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Geological investigation on Ruan Changkul landslide

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Abstract: Sarawak's worst landslide occurred when a catastrophic slope movement destroyed an eight-door long house and two nearby houses, and claimed sixteen lives in the incident at Ruan Changkul, Simunjan on the 28th January 2002. The landslide occurred in Serian Volcanic derived soils. The affected area was located within the hillslopes with angles ranging from 25° to 40°. Field inspection in the vicinity of the landslide area revealed small recently active landslides and slope failures, indicating slope instability.

Based on the site investigations and soils analyses, the contributory factors leading to the incident were determined. The landslide was triggered by prolonged torrential rainfall.

Abstrak: Satu kejadian gelongsoran tanah yang terburuk di Sarawak berlaku di Ruan Changkul, Simunjan yang telah memusnahkan sebuah rumah panjang lapan-pintu dan dua buah rumah yang berdekatan serta mengorbankan seramai enam belas orang. Gelongsoran tanah tersebut berlaku di tanah sisa yang terhasil dari peluluhawaan batuan Serian Volkanik. Kawasan yang terjejas terletak di atas cerun-cerun bukit dengan sudut yang berjulat dari 25° ke 40°. Pemeriksaan lapangan di sekitar kawasan yang terjejas mendapati beberapa kesan kejadian gelongsoran tanah dan kegagalan cerun yang baru, menggambarkan keadaan cerun yang tidak stabil.

Berdasarkan kepada penyiasatan tapak dan analisis makmal faktor-faktor penyumbang kepada kejadian tersebut telah ditentukan. Hujan lebat yang berpanjangan merupakan pencetus kejadian gelongsoran tanah tersebut.

INTRODUCTION

The Ruan Changkul area is located about 64 km Northeast of Serian town (Fig. 1). The area can be easily accessed by the tarred road to Simunjan. It is a low-density population with a total of 69 residents residing in the area. The landslide occurred on Monday, 28th January 2002 at about 1.00 a.m. The landslide destroyed an eight-door longhouse and two nearby houses. Sixteen villagers died and five others were injured. Following the initial emergency actions, the other houses were evacuated due to the likelihood of recurrence of slope movement.

This incident, received wide media coverage and raised concern from the authorities and local population over the stability of the surrounding slopes. The Minerals and Geoscience Department Malaysia, Sarawak made a reconnaissance visit on 28th January 2002 followed by detailed site investigation between the 6th to 20th February 2002 at the area concerned.

GEOGRAPHY

The area is located in the vegetated hill ridge trending east-west direction, bordered by lowland area on the northern part (Fig. 2). Sungai Spaoh is the main river in the region, which flows westwardly. The population of the area is made up predominantly of Ibans, mostly farmers, growing wet paddy in the swampy areas, and pepper and hill paddy in the hilly region. It is hot and humid tropical climate throughout the year. Mean daily temperature ranging from 23°C to 32°C during the day. It experiences two monsoonal changes. The northeast monsoon usually occurs between November to February, bringing heavy rainfall. The southwest monsoon is usually less wet. Except for monsoonal changes, the climate remains fairly stable throughout the year.

GEOLOGY

The area is underlain by the Serian Volcanic formation; it consists predominantly of andesite, basalt, limestone and diorite (Haile, 1954) forming the major terrain in this area. Fresh outcrop of highly fractured Serian Volcanic is exposed at the lower part of the affected slope (Fig. 3). Three sets of joint were determined, i.e. 12°/N45°E, 48°/E45°W and 85°/S45°W.

The lowland in the northern portion of the area is covered by soft unconsolidated Quaternary alluvium of clay and sand overlain by peat. The area is mostly covered by thin to thick (<1 m to >5 m) overburden; dominantly residual soils derived from the parent material forming dark brown and yellowish red, mechanically loose unconsolidated material.

LANDSLIDE INVESTIGATION

Detailed landslide investigation was carried at the affected area and its surroundings. The main objectives of

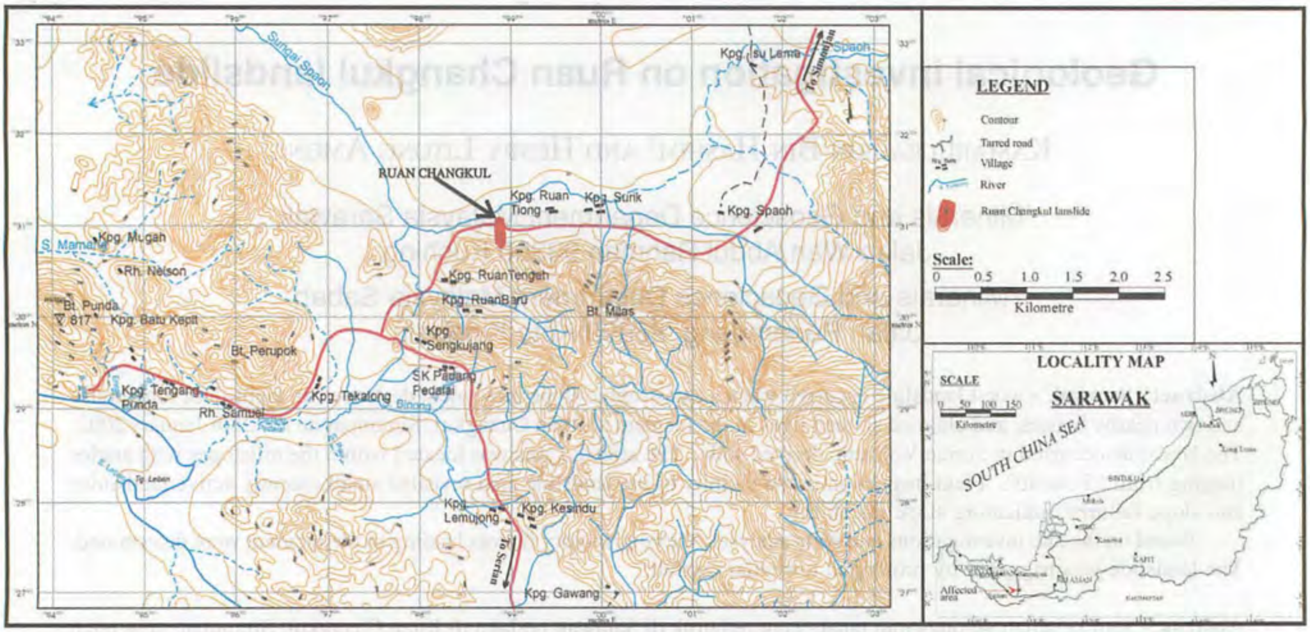

Figure 1. Map showing the location of the Ruan Changkul, Simunjan area.

Figure 2. Aerial photo of the Ruan Changkul Landslide (Courtesy of Berita Harian).

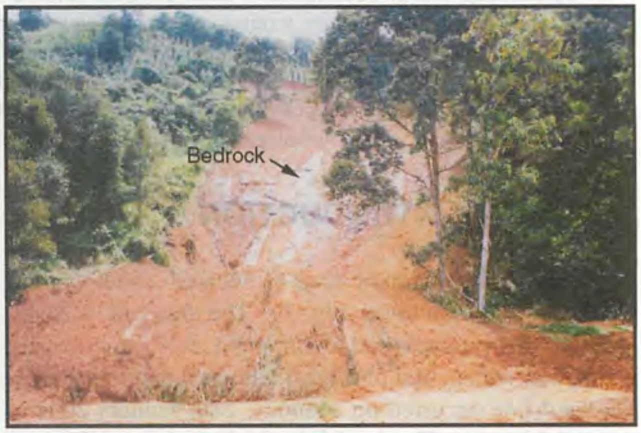

Figure 3. Exposed bedrock of Serian Volcanic.

Figure 4. Collecting soil samples using hand auger.

the site investigation among others are as follows:

i. to determine the geological factors contributing to the landslide;
ii. to delineate the areas of landslide occurrence, and
iii. to incorporate temporary remedial measures where possible to prevent further deterioration.

The study was started with an extensive review of topographical map and geology of the area. The geological literature by Haile (1954) provided excellent Tertiary to Quaternary geological history of the area.

Detailed engineering geological mapping to determine, and thereby understand, the nature of the ground conditions was done comprehensively based on guidelines by Geological Society Engineering Group Working Party (1972), Culshaw *et al.* (1987) and Dearman (1991). This mapping consisted of the following tasks:

i. investigating 400 x 150 m^2 of the mapping area, right to the heavily vegetated areas;

ii. recording all instability features onto the base map of 1:1,000;
iii. filling out a landslide investigation worksheet;
iv. noting any hydrologic features (springs, ponds etc.);
v. taking photographs;
vi. determine the thickness of the residual soil by hand auger.

The area was mapped in detail at two different stages. The first mapping of the landslide was performed with a classical approach, traversing the area using the 100 m measuring tape and compass at a scale 1:1,000. The second mapping was done comprehensively with a electronic total station at a scale of 1:1,000.

The laboratory tests were performed on samples collected at five locations from the both flanks and crown. Sampling of residual soils was done using the hand auger. Tests were performed for the following soil properties:
i. grain size distribution,
ii. Atterberg limits,
iii. moisture content,
iv. unconfined compressive strength, and
v. permeability

The tests are essential to evaluate the material properties as a comparison for use in the vicinity of the affected area.

RESULTS

Hand augering was carried out to determine the bedrock-soil contact (Fig. 4). The contact is mainly transitional and defined by a zone of weathered bedrock (Grade V - Grade III). The augering work only characterises the upper softer overburden layer whereas harder bedrock is not represented. The bedrock-soil contact is of great importance because it marks a change in strength of materials and as a result, sliding planes occur at this contact. Thickness of the residual soils from auger hole (Table 1) and observation on the exposed soil profile varies depending on topographical relief. The thickness ranges from <1 m thick on steep slopes to >5 m thick on gentle to level slopes. Material properties from the samples collected are shown in Table 2.

Table 1. Thickness of residual soil determined by hand auger.

Auger Hole No.	Thickness (m)
RC1	6.3
RC2	5.7
RC3	4.9
RC4	1.2
RC5	5.5

Grain size distribution

The grain size distribution was determined by sieve and hydrometer analysis. Based on its texture, the dominant soil is clayey SILT with some sand and siltstone fragments. The soil colour slightly varies from dark brown to yellowish red.

Moisture content

The natural moisture content of the samples is less variable, from 44.9% to 59.9% and slightly lower than the liquid limit. Values >40% indicates saturated soils (Lambe and Whitman, 1969).

Atterberg limits

The range of plastic limit (PL) varies from 35% to 52%, liquid limit (LL) ranges from 57% to 71% while the plasticity index (PI) varies from 17% to 28%. The liquid limit (LL) value can be classified as high plasticity soils, suggesting a low bearing capacity and a high shrink-swell potential (Berkman and Ryall, 1976) whereas the plasticity index (PI) value can be classified as highly plastic.

Unconfined compressive strength

The soil is stiff indicated by unconfined compressive strength values range from 185 kPa to 233 kPa.

Permeability

The presence of clay materials led to the slightly permeable residual soils layer. The magnitudes of the permeability value, *k* determined for two samples at different depths are 4.481 x 10^{-8} m/s and 3.711 x 10^{-8}m/s.

Table 2. Properties of residual soils within the extent of the landslide area.

Sample	Sampling Depth (m)	Colour	Grain Size Distribution				Moisture Content (%)	Atterberg Limit			Unconfined Compressive Strength Test (BS 1377 : Part 7 : 1990), (kPa)	Permeability, *k* (Falling Head Permeability Test), (m/s)
			Clay (%)	Silt (%)	Sand (%)	Gravel (%)		Liquid Limit, *LL* (%)	Plastic Limit, *PL* (%)	Plasticity Index, *PI* (%)		
RC 1	5.0	Dark brown, yellowish red	16	48	27	9	44.9	57	40	17	233	3.711e-8
RC 2	4.0	Dark brown, yellowish red	42	40	16	2	58.4	71	47	24	-	-
RC 3	3.5	Dark brown, yellowish red	27	39	28	6	51.9	69	48	21	316	4.481e-8
RC 4	1.0	Dark brown, yellowish red	35	33	25	7	45.8	69	52	17	185	-
RC 5	5.0	Dark brown, yellowish red	26	44	22	8	49.2	63	35	28	-	-

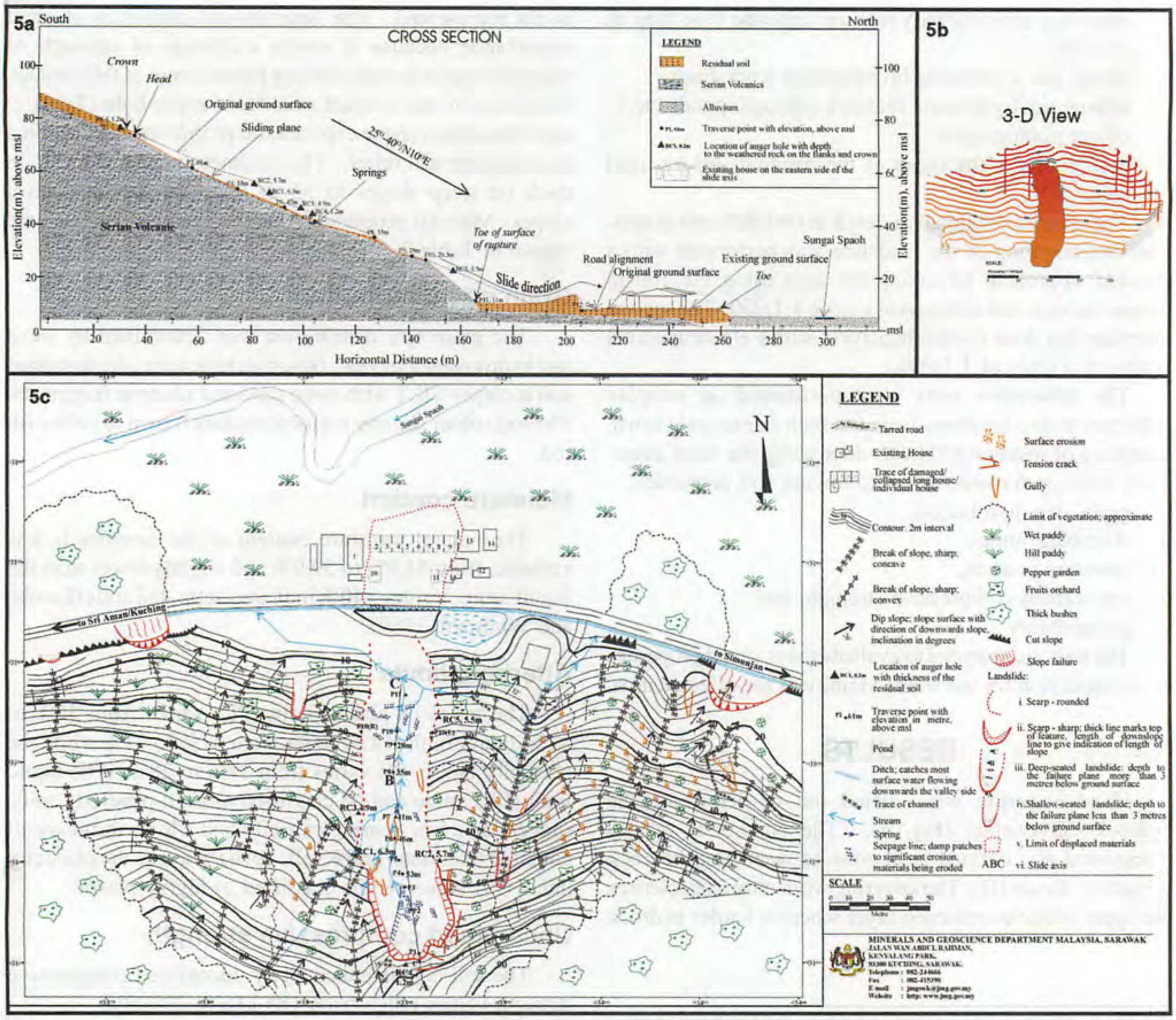

Figure 5. (a) Engineering geology plan of the Ruan Changkul area. (b) Cross section of the area affected by landslide. (c) 3-D view of the affected area.

LANDSLIDE DETAILS

General

The landslide occurred on a hillslopes with angles ranging from 25° to 40°. The affected area reached the maximum relief of 76 m above mean sea level (Fig. 5a). The length of the ruptured surface is 170 m long from crown to foot. The maximum width of the scar is 40 m wide whereas the depth to the ruptured surface ranges from 2 m to 9 m deep. The main body is considerably flatter than the top. The failed mass consists of large amount of debris with an approximate volume of 20,000 m^3 to 22,000 m^3 wet slurry, which indicates very high infiltration. The failed mass ends approximately 100 m from the top of surface of rupture to the toe marked by a 3 m drop-off to undisturbed ground at the valley side. Denuded area is oblong bowl-shaped in plan view (Figs. 5b and 5c).

Landslide Associated Features

Morphology

Active features found in the affected area contained the most pronounced morphological changes to the slope. The main scarp is sharp, bare soil escarpment, with concave-shaped, located at the uppermost scarp, approximately between levels 60 m to 70 m above msl (Fig. 6). The main scarp is approximately 30 m wide and 70 m long, with vertical height ranging from 1 m to 4.5 m, steep to near vertical (65°-85°) surface, with no vegetation left standing. Minor scarps were observed within the moving mass and mark the beginning or end of a down drop block or bench (Fig. 6). These scarps are morphologically similar to the main scarp but with length <5 m.

Other prominent features observed are the shear zones forming the right and left flanks (Fig. 6). Both flank

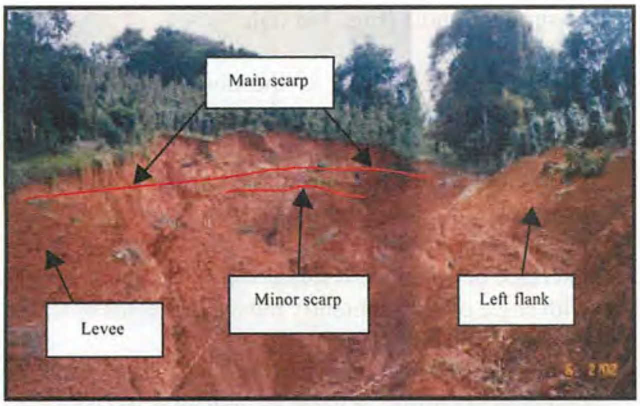

Figure 6. View of the landslide looking up the head scarp.

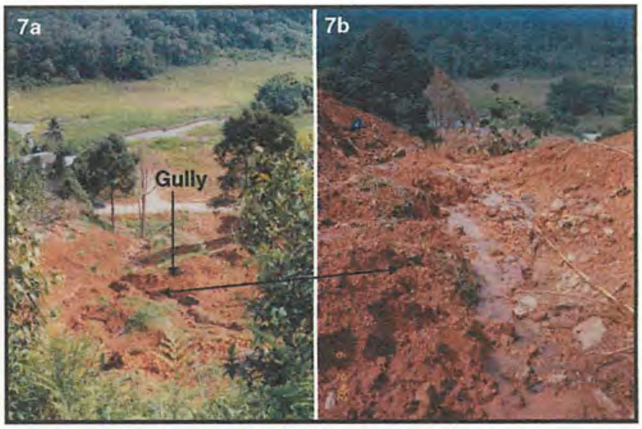

Figure 7. Irregular, gentle to slightly flat main body of the landslide showing a) gully and b) residual soil lobe.

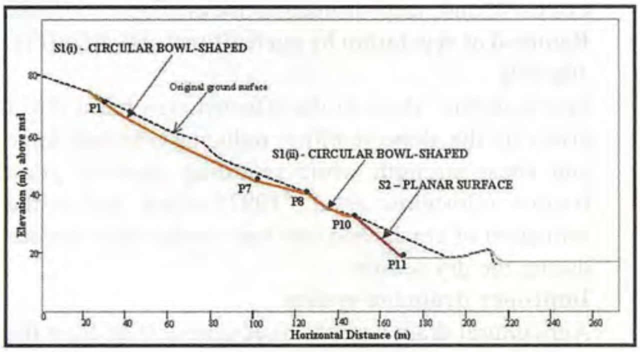

Figure 8. Sliding planes of the landslide.

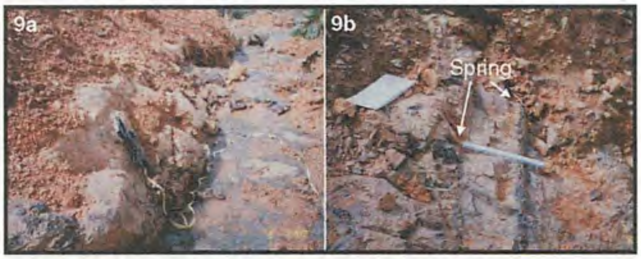

Figure 9. Hydrological features in the main landslide body showing a) stream and b) springs.

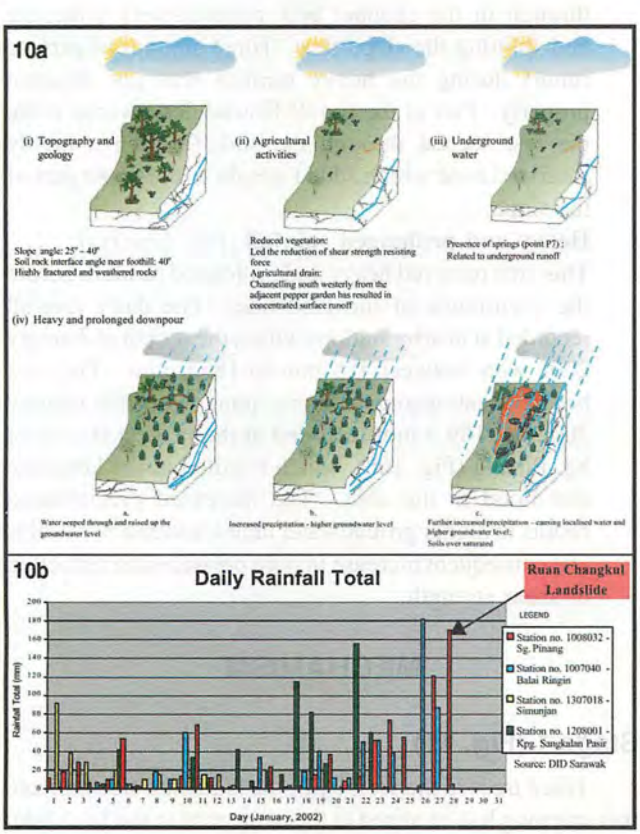

Figure 10. (a) Schematic diagrams of landslide contributory factors. (b) Total rainfall in January 2002 recorded from nearby stations.

Figure 11. Mechanism of landslide.

Figure 12. Features related to slope movements indicating slope instability near the major landslide area. (a) Tension cracks. (b) Gully. (c) Minor slide.

scarps, from P5 to P11 are rounded and continuous. These shear zones were easily identified by the changes from a predominantly vegetated area to a predominantly non-vegetated area. These zones separate the moving mass from the surrounding stationary slope. Shearing is shown by the slickensides on the bare surfaces of both flanks. The uppermost left flank was seen experiencing small sloughing. The left flank at P6 (left) – Figure 5c, is dissected by a small drain approximately 1 m wide. Both flanks were littered with tension cracks, some of which were en-echelon style. These tension cracks were usually left-stepping along the right flank and right-stepping along the left flank. Several cracks were observed parallel to the flanks, usually extending out from the main shear zone. Some of the tension cracks had openings as wide as 20 cm. Debris levees were also observed on both flanks (Fig. 6). The tops and sides of some of these debris levees had scour marks and trended northwardly, parallel to the general direction of the slide due to the flow of water.

The main body consists of saturated residual soil lobes (Fig. 7). The residual soils lobes are slurry material and non-blocky in nature. These lobes occurred just after the main failure as a result of head scarp, minor scarp, and flank sloughing. Other shear zones appeared as erosional gullies as seen from point P4 to P7 (Fig. 5c) of depth ranging from 0.5 m to 1 m deep and width ranging from 1 m to 2 m wide (Fig. 7).

Two main sliding planes from which the main body descended the slope were identified (Fig. 8), i.e.:

i. The upper portion, S1(i) from P1 to P8 and S1(ii) from P8 to P10 - is a circular bowl-shaped feature of weathered bedrock. It is steeper (>25°) on its upper part, and gentler (<20°) in the middle and lower part (P7 to P8).

ii. The lower portion S2, from P10 to P11 – is a planar surface of fresh bedrock-soil interface, situated at the lower part. This plane is dipping 40°/N, slightly greater than the angle of the original ground surface.

Hydrological Condition

There are a few damp and permanent flowing seepage lines and small permanent flowing streams (Fig. 9a) observed throughout the denuded area.

Two spring lines mark the contact between the failure plane and the main body of this saturated zone were identified, located at point P7 (Fig. 9b) on top of a down-dropped bench. These features usually mark a vertical change in conductivity (Richards, 1982). Sag pond, when dry, would appear as a local depression.

CONTRIBUTORY FACTORS

Based on the investigation, the factors that may have contributed to the occurrence of the landslide are as follows:

- **Topography**
  Elongated undulating concave slopes with angles ranging from 25° to 40° dipping towards the Northwest lying within the catchments area allows accumulation of surface runoff [Fig. 10a (i)];
- **Geology**
  Highly fractured basalt is the dominant bedrock of Serian Volcanic in the affected area. Fracturing and weathering of the bedrock creates changes in the ground water flow regime (Schultz and Cleaves, 1955). Upper layer of soft and slightly permeable residual soil facilitates infiltration into the slope. Sharp underlying interface between the residual soil and parent material with angle of 40° inherently reduce the factor of safety of the slope [Fig. 10b (i)];
- **Groundwater**
  Presence of springs at point P7 indicates the landslide is also related to the groundwater runoff, which progressively build up the water pores and opened extensive and deep shrinkage cracks (Fig. 10c (iii));
- **Removal of vegetation by agricultural activities** [Fig. 10a (ii)]
  Sparse to bare slope in the affected area has a direct effect on the slope stability, reducing resisting force and shear strength while retarding grain-by-grain friction (Gostelow *et al.*, 1997) which led to the formation of cracks and crevices on the slope surface during the dry season;
- **Improper drainage system**
  Agricultural drain was observed channelling from the adjacent pepper garden into the main body [Fig. 10a (ii)]. Prior to the landslide, concentrated runoff seep through in the channel bed, progressively widening and splitting the slope face. Huge amount of surface runoff during the heavy rainfall was not diverted properly. Part of the runoff flowed downwards while the rest seeped through the soil, forming a highly saturated zone which added weight to the upper part of the slope;
- **Heavy and prolonged rainfall** [Fig. 10a (iv)]
  This area received heavy and prolonged rainfall, before the occurrence of the landslide. The daily rainfall recorded at nearby stations within the month of January 2002 were between 0.5 mm to 185.0 mm. The area had the greatest amount of precipitation on 28th January 2002 i.e. 169.9 mm recorded at the nearest station of Sg. Pinang (Fig. 10b), which resulted in the landslide and flood in the area. The increased precipitation results in higher groundwater tables, saturation of soils, and consequent increase in pore pressure and reduction of shear strength.

MECHANISM

Stage 1 (Fig. 11)

Tilted trees in the vicinity of the landslide area indicate that creeping has occurred in this area prior to the landslide. The slope was unstable and the process is continuous. Infiltration of rainwater into loose and slightly permeable residual soils gradually widened the cracks to form wide crevices. Further heavy rainfall resulted in raised water table i.e. higher than normal perched water table in the residual soils on the slope that might not normally have such a high water table. Accumulation of rainwater in the pore spaces reduced the effective shear strength (Abell, 1997). These increased the driving forces needed to initiate movement. The movement occurred along the boundary between the residual soils and the bedrock.

Stage 2

After this initial stage, the movement stopped when it reached the protruded resistant bedrock. The residual soils and Grade V- Grade IV rock slide into the channel and gullies, where it blocked the channel. Some smaller sloughing took place along the head scarp and both flanks, which led to the damming of the channel, creating a sag pond and saturated flow lobes.

Stage 3

Slope base undercutting and scouring by the small stream at the foothill removed the material at the toe. It increased the slope angle and destabilised the base and the overlying material with loads on top. Further excessive precipitation decreases the amount of friction between particles and creates pore pressures that push the particles apart. This effect is compounded by the presence of a weak ionic bond between clay particles, easily broken when wet (Santoso *et al.,* 1993). As a result, when fully saturated the elevated pore water pressures do not allow intergranular contact. The slope was not able to withstand the additional load and extraordinary weight. The dam section broke and burst, initiating a debris flow. Large amount of debris entrained in the flow. The saturated mass of tip of the colliery debris slumped from its base and its apex causing a mass of viscous soil mixed with water flowed down from the tips elevated upland position, clean across the road below it and onto the local houses, crushing and burying buildings in its path rapidly. A flow occurred over the sharp planar bedrock-soil interface until it reached the valley side.

LANDSLIDE CLASSIFICATION

The landslide can be considered as a deep-seated landslide as the ruptured surface reached more than 5 m deep from the original ground surface. The landslide in the affected area can be classified as a debris flow according to the classification of Coates (1977), Flemming and Varnes (1978), Hunt (1984) and IAEG Commission on Landslides (1990), based on the major factors such as movement form, mass coherency, constituency and relative speed.

CONCLUSIONS

Based on the investigation, it can be concluded as follows:

a) The main factors which contributed significantly to the occurrence of the landslide were the topography, geology, agricultural activities, underground water and over saturated residual soils.
b) From the rainfall data provided it is believed that the landslide was triggered by heavy and prolonged downpour.
c) The main parameters of the soil properties such as plasticity index (PI), permeability and soil strength of the surrounding slope should be taken into consideration as it could influence the factor of safety of the slope.

FUTURE PRECAUTIONARY MEASURES AND RECOMMENDATIONS

Based on the investigation in the area, geomorphological and geological conditions are fairly homogeneous over the mapped areas. Ruan Changkul and the surrounding areas can be classified as a landslide prone area and exposed to the occurrence of the landslide. There are signs of slope instability in the adjacent areas such as tension cracks, erosions, soil creeps, gullies, slope failures and minor slides (Fig. 12). Tension cracks were found on the ground surface along the crown and flanks, outside the main landslide zone. The cracks are signs of the instability prior to the catastrophic landslide. Three prominent large cracks were observed in the ground very close to the upper right flank perpendicular to the contour with an approximate 1 m to 2 m long and 10 cm to 20 cm opening (Fig. 12a). Two cracks, which are 0.5 m apart, are located on the crown. Each crack has an opening of 30 cm.

Measures should be taken to prevent further slope movements in the areas that are vulnerable to the slope movement and among the measures suggested are as follows:

- Erosion control. Slope reduction by grading or terracing, including buttressing and retaining systems such as riprap or gunnite to protect the base of slope. Restrictions on land use should be imposed and enforced by local governments by means of land use zoning and regulations;
- Control of water movement on or within slope (provide adequate drainage) – proper drainage system should be build to contain excessive surface run-off and localised concentration;
- Refill crevices and other openings to prevent water from obtaining access into the ground. Covering the barren slope surface with plastic sheets as a temporary measure;
- Planting of vegetation. Plant more trees with 'anchoring' roots as a long-term prevention;
- Issue of warnings. Hydrologic conditions such as heavy precipitation can be forecasted with some certainty, warnings can be issued to areas that might be susceptible to slope movement;
- Installing real-time landslide monitoring and warning

systems. Monitoring instruments such as extensometer, piezometer and rain gauge should be installed at every designated dangerous slope to measure ground movement, ground water and to record precipitation (Dunnicliff, 1988).

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