and illite. This clay easily absorbs water and expands. Then, facilitate mass movement by reducing the resisting force in slope-forming rock materials, especially during heavy or prolonged rainfall (Baba Musta, 2021).

Figure 7 The weathered (class IV) rock unit. A- Crocker formation; B- Trusmadi formation; C- planar failure.

Sheared and jointed material

Field observation shows that the rock unit was highly jointed and sheared (Photo 2). The discontinuities are varied from four (4) to six (6) sets. Some as individually and some are intersected with other sets to 'daylight' on slope face to form planar, toppling, and/ or wedge types of mode of rock slope failures. These show that the occurrence of joint and shear planes has naturally caused landslides by decreasing resisting force for slope-forming rock materials.

Photo 2 Fractured and sheared meta-sandstone of Trusmadi formation forming the wedge failures, toppling failure, and rock fall (A-C).

Adversely orientated mass discontinuity or structural discontinuity

Adversely oriented discontinuities (bedding) or structural (fault) discontinuity with slope face have been observed in the study area. The first example is shown in Figure 8. This Trusmadi formation was cut by six (6) discontinuity sets including joint, bedding, and fault planes. The intersection of joint 1 (J1) and bedding (B) planes was 'daylight' on slope face or contributed to 'unfavourable' discontinuity orientation. This was causing the formation of potential wedge failure. This indicates that adversely oriented discontinuities are a naturally causal factor for landslides.

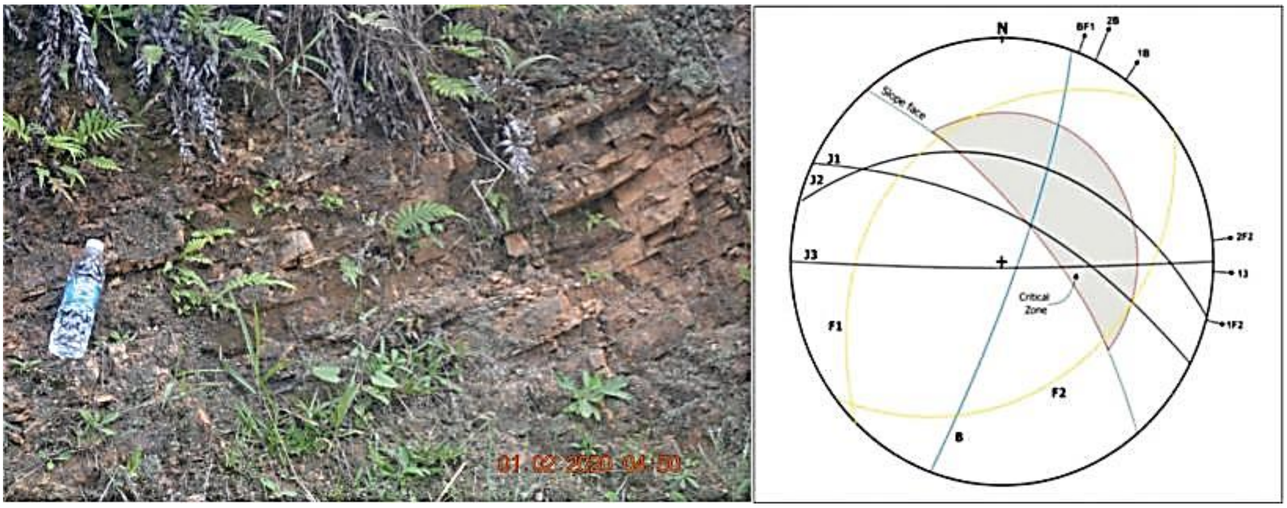

Figure 8 Trusmadi formation's outcrop and wedge failure from Markland test representing adverse discontinuity orientation with slope face.

In general, the Kundasang area is situated at the intersection of major fault zones of the Quaternary ages as highlighted in Tjia (2007) (Figure 9). The study area is situated inside the northern part of Crocker Faults Zone, CFZ which is known as an oblique normal fault of Lobou-Lobou Fault Zone (LFZ). The slope face is facing the lower altitude of sg. Kayongang valley in LFZ and the movement of this fault has broken and fractured the bedrock along the fault line and slope toe (JMGM, 2012). This condition has been reducing toe support and shear strength (resisting force) but raising the driving force (plus the weight or gravity) of the slope forming rock material, especially during rainy days. Then, the adverse orientation of structural discontinuity has been causing a landslide-prone condition in the study area.

Contrast in permeability

Field capacity condition, temporary preached water table, and artesian condition are caused by permeability contrast of colluvium and bedrock unit which accommodate landslide to occur. Field capacities achieve when water drains from the soil (Colluvium) at the same rate as it is added (recharge) by at least 267 mm of rainfall (Campbell, 1975).

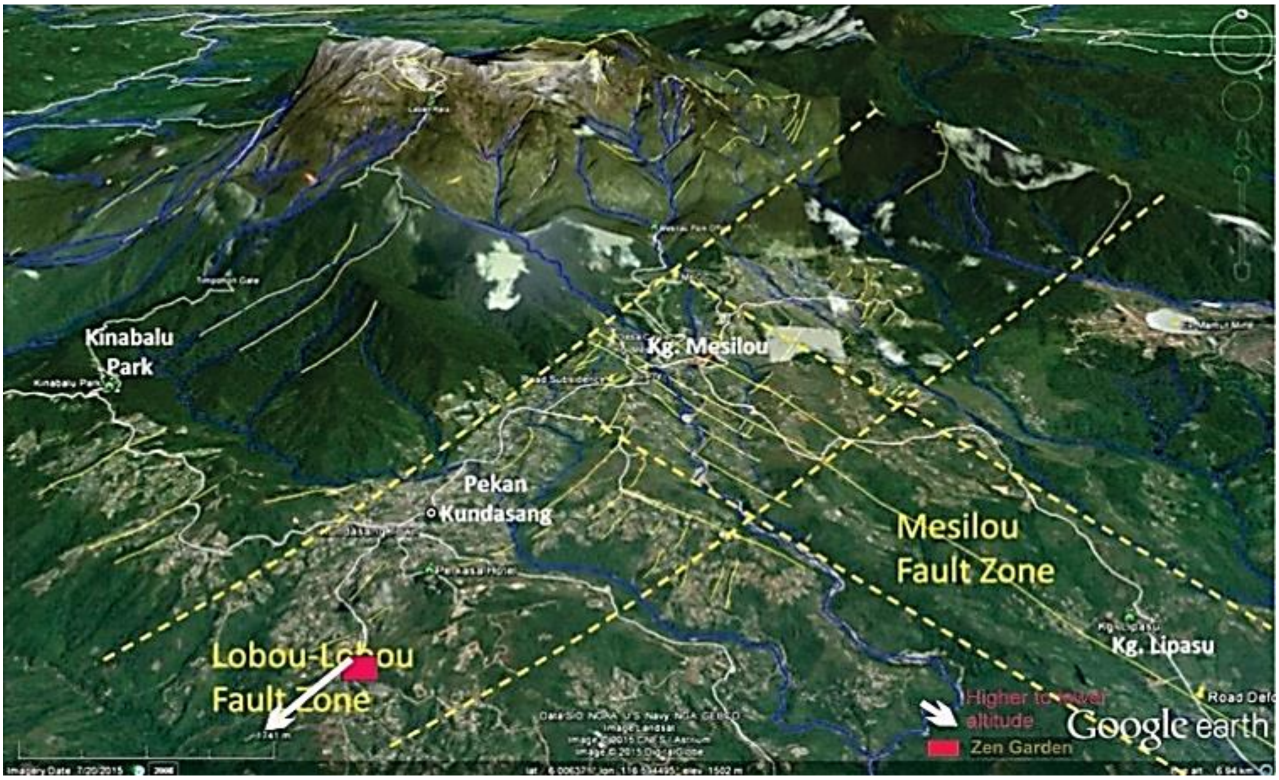

Figure 9 Normal fault scarp (in yellow) trending NE-SW across the Kundasang- Mesilou areas. These faults are grouped under the Lobou-Lobou Fault Zone. White arrows show driving force direction). Adapted from Ismail Abd Rahim et al. (2015).

In the 2011 Zen Garden Resort landslides, the rainfall is only 37 mm, and it was unable to bring the soil (Colluvium) into field capacity condition. But, according to Figure 5, there was 100 mm of rainfall thirteen days before the event and prolonged moderate to occasional heavy rainfall for four (4) months. Then, the field capacity may be achieved during that event. The slope material (Colluvium) was saturated and resisting force was decreased then landslides occur.

The thickness of Colluvium in the studied slope varies from 10-20m (Figure 10). The rainfall intensity during that event is only 1.54 mm/hrs. which is far from the suggested values (rainfall intensity of 3 to 4 mm/hr.) for the formation of a perched water table. But the daily rainfall ranges from 0.5 to 4.85 mm/hrs. for several days before the event may cause the water to percolate into colluvium and exceed the rate of seeping into bedrock. This condition forms a temporary perched water table in the Colluvium, and a downslope seepage force develops within the Colluvium. Excess pore pressures develop, the Colluvium becomes buoyant, the resisting forces are decreased, and landslides will occur (Turner, 1996; Kesseli, 1943).

Permeability contrasts within the bedrock may result in artesian conditions (Turner & Schuster,1996). The water contains Colluvium (dark brown) and bedrock units (dark green), and artesian (dark brown greenish color) conditions are shown in Figure 10.

This artesian condition was causing the water flow to concentrate within the Colluvium by the differences in permeability within both the Colluvium and the bedrock (Ellen, 1988) and facilitated landslides to occur.

Water table

The underground water table in the study area is high due to the natural surface erosion for the slope equilibrium process after the old landslide phenomena (refer to Figures 4B & 4C). The barren surface increased and the Colluvium deposits formed along the sliding surface. Rainwater was infiltrated freely by the barren area to increase water recharge, while soft Colluvium deposit is actively eroded and lowered at the surface level. These in turn will generally raise the water table in the slope areas.

The seismic profile in Figure 10 also shows the thin Colluvium deposit and high-water table of less than 20m depth. This high-water table will allow fast saturation conditions and reactivation or/ and creation of sliding plane, sliding process or landslide.

Artificial Causing Factors

The artificial causes are related to excavation of the slope or its toe, cut and fill activity, subterranean erosion, irrigation or water leakage from utilities, and vegetation removal or deforestation.

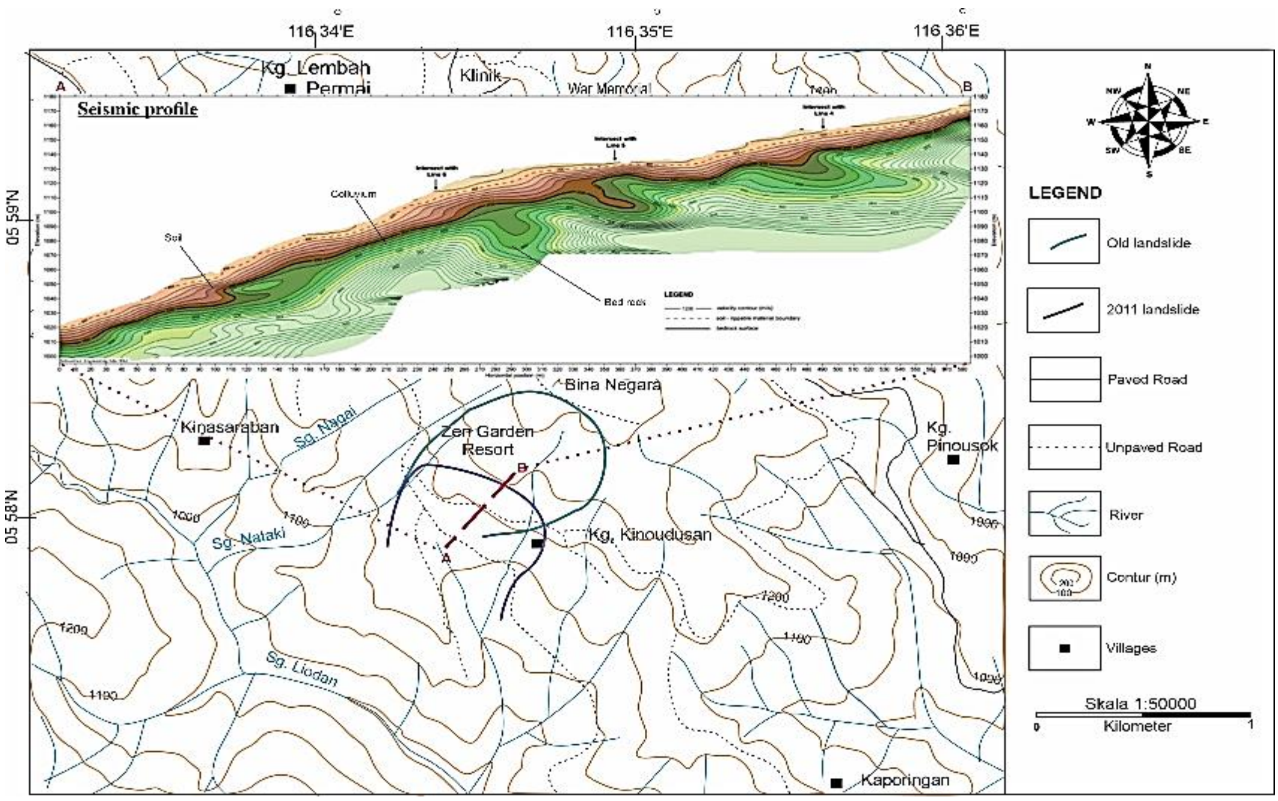

Figure 10 Seismic profile showing bed rock (Trusmadi formation), colluvium and soil. The 10-20m thick colluvium deposit can reach field capacity condition and perched water table. The dark brown and green show the contrast in permeability between colluvium deposit and

Excavation of the slope or its toe

The purpose of excavating the slope and slope toe is to stabilize and protect slopes as well as provide accessibility. The slope face is normally excavated for optimum slope angle, to reduce erosion, infiltration, and weathering rates, and to control surface water (Photo 3). But improper excavation will result in causing slope failures. Such as inaccurate optimum slope angle, improper berm drains, infiltration, and surface water controls.

Slope toe excavation was conducted to provide facilities for the resort itself or local residence surroundings (Photo 4). But improper excavation on slope toe has caused slope failure due to loss of or reduction of resisting force for slope forming materials.

Photo 3 Slope excavations. Construction of optimum slope angle, terrace, berm drain and shotcrete to increase resisting forces.

Cut and fill

There are about two square kilometers have been cut and filled to design and build the facilities in Zen Garden Resort (Figure 11). The cut and fill materials on the original ridge topography area may also contribute to weakening the ground foundation in a long-term condition since water flow, soil, and rock condition were already disturbed and altered. These activities altered the slope faces and drainage patterns in that area. The slope cutting has risen the rate of weathering, erosion, and infiltration. These in turn were reducing the resisting force of the slope.

Filling the slope or an area such as a lower area, major, minor valleys or a reservoir into a flat area has been altering the natural environment, drainage pattern, or types (Photo 5A). These alterations were normally causing blockage and inappropriate recharge and discharge of water into the drainage system or reservoir (Photo 5B). These cut and fill activities have changed water balance or equilibrium then increasing the driving force on the slope face.

Photo 4 Construction of minor roads at slope toe for the accessibility of the surrounding residents.

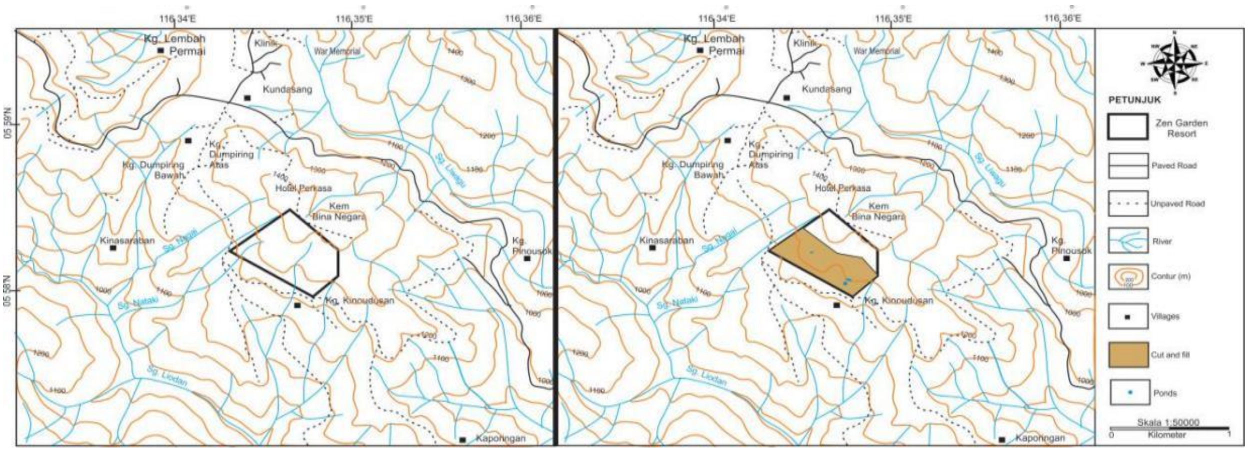

Figure 11 Zen Garden Resort landslide area and cut and fill section. Some rivers were filled and altered for this development.

Photo 5 A- Evidence of old drainage channel and landslide which has been cut (for foundation and building) and filled (red circle) and alteration of natural drainage by the construction of concrete drainage (yellow square). B- filling activity and changing natural drainage channel into the culvert.

Subterranean erosion

Subterranean drainage is a subsurface drainage system which is not seen from the surface. Normally subterranean drainage is made of PVC (Photo 6B) in various sizes or constructed of concrete (Photograph 6C). There is no landslide issue if this subterranean drainage is working. The problem is if the channel break or leakage (Photo 6A) then, subterranean erosion will occur. This leakage will erode the slope forming rock materials and finally reduce the resisting force.

Irrigation or water leakage from utilities

Kundasang is a highland area and doesn't have a proper water supply station except for collected from the natural spring water by Sabah Drainage and Irrigation Department, JPS. The activities or operation in Zen Garden Resort was conducted by using the water supply from JPS and collecting rainwater from Resort's personal tank. The photograph below shows the Resort water tank (in black color, Photo 7A) and irrigation system (Photo 7B)

The landslides become an issue if there is leakage in the tank and irrigation networks. This leakage will behave like rainwater that decreases the resisting force of rock-forming slope materials. The same condition will happen if a concrete ditch leaks by the occurrence of faults (Photo 7C).

Photo 6 Subterranean erosion. A- water leakage (red circle) due to broken channel or connection failure: B- subterranean drain (PVC) that is connected to the river; C- a small pond that is connected by the subsurface concrete drain. This pond is believed to be a small old river channel that fills and alters into a subterranean concrete ditch.

Photo 7 Water leakage from utilities. A- water tank to reserve water supply; B- part of irrigation or drainage system around this Resort; C- concrete ditch filled with water shows a fault (?) form fracture.

Deforestation/ Vegetation removal.

Deforestation or vegetation removal is a common practice by the local people for their own good. The Zen Garden Resort area was occupied by them for so long and just depended on agriculture. After some time, the area was developed for the Resort. Land clearance or vegetation removal was conducted but agricultural activity continued by the locals outside the Resort area.

Agricultural activity is still can be seen today (Photo 8). The land clearance has been causing the rate of erosion, weathering, and infiltration (runoff) to increase but reducing resisting force for slope forming rock material and contributing to landslides occurrence.

Photo 8 Vegetation removal or deforestation and planting activity by the locals.

CONCLUSIONS

The triggering and causal factors for the rotational clay slide of the 2011 Zen Garden Resort landslides are as follows:

i. Triggering factors are prolonged moderate to occasionally heavy rain.
ii. The causal factors are divided into natural and artificial sub-factors.
   - Natural sub-factors are tectonic uplift, weak materials, weathered materials, sheared or jointed materials, adversely oriented mass discontinuity or structural discontinuity, a contrast in permeability, and water table.
   - Artificial sub-factors are excavation of the slope or its toe, cut and fill, subterranean erosion/ piping, irrigation or water leakage from utilities, and deforestation or vegetation removal.

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