DETAILED STUDY OF THE 7 JUNE 2008 LANDSLIDE ON THE NATURAL HILLSIDE BEHIND CHOW YEI CHING BUILDING AT THE UNIVERSITY OF HONG KONG, POK FU LAM

GEO REPORT No. 276

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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This report is largely based on GEO Landslide Study Report No. LSR 3/2009 produced in May 2009

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

H.N. Wong
Head, Geotechnical Engineering Office
March 2013

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FOREWORD

This report presents the findings of a detailed study of a landslide incident (Incident No. 2008/06/0193) that occurred on a natural hillside behind Chow Yei Ching Building at the University of Hong Kong, Pok Fu Lam. The landslide was reported on the morning of 7 June 2008 during which the Landslip Warning and the Black Rainstorm Warning were in force. The landslide involved a total displaced volume of about 2,740 m^3 and comprised a larger primary and a smaller secondary source area. The detached material travelled a maximum distance of about 210 m down the hillside eventually coming to rest adjacent to the Chow Yei Ching Building. A 200 mm diameter fresh water main, associated with a paved footpath traversing the primary source area, was severed, and a temporary footbridge adjacent to the Chow Yei Ching Building was destroyed. Some outwash debris passed into the lower floors and car park of the Chow Yei Ching Building before entering Pok Fu Lam Road. No casualties were reported as a result of the landslide.

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. The scope of the study comprised desk study, site reconnaissance, field mapping, ground investigation and laboratory testing, together with theoretical analyses. Recommendations for follow-up actions are presented separately.

The report was prepared for the Geotechnical Engineering Office of the Civil Engineering and Development Department, under Agreement No. CE 41/2007 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

Fred H Y Ng
Project Director
Maunsell Geotechnical Services Limited

Agreement No. CE 41/2007 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2008 and 2009- Feasibility Study

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1. INTRODUCTION

On the morning of 7 June 2008, during which the Landslip Warning and Black Rainstorm Warning were in force, a landslide (Incident No. 2008/06/0193) occurred on a natural hillside behind Chow Yei Ching (CYC) Building at the University of Hong Kong (HKU), Pok Fu Lam (Figure 1 and Plate 1). The landslide comprised a larger primary and a smaller secondary source area, involving a total displaced volume (terminology after Cruden & Varnes, 1996) of about 2,740 m^3, with about 2,340 m^3 coming from the primary source area and entrainment along the associated debris trail below, and the remaining 400 m^3 from the secondary source area and entrainment along the associated debris trail. There were also two other minor failures, one to the north of the secondary source area and another to the east of the primary source area (Figure 2). They involved a failure volume of about 45 m^3 and 25 m^3 respectively with the debris remaining at the scars. This landslide investigation focuses on the large landslide.

The detached material from the primary and secondary source areas entered an ephemeral drainage line in the lower hillside area where the debris became confined and channelised. The landslide debris travelled a total distance of about 210 m (Figure 3) before coming to rest at the side of CYC Building. Outwash material continued into the basement and car park of CYC Building, before entering Pok Fu Lam Road. A 200 mm diameter fresh water main that traverses the lower part of the primary source area and a 300 mm surface channel located in the middle of the primary source area were severed, and a temporary steel footbridge adjacent to CYC Building was destroyed. No casualties were reported as a result of the landslide.

Following the incident, Maunsell Geotechnical Services Limited (MGSL) carried out a detailed study for the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD), under Agreement No. CE 41/2007 (GE).

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. Recommendations for follow-up actions are reported separately.

This report presents the findings of the detailed landslide study, which comprised the following key tasks:

(a) review of all relevant documents relating to the study area,

(b) aerial photograph interpretation (API),

(c) topographical surveys, detailed field observations and measurements,

(d) ground investigation and laboratory testing,

(e) analysis of rainfall records,

(f) theoretical stability analyses and debris mobility modelling, and

(g) diagnosis of the probable causes of the landslide.

2. THE SITE

2.1 Site Description

The 7 June 2008 landslide is located on a north-facing natural hillside above CYC Building of HKU and about 170 m north of the peak of Lung Fu Shan (Figures 1 & 2 and Plate 1). The landslide occurred within a hillside catchment (the landslide catchment) defined by a broad topographical depression between two rounded spurlines trending north-northeast and north. The catchment is approximately 130 m wide and 250 m long, with a plan area of about 1.9 hectares. The top of the catchment has an elevation of approximately 250 mPD. At the toe of the landslide catchment is the multi-storey CYC Building of HKU at about 74 mPD. An access road is located in front of CYC Building, and Pok Fu Lam Road is located further downhill. A construction site for the development of the HKU's Centennial Campus is located at the toe of a natural hillside adjacent to the landslide catchment (Figure 4).

The landslide catchment is generally densely vegetated, and was subject to some minor anthropogenic disturbance in the past. Three footpaths crossing the site were identified, a paved section of Pik Shan Path (FP1, Figure 2) which traverses approximately the mid-slope portion of the catchment, a minor unpaved footpath (FP2) which traverses the upper part of the landslide catchment, and a footpath (FP3) which is located along the western spur of the landslide catchment. Cut slopes Nos. 11SW-A/C608, 11SW-A/C1139 and 11SW-A/C593 are located immediately above Pik Shan Path (Figure 2).

Several drainage lines are located within the landslide catchment (Figure 2). Drainage line DL1 is the most prominent drainage line. It is incised in the upper part and a concrete stepped channel has been constructed in the lower part of the drainage line. Drainage line DL2 is a continuous ephemeral drainage line located along the central part of the landslide catchment and adjoins drainage line DL1 at its lower section. Several minor, discontinuous ephemeral drainage lines are located on the flanks of the landslide catchment, two of which are located near the 7 June 2008 landslide primary source area.

The primary source area of the 7 June 2008 landslide is located on the eastern side of the upper catchment (Figure 2). The crown of the primary source area is located at an elevation of about 190 mPD (approximately 46 m above Pik Shan Path). The adjacent upper hillside is generally inclined at an angle of about 34°, locally increasing to over 40° just below Pik Shan Path before gradually decreasing to about 22° near the confluence of the two landslide debris trails at about 110 mPD (Figure 3). A detailed description of the primary source area is given in Section 4.3.

The secondary source area of the 7 June 2008 landslide is located on the middle part of the western side of the catchment (Figure 2 and Plates 1 & 8) and below the intersection of Pik Shan Path and the staircase leading to footpath FP3. The crown of the secondary source area is located at an elevation of about 145 mPD, and the adjacent hillside is generally inclined at an angle of about 35°. A detailed description of the secondary source area is given in Section 4.5.

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2.2 Water-carrying Services and Other Utilities

According to information provided by the Water Supplies Department (WSD), a 200 mm diameter fresh water gravity main, a 300 mm diameter salt water main and a 24-inch diameter raw water gravity main run along Pik Shan Path within the 7 June 2008 landslide catchment. The salt water main is a ductile iron pipe and was laid in 1997 (Figure 2 and Plate 2). Based on WSD's records, this water main is pressurised. The fresh water gravity main is also a ductile iron pipe and was laid in 1996 (Plate 2). Another 24-inch diameter raw water conduit is located along Pik Shan Path on the western side of the landslide catchment, immediately above the secondary source area. According to WSD, this section of the conduit was no longer in use prior to 7 June 2008.

On the eastern side of the primary landslide scar, the 200 mm diameter fresh water pipe was severed whilst there were no signs of leakage or damage to the salt water pipe.

According to the WSD, there was no reported water main leakage in the vicinity of the landslide in the past five years prior to 7 June 2008.

2.3 Construction Activities at the HKU's Centennial Campus

At the time of the 7 June 2008 landslide, major site formation and tunnel construction works were in progress at the toe area of the adjacent natural hillside to the west of the landslide catchment (Figures 2 & 4). Black & Veatch (HK) Limited (BV) was appointed by HKU as the Supervising Officer for the works, and Gammon Construction Ltd. (GCL), is the main Contractor. The works commenced in April 2007 and include the formation of tunnels and two caverns in the hillside adjacent to the landslide catchment, for relocating existing WSD reservoirs. The works also include provision of a pipe gallery, demolition of existing reservoirs, construction of an emergency vehicular access (EVA) and slope upgrading works (Plate 1). The development of the vacant land will follow.

Tunnel excavation works adopted the drill and break technique by means of hydraulic splitting/breaking, without blasting. In order to form a pipe gallery and the EVA, pipe piles have been installed along the base (at about 100 mPD) of the rounded spur that separates the landslide catchment from the main site of the proposed HKU Centennial Campus. These piling works are located approximately 170 m from and 90 m below the primary source area and secondary source area respectively. In order to divert a hiking trail near CYC Building, a temporary steel bridge across the toe of the main drainage line DL1 (Figure 2) was constructed. The above works were completed in April 2008.

A salt water reservoir was demolished in 7 June 2007 (Figure 4) to allow access for tunnel portal construction.

2.4 Previous Assessments and Natural Terrain Hazard Studies

As part of the infrastructure works for the proposed HKU centennial campus and re-provisioning of WSD facilities, BV was required to carry out a Natural Terrain Hazard Study (NTHS) for the hillside area above the site of the proposed HKU Centennial Campus. The

NTHS area also included the 7 June 2008 landslide catchment (Figure 4). Another NTHS was conducted by Mott Connell Limited (MCL) for the main Contractor. The mitigation measures proposed by the NTHS were not yet approved by the GEO at the time of the 7 June 2008 landslide.

2.5 Geotechnical Area Studies Programme (GASP)

According to the Geotechnical data which are shown on 1:20 000 scale maps, in the Geotechnical Control Office's (GCO, renamed GEO in 1991) Geotechnical Area Studies Programme (GASP) Report No. 1, Hong Kong and Kowloon (GCO, 1987), the hillside where the 7 June 2008 landslide occurred is classified as an area of general instability with pyroclastic rocks located in the upper area, granite on the lower area and colluvium along the toe. However, it should be noted that the resolution of the maps is limited. They are not intended for the assessment of local areas, such as the subject hillside.

2.6 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 11 - Hong Kong & Kowloon (GCO, 1986), the site is underlain by coarse ash crystal tuff of the Tai Mo Shan Formation in the upper portion, and medium-grained granite of late Cretaceous age in the middle and lower portion (Figure 5). The granite has intruded the volcanic tuff and the contact is shown to traverse the site in a northwest-southeast direction. The intrusive contact between tuff and granite dips towards the southwest at about 20° with thermally altered rock along the contact zone. The tuff/granite contact is complex, being irregular in shape and may form a mixed zone tens of metres wide (GCO, 1982).

In the HKGS 1:20 000 scale geological map, the jointing in the volcanic rocks is shown to dip north-northwest and west at about 50° along the western spur of the study area. A northeast trending fault is shown about 30 m northwest of the landslide site although no faults or photogeological lineaments intersect the site. The geological map also indicates the presence of Pleistocene debris flow deposits within the landslide catchment, and these debris flow deposits are shown extensively across the foothill area.

The HKGS 1:100 000 scale Pre-Quaternary Geology Map of Hong Kong (Sewell et al, 2000) subsequently reclassified the volcanic rocks in the study area as belonging to the Mount Davis Formation (Krd) comprising coarse ash crystal tuff with intercalated tuffaceous siltstone and sandstone. The granitic rocks have been classified as Kowloon Granite (Klk) and comprise equigranular medium-grained granite.

3. SITE HISTORY AND PAST INSTABILITIES

3.1 General

The history of the study area has been determined from an interpretation of the available aerial photographs (Appendix A), together with a review of relevant documentary information (Figure 6).

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3.2 Site History

Based on the earliest aerial photographs reviewed (1924), the landslide catchment is located on a north-facing natural hillside below Lung Fu Shan. Anthropogenic disturbance was observed in the area below the landslide catchment and in adjacent lower hillside areas prior to 1924, with construction of water supplies facilities to the west (WSD filter beds), and apparent borrow area excavations to the east (Plate A1). Evidence of some minor anthropogenic disturbance is also evident across the middle and upper hillside areas with footpaths FP1 (Pik Shan Path), FP2 and FP3 being visible in the 1924 aerial photographs. On the hillside adjacent to the landslide catchment, some military structures were present around Lung Fu Shan in 1963 (Plate A3), and a transmission line tower was erected in 1973.

In 1978, large-scale site formation works were underway in the lower hillside area to the east of the 7 June 2008 landslide catchment associated with stabilising the borrow area excavations. About the same time, site formation works for several HKU buildings were underway. In 1994, CYC Building was being constructed and the works were completed in 1995.

3.3 Past Instabilities

3.3.1 Natural Terrain Landslide Inventory (NTLI)

In 1995, GEO compiled the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high-altitude aerial photographs dating from 1945 to 1994 (Evans et al, 1997; King, 1999). According to the NTLI database, there are seven landslides in the immediate vicinity of the landslide catchment. A relict NTLI landslide with scar width > 20 m (Tag No. 11SWA0023) is indicated about 26 m on the hillside above the primary source area (Figure 7). The inventory indicates that there is a retrogressive failure (Tag No. 11SWA0081) at the same location as the landslide Tag No. 11SWA0023, between 1964 and 1967. The other five landslides are recent events first observed in the 1967 aerial photographs (Figure 7).

3.3.2 Enhanced Natural Terrain Landslide Inventory (ENTLI)

In 2004, GEO commenced a project to update the NTLI using low-altitude (8,000 ft and below) aerial photographs and produced the Enhanced Natural Terrain Landslide Inventory (ENTLI). The ENTLI database records six relict and seven recent features within the landslide catchment (Figure 7).

Of the six relict landslides, a feature with Tag No. 11SWA0022E is located at about 24 m above the primary source area of the 7 June 2008 landslide (Figure 7). Another four landslides with Tag Nos. 11SWA0071E to 11SWA0073E occurred on the upper part of the landslide catchment. The sixth landslide with Tag No. 11SWA0074E is possibly related to a failure directly upslope of registered man-made slope No. 11SW-A/C593.

There are seven recent landslides identified within the landslide catchment. Five of them were located near to the 7 June 2008 landslide source areas; one landslide (with Tag No. 11SWA0377E), occurred about 30 m above the primary source area, had a runout distance

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of about 50 m, two landslides (with Tag Nos. 11SWA0347E and 11SWA0376E) were located immediately below the secondary source area, one landslide (with Tag No. 11SWA0375E) was located near a relict landslide above the registered slope No. 11SW-A/C593 and the last one (with Tag No. 11SWA0346E) was located about 20 m downslope of the secondary source area. The remaining two recent landslides (with Tag Nos. 11SWA0373E and 11SWA0374E) identified were located at the head of the ephemeral drainage line DL1.

3.3.3 Large Landslide Database

According to the GEO's Large Landslide Database (Scott Wilson, 1999), there are no observed or reported landslides in the immediate vicinity of the 7 June 2008 landslide. However, a scar with Tag No. 11SWAL009 is recorded on the adjacent hillside catchment, about 60 m east of the 7 June 2008 landslide (Figure 7), at the present day location of slope No. 11SW-A/C600 (Figure 2). This scar was likely formed in association with pre-war (i.e. before 1939) borrow area activity, and not related to landslide activity.

3.3.4 GEO's Database of Reported Landslides

According to the GEO's landslide database, there are no recorded landslides within the immediate vicinity of the landslide site. However, five incidents were reported in the vicinity, all of which are located more than 40 m away from the 7 June 2008 landslide scar (Figure 7). Among them, two reported incidents occurred on the natural terrain.

One of the natural hillside landslides (Incident No. 2005/06/0216) occurred in June 2006 about 45 m to the northwest of the secondary source area of the 7 June 2008 landslide, with a source volume of about 100 m^3. The GEO incident report noted that infiltration was a possible cause of failure. Another incident occurred on the natural hillside above slope No. 11SW-A/C600 behind CYC Building (Incident No. 2002/02/0005) in February 2002, involving a small-scale surface erosion (0.3 m^3) and three or four fallen boulders. The other three landslide incidents occurred on registered man-made slope Nos. 11SW-A/C600, 11SW-A/C148 and 11SW-A/C149 with failure volumes ranging from about 2 m^3 to 10 m^3; they are of no relevance to the subject natural terrain landslide.

3.3.5 Historical Landslide Catchment

The 7 June 2008 landslide catchment was designated as a Historical Landslide Catchment (HLC), i.e. a natural hillside catchment with a known history of landslides. Under the HLC ranking system, assessment of the characteristics within the 7 June 2008 landslide catchment resulted in the catchment being ranked No. 1 (i.e. with the highest risk).

3.3.6 Aerial Photograph Interpretation

An Aerial Photograph Interpretation (API) has been carried out as part of the desk study for the purposes of establishing the site history, past instability and geomorphological characteristics of the landslide catchment and adjoining area. Prior to 1963, no obvious

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landslide scars can be seen within the 7 June 2008 landslide scar area, although a large area of apparent hillside disturbance is observed on the adjacent lower hillside area to the east, at the location of present day slope No. 11SW-A/C600 (Plates A1 & A2). Furthermore, an area of abandoned military structures and a small trench (about 50 m long, 1.8 m wide and 2.5 m deep) are evident some 50 m behind the landslide catchment (Plate A3). The trench is situated adjacent to the ridgeline with virtually no upslope catchment. Site inspection conducted after the 7 June 2008 landslide observed that the base and sides of the trench were paved (Plate A3), and the paving appeared to be in relatively good condition.

The high quality 1963 photographs show that the geomorphology of the site comprises a broad depression which delineates the 7 June 2008 landslide catchment and is characterised with an dense vegetation cover and a hummocky nature that suggests the probable deposition of unconfined hillside colluvial deposits. In addition, the hillside morphology indicates the presence of distinct lobes of probably more recent colluvial deposits at the toe of one of the relict landslide scars (R7, see Figures 7 & A1 and Plate A3) and at the toe of the landslide catchment where drainage lines converge.

Two main ephemeral drainage lines DL1 and DL2 are observed adjacent to the west flank and middle of the landslide catchment, draining approximately north-northeast and north respectively (Figure A1 and Plate A3). Several minor, discontinuous ephemeral drainage lines are located on the flanks of the landslide catchment, two of which are located near the 7 June 2008 landslide primary source area. A break-in-slope is apparent near the head of drainage line DLl near the secondary source area, which possibly corresponds to relict landslide R4 with two small-scale relict landslides (GRS4 and GRS5) within it (Figure A1).

The landslide catchment has a history of landslides. About 30 m uphill of the 7 June 2008 landslide primary source area, a degraded relict landslide scar R7, (approximately 12 m wide by 17 m long, 200 m³ in volume, see Figure A1 and Plate A3) is visible. Based on the setting and morphology, a colluvial lobe (about 45 m long) is apparent downhill from landslide R7, which coincides with the upper portion of the primary source area (Figure 8). Landslide R7 is identified under the ENTLI as Tag No. 11SWA0022E. Several recent landslides are visible within the landslide catchment, which are concentrated on the western flank of the landslide catchment. In the 1967 photographs, nine recent landslides (L7, L8, L10, L11, L13, L15, L16, L17 and MGS1) are visible within the landslide catchment, with estimated source volumes ranging from about 10 m³ to 70 m³. The landslides might have been triggered by the severe rainstorm in June 1966. One of the landslides, L15 (ENTLI Tag No. 11SWA0377E) was located directly above the primary source area of the 7 June 2008 landslide, about 25 m upslope of the main scarp. The source volume of L15 was about 50 m³ and the debris trail terminated a few metres downhill of footpath FP2.

There are no significant observable changes to the landslide catchment since 1967, other than a general increase in vegetation density.

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4. THE 7 JUNE 2008 LANDSLIDE AND POST-FAILURE OBSERVATIONS

4.1 Eye Witness Account

The 7 June 2008 landslide has two distinct source areas, a larger primary source area in the upper eastern part of the landslide catchment, and a smaller secondary source area in the mid western part of the landslide catchment (Figure 2 and Plate 1).

According to eyewitness accounts, the landslide occurred in several stages between about 7.30 a.m. and 9.30 a.m. on 7 June 2008. Evidence that the initial part of the event occurred within the upper part of the primary source area was given by a Site Agent for the works Contractor, who made his observations "between about 7.30 a.m. and 8.00 a.m.". The witness noticed that "the uppermost portion of the eastern landslide had failed already" at that time, and that "muddy water" was descending along the drainage line adjacent to CYC Building. However, the temporary footbridge was still intact and no landslide debris downhill of the footbridge was observed then.

A plant operator for the works Contractor took video footage at 8.42 a.m. of the landslide catchment and drainage line from the podium on the west side of CYC Building. The video shows the secondary source area (Plate 3), and some of the debris trail below. Although significant muddy water flowed along the drainage line adjacent to CYC Building, the temporary footbridge was still intact at about 8.45 a.m., as shown by the video (Plate 4), although some debris apparently were piling up behind the bridge at that time.

Some other eyewitness accounts indicate that the detachment occurred in stages sometime between about 8.45 a.m. and 9.30 a.m. at the location of the primary source area. Between about 8.45 a.m. to 9.00 a.m., the Site Agent noticed that slow movement initially occurred with "trees leaning forward" and exposure of soil in back scarps. He also reported a "loud noise" when the landslide "moved in one go" near Pik Shan Path, although the exact time of this is not clear. The plant operator observed "trees at the toe area lean forward" before immediately vacating the area at about 9.30 a.m. just prior to the main failure pulse. The Estate Office at HKU also estimated the time of the main failure pulse at about 9.30 a.m. although they did not directly witness the event. The eyewitness observations suggest that the main pulse of detachment from the primary source area was probably preceded by a progressive movement of the displaced groundmass before rapid failure.

In summary, eyewitness accounts indicate that the 7 June 2008 landslide probably comprised 4 phases. The first three phases involved detachments or displacements in the primary and secondary source areas between 7:30 a.m. and 9:30 a.m. before the main pulse occurred at about 9:30 a.m., involving detachments in one go from the primary source area (Figure 9).

4.2 Site Observations

The landslide was initially inspected by Fugro-Scott Wilson Joint Venture (FSWJV), as the landslide investigation consultants for Hong Kong Island, on 8 June 2008. MGSL first inspected the landslide on 22 June 2008 and commenced field mapping. A plan of the landslide scar showing details of mapping and field observations is shown on Figure 10. General views of the landslide primary and secondary source areas are shown in Plates 5, 6 and 7.

The landslide mass balance has been estimated from a combination of field mapping measurements, pre-failure LiDAR (Light Detection and Ranging) survey, post-failure topographical survey data and site records of debris removal. Uncertainties in the estimate involve removal of debris from the toe area and access difficulties due to emergency repair work (shotcrete placement) ongoing at the time of inspection. The landslide involved a total displaced volume of about 2,740 m^3, with about 2,340 m^3 coming from the primary source area and entrainment along the associated debris trail below, and the remaining 400 m^3 from the secondary source area and entrainment along the associated debris trail. The primary source area involved a detachment of about 1,750 m^3 of which about 220 m^3 remained within the source area. The secondary source area involved a detachment of about 210 m^3.

The detached material removed a minor footpath about 10 m below the crown, a 300 mm surface channel in the middle of the primary source area, buried and partly damaged an approximately 30 m section of Pik Shan Path, and severed a 200 mm ductile iron fresh water pipe adjoining Pik Shan Path. The detached material on the eastern side of the primary source removed parts of some existing small cut slopes within slope No. 11SW-A/C608, above Pik Shan Path although they appear to be mostly intact on the western side.

The severed fresh water pipe was discharging water onto the eastern part of the debris trail area just below Pik Shan Path for approximately 7 hours following the failure, enlarging a local scarp within the detached material which had accumulated from the primary source area (Section 4.4). Post-event erosion is apparent downhill due to the water discharge (Plates 8 & 9). An adjacent ductile iron 300 mm pressurised salt water main adjoining Pik Shan Path was not damaged.

The detached material from both primary and secondary source areas entered an ephemeral drainage line in the lower hillside area where the debris became confined and channelised. It was estimated that about 590 m^3 and 190 m^3 of materials were entrained along the primary and secondary debris trails respectively. The landslide debris travelled a total distance of about 210 m (Figure 2) and came to rest at the side of CYC Building, destroying a temporary footbridge (Plate 10). Outwash material continued into the basement hydraulics laboratory and car park of CYC Building (Plates 11 & 12), before entering Pok Fu Lam Road and continuing down to Bonham Road.

A longitudinal section of the primary landslide, together with the estimated volumes of material entrained and deposited, is presented in Figure 3. The difference in elevations between the landslide primary source and the end of the debris trail was approximately 116 m. The primary and secondary landslide source areas have an aspect of about 340° and 055° respectively. A map of the debris trail is presented in Figure 10. Longitudinal sections through the 7 June 2008 landslide primary source area are presented in Figures 11 and 12, and a plan of the distribution of the debris mass balance is shown in Figure 13.

Two separate, minor failures occurred on the periphery of the 7 June 2008 landslide catchment at about the same time as the primary and secondary landslides (Figure 2). One failure occurred adjacent to footpath FP3, below the secondary source area, and had an estimated volume of approximately 45 m^3. Another failure occurred adjacent to small cut slopes along Pik Shan Path to the east of the primary source area. This incident involved a shallow detachment with an estimated volume of approximately 25 m^3. The volumes of

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these failures are almost two orders of magnitude smaller than the primary source area and are likely the result of different landslide processes. Furthermore, these minor failures are not located within the 7 June 2008 landslide scar and are not considered to be related to the primary or secondary source areas and debris trails. Thus, for clarity, they have not been shown in other figures or discussed further in the rest of the report.

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4.3 Primary Source Area

The primary source area of the 7 June 2008 landslide is irregular in morphology, with several erosion channels up to 3 m deep, together with rafts of relatively intact material that still remained on the upper scar area. Most detachment had taken place in the upper and eastern portion of the primary source area (Figure 13).

The crown of the 7 June 2008 primary source area is located at approximately 190 mPD, on a natural hillside inclined at approximately 34° within a broad topographic depression. The crown is located at a local convex break-in-slope above which the slope gradient decreases to about 23° before increasing again to about 40° within 20 m (see Figure 3). This localised change in slope gradient is associated with a topographic depression inferred as the site of relict landslide scars as identified in the 1963 aerial photographs (see Figure 8). Aerial photographs and site photographs taken prior to the 7 June 2008 landslide show the primary source area to be densely vegetated with bushes and trees.

The primary source area is irregular in shape with a narrower, smaller, upper portion and a larger, wider middle and lower portion with two distinct ‘shoulders’ separating the two. At the maximum dimensions, the primary source area is approximately 60 m long and 42 m wide, with a maximum and average depth of about 3 m and 1.8 m respectively, based on site measurements and pre-failure LiDAR survey (carried out over Hong Kong Island in 2006) and the post-failure topographical survey. The volume of displaced material is estimated to be approximately 1750 m^3, with approximately 220 m^3 remaining within the primary source area (see Figure 13 and Plates 5 & 6).

Several areas can be identified where material has detached in several stages, some of which has remained in the source area as remoulded lobes, relatively intact rafts (with associated vegetation), or slumped debris. The material that remained within the source area included several slumped debris rafts up to 6 m wide and 10 m long along the eastern flank of the source area that retained much of the original vegetation on the top (Plates 5 & 6). On the western flank, a slumped mass of relatively intact debris can be seen with retained vegetation at the toe and steep back scarp behind (Figure 10). In the central and eastern part of the source area, there has been relatively deep detachment (up to about 3 m) delineated by erosion channels. In other areas (to a lesser degree), only shallow erosion/transport has occurred leaving relatively flat topographic high zones or narrow islands of pre-failure intact material.

The surface of rupture was irregular and poorly defined in the source floor, much of which was covered in a thin (about 100 mm thick) veneer of fine landslide debris (locally fluvially re-worked) or thicker (average 1 m thick) detached rafts of partly intact colluvium and slumped lobes of landslide debris containing coarse tuff fragments and vegetation. The post-landslide ground investigation (GI) comprising trial pits/trenches and boreholes (see Section 5.3), carried out within the primary source area did not expose any obvious remnants of discrete failure planes or zones of disturbance that could be associated with the surface of rupture. Although the angular morphology of the upper source area might have pointed to some degree of structural control on the landslide initiation, no features such as planar joints/relict joint surfaces defining side, back or basal release surfaces, were observed during the detailed field mapping and ground investigation.

The observations made from the trial pits and trenches indicate that the surface of rupture was at or near to the interface of old colluvium and residual soil (RS) derived from tuff. The colluvium could be divided into at least two distinct layers representing differing ages and processes of deposition (Plate 13). The insitu weathered tuff varied from residual soil (with no relict structure or fabric) to partially weathered and rock mass with variable portions of highly to moderately decomposed cobble-sized tuff fragment (Plate 14).

4.4 Debris Trail (Primary Source Area)

The main debris trail for the 7 June 2008 landslide primary source begins at Pik Shan Path below which there is a break-in-slope and where the local slope gradient increases to about 37°. Most of Pik Shan Path was buried by the debris but still remained intact with only the eastern portion partly damaged by the landslide debris. Trial pit TPH6 located near the centre of the debris trail identified the intact footpath and the severed 200 mm diameter fresh water main underneath a layer of 1.5 m thick remoulded landslide debris, which included much decaying organic matter.

On the eastern flank of the debris trail, about 100 m^3 of remoulded debris has accumulated, straddling the footpath to over 2 m in height. In this vicinity, the remnants of a 300 mm surface channel (Figure 10 and Plate 15), which traversed part of the source area prior to failure, can be seen. A broken section of the 200 mm water main can be seen approximately 5 m below Pik Shan Path. A downhill gully has formed, possibly due to several hours of water discharge following the failure (Plate 16). Further down from the eastern part of the debris trail, where there is debris deposition adjacent to CYC Building, 3 erosion gullies (about 10 m wide and 1.5 m deep in total) were observed, exposing highly decomposed granite in the narrow base of the drainage line.

The western part of the debris trail has generally been less eroded than that in the eastern part, with some areas of transportation process denoted by surficially eroded topsoil and flattened vegetation. Landslide debris from the primary source has formed some lobes downhill containing some dead vegetation. A small area (8 m × 5 m) of highly decomposed tuff (HDT) to moderately decomposed tuff (MDT) can be seen further downhill which has a live tree growing on its upslope side indicating that it was probably pre-dated the 7 June 2008 landslide. Another large (10 m × 5 m) lobe of displaced debris is located near the confluence of the two source areas, with dead trees within intact topsoil, indicating the roots had probably been severed during debris displacement (Figure 10 and Plate 6).

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4.5 Secondary Source Area

The crown of the secondary source area is at about 145 mPD and the main scarp forms a boundary with the junction of Pik Shan Path and the staircase leading to the footpath FP3 (Figure 2 and Plate 7). The dimensions of the secondary source area are approximately 14 m wide and 15 m long, with an average depth of about 1.5 m giving an estimated volume of about 210 m³ (Figure 10). The source area was inclined at about 34° to 38°, locally steepening up to over 40°. Materials encountered within the source area typically comprise local fill (0.6 m) adjacent to the staircase, overlying CDT and RS (Plate 17). The CDT and RS generally comprise pale brown very sandy silt or very silty clay. Relict joints with near sub-vertical orientations were observed in the CDT.

The southern part of the source area had the deepest erosion of about 2 m, with erosion gullies about 1 m deep, cutting through the RS and extending into CDT. These gullies were probably caused by surface runoff discharging onto the slope. Minor tension cracks can be seen in the fill body immediately adjacent to the southeast corner of the main scarp below Pik Shan Path (Figure 10). There is a minor ephemeral drainage line running down to the eastern flank of the source area (Figure 10).

4.6 Debris Trail (Secondary Source Area)

The debris trail is relatively short, intersecting the primary source debris trail about 35 m from the toe of the secondary source. The north flank of the debris trail has relatively little entrainment with significant areas of flattened vegetation and superficially eroded topsoil. The southern flank of the debris trail is relatively deeply entrained with an average of about 1 m depth of material. This part of the debris trail intersects the ephemeral drainage line adjacent to the source and the main landslide catchment drainage line DL1. Fluvial erosion and deposition is evident in both drainage lines with gullying and deposition of alluvial sand and gravel along the bottom. A small outcrop of fine ash tuff (HDT to MDT) is apparent along the northern flank.

4.7 Debris Trail (Toe)

After the confluence of the two debris trails the inclination of the drainage line reduces to an angle of about 15°. Most of the debris was deposited at this location, and resulted in the destruction of a temporary footbridge (Figure 13 and Plate 10). A pre-failure view of the area around the temporary footbridge is shown in Plate 18. Approximately 2130 m³ of debris was removed from the side of CYC Building based on the number of truckloads involved. In addition, an estimated 210 m³ was deposited along the back of the building in a narrow passage between the building basement and an adjacent slope.

The debris comprised remoulded debris (sandy clayey silt) with tree branches and significant amount of foliage as well as boulder-sized rock fragments.

A significant amount of fine outwash material from the landslide, comprising muddy water with silt and sand in suspension, passed round the back of CYC Building into the hydraulics laboratory and resulted in flooding of the laboratories with deposition of clayey silt

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and sand of up to 300 mm thick. The outwash material continued down and flooded the basement car park CPF/1 (Plate 11). The outwash debris continued into Pokfulam Road and partly flooded the east-bound carriageway and proceeded downhill around Chiu Sheung School towards Hill Road.

5 SUBSURFACE GROUND CONDITIONS

5.1 General

The subsurface conditions at the site were explored via desk study and field works. The desk study comprised a review of all available data and published geological information including Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 11 (GCO, 1986), and the 1:100 000 scale Pre-Quaternary Geology of Hong Kong (Sewell et al, 2000) (see Section 2.6). The field study included landslide mapping and site-specific ground investigation.

5.2 Previous Ground Investigation

A review of the previous GI records in the vicinity of the 7 June 2008 landslide has been carried out. A summary of the locations of previous GI carried out in the vicinity of the study area is shown in Figure 14. A summary of the relevant GI is given below.

In 2006, Gammon Construction Ltd. completed 16 trial pits (Nos. TPN1 to TPN16) for the NTHS above the HKU construction site (see Section 2.4). Trial pits Nos. TPN11 to TPN14 were excavated in the vicinity area of the primary source area of the 7 June 2008 landslide. These trial pits encountered 0.1 m to 0.4 m of topsoil overlying 0.4 m to 1.2 m of colluvium. The colluvium was described predominantly as silty clay with varying amount of gravel, cobbles and boulders. Trial pits Nos. TPN11 and TPN12, which were located near the western flank of the primary source area, encountered a thin layer of residual soil up to 0.35 m thick and/or disturbed rock mass underlying the colluvium. In trial pit No. TPN13, moderately decomposed tuff was encountered below a 0.75 m thick layer of colluvium, and a 1.5 m thick layer of colluvium was encountered in trial pit No. TPN14 overlying completely to highly decomposed tuff.

Trial pit No. TPN4 was excavated within the secondary source area, which is adjacent to drainage line DL1. Three layers of topsoil between 0.1 m to 0.35 m thick were found interbedding with colluvium. The colluvium was generally described as silty sand with some cobbles and boulders.

Drillholes Nos. DH21 and DH24 located near the lower portion and the toe area of the landslide site along the drainage line encountered colluvium up to 5 m thick, overlying 3 m to 7 m of highly decomposed granite/tuff. Slightly to moderately decomposed granite/tuff was found below a depth of 8 m to 10 m.

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5.3 Post-landslide Ground Investigation

The ground investigation was undertaken to identify the nature and condition of the materials involved in the 7 June 2008 landslide. The locations of the post-landslide ground investigation stations are shown in Figure 14. Two contractors, Vibro (H.K.) Ltd. and Driltech Ground Engineering Ltd., carried out the GI from 9 September 2008 to 29 November 2008. The GI comprised two vertical drillholes, installation of two standpipe piezometers and one standpipe, seven trial pits, two trial trenches, two slope strips, six GCO probe tests, seven insitu density tests and installation of three clusters of tensiometers (which consisted of eight tensiometers with tips at various depths). Constant head permeability tests were also carried out in the drillholes.

5.4 Superficial Deposits

The superficial deposits encountered at the site essentially comprise colluvium below an approximately 200 mm thick mantle of organic-rich dark brown sandy silt/clay (topsoil). Two main types of colluvium were identified on the basis of different ages and formational processes. For the purposes of differentiation, the terms ‘young colluvium’ and ‘old colluvium’ have been adopted for the upper and lower layers respectively.

5.4.1 Young Colluvium

The young colluvium was only encountered in GI locations adjacent to the main scarp of the primary source area (drillhole No. DHH 1, trial pit Nos. TPH 4 & PH 5, and trial trench No. TTH 1). It was not encountered further downhill. The young colluvium is up to about 1.5 m thick and generally comprises a firm, yellowish to orange brown, slightly sandy silt/clay with some sub-angular to sub-rounded fine to coarse gravel-sized altered coarse ash tuff fragments, and occasional cobble- and boulder-sized coarse ash tuff fragments.

The young colluvium appears to be associated with relatively recent local landslide activity from the relict landslide scars immediately uphill, forming a lobe shaped deposit which partly intersects the upper portion of the 7 June 2008 landslide primary source area. The material within the landslide scar has mostly been displaced with only remnants observed in trial pit No. TPH4 and trial trench No. TTH1 (Plate 14).

5.4.2 Old Colluvium

The old colluvium, which was up to about 2.5 m thick, typically comprised firm to stiff, reddish brown, yellowish brown and purplish red, sandy SILT/CLAY with some to many cobble- and boulder-sized, sub-rounded coarse ash tuff fragments of CDT and HDT (Plate 13). The old colluvium was encountered in most GI locations, except in trial trench No. TPH 1 where the material was probably displaced as a result of the 7 June 2008 landslide, and also in trial trench No. TTH2 in the secondary source area.

The origin of the old colluvium is probably related to past landslide activity over time as indicated by several relict landslide scars that are still evident within the upper part of the

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landslide catchment. Although the old colluvium has weathered, occasional layered variations within the component materials can be observed in some exposures probably indicating separate deposition events. The old colluvium is probably extensively distributed across the upper and middle hillside areas of the broad depression which forms the landslide catchment. There is some evidence that the old colluvium within the topographical depression thins out along the western flank of the 7 June 2008 primary source area where partially weathered rock mass is locally close to the ground surface as revealed from trial trench Nos. TPH3 and TTH1.

No discrete shear surfaces can be found from the GI. There are zones of wetted, clayey material at about 2 m depth within the old colluvium at some locations including trial pit Nos. TPH5 (Plate 19) and TPH7. The material in these zones appears ‘remoulded’ and may be associated with local deformation movement of the material above. Although apparently disturbed, no evidence of relative movement such as slickensides or smearing were observed in these zones**.** Further evidence of local progressive deformation of the old colluvium is given by the presence of relict tension cracks observed in trial pit TPH5 (Plate 20).

5.5 Solid Geology

The solid geology of the site generally comprises volcanic tuff and medium grained granite. A geological contact between the two lithologies is located along the eastern part of the landslide catchment (Figure 10), trending approximately northwest-southeast with the tuff on the west side and the granite on the east side. Evidence of contact metamorphic effects within the highly and completely decomposed tuff is common, although little or no tuff or granite of moderate decomposition grade or better was exposed during the GI. However, much of the weathered tuff material exposed within the primary source area appeared to be derived from coarse ash crystal tuff, although occasional surface exposures of fine ash tuff and volcaniclastic rock were observed within the eastern and lower areas of the landslide catchment. Completely to highly weathered granite was exposed above the main scarp within drillhole DHH1 underlying the tuff at depth, about 22 m below ground level, and in the east part of the lower source area near surface within drillhole No. DHH2.

Within the volcanic tuff, a narrow (about 0.5 m thick) residual soil (RS) horizon was observed in some GI locations, suggesting the material may be discontinuous across the site. The RS was typically a firm reddish brown to greyish brown clayey SILT, which locally indicated some texture but no structure (possibly gradational RS/CDT). The CDT is clearly exposed in the secondary source area where it generally comprises extremely weak, light greyish brown and yellowish brown with closely spaced planar, occasionally undulating manganese oxide coated (indurated) relict joints (very sandy clayey SILT (locally silty SAND) with occasional fine gravel-sized quartz and tuff fragments). The nature of the weathered tuff material within the secondary source area suggests that it may be derived from fine ash tuff. HDT is mainly observed as corestone fragments or as a component of a weathered rock mass zone (PW30/50 to PW50/90) encountered in the base of trial pits (Plate 14) near the western part of the upper primary source area.

MDT was only encountered as weathered rock mass/corestone fragments within and adjacent to the primary source area (Plate 14). Where encountered, the material was typically altered, probably by contact metamorphic effects, and comprised a moderately strong, dark greenish grey, purplish red, locally micaceous, moderately decomposed coarse ash crystal tuff. Alteration effects varied locally but generally included partial re-crystallisation rendering some of the exposed material friable with a ‘sugary’ texture, and some mica crystal growth. Joints were not particularly well developed in the exposed MDT due to its main occurrence as part of a weathered rock mass although those observed were typically close to medium spaced planar to occasionally stepped, dipping between 60° and 70°, occasionally iron stained and locally infilled with kaolin. Shallow angle joints observed were generally dipping across the slope at between 20° and 38°. There was no evidence of any discontinuities or adverse jointing that may influence the surface of rupture.

Granite was only encountered in drillholes Nos. DHH1 and DHH2 at the upper and lower part of the primary source area. Within drillhole No. DHH1, CDG and HDG were encountered below the contact with the tuff at about 22 m below ground level, and at about 22.75 m a 1.5 m thick corestone of MDG comprising strong, pinkish grey, spotted dark grey, slightly decomposed medium grained granite could be seen. No obvious metamorphic effects could be seen within the granite below the contact. Below this depth, the granite alternated between HDG and CDG before the drillhole was terminated at 40 m.

From the limited GI information within the upper and middle part of the landslide catchment, it appears that there is a significant (> 40 m) depth of weathered profile in the vicinity of the primary source area. The lateral extent to which this significant depth of weathering extends towards the edge of the landslide catchment is uncertain. Bands of more resistant MDT and HDT material within the weathered profile (see trial pit No. TTH1 (Plate 14) and trial pit No. TPH3) may be associated with localised contact metamorphic variations (e.g. hornfelsic alteration), evidence of which can be seen in some MDT and HDT in these locations.

5.6 Field Monitoring and Field Tests

Groundwater monitoring has been carried out in drillhole Nos. DHH1 and DHH2 within the 7 June 2008 landslide primary source area between November 2008 and January 2009. A standpipe and a piezometer were installed in drillhole No. DHH1. The standpipe was installed at a depth of about 2.5 m within colluvium/residual soil, and the piezometer (standpipe piezometer) was installed at a depth of about 14 m within CDT. The piezometer and the standpipe is dry over the monitoring period from November 2008 to February 2009. Drillhole No. DHH2 is located approximately at the level of Pik Shan Path and the piezometer tip is located near the base of the drillhole at a depth of 14.5 m. No water was recorded in this drillhole over the monitoring period.

Jetfill tensiometers were installed adjacent to the 7 June 2008 landslide primary source area in early November 2008. The tensiometers were installed in three clusters (TS1 to TS3), between 1 m and 3.5 m deep. The suctions in the tensiometers were manually measured daily from November to early December 2008 and weekly thereafter. The location of the tensiometers is shown in Figure 14.

The tensiometer depths at each cluster were typically selected to coincide with a specific regolith horizon identified from the post-landslide GI. The measurements generally

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indicate dry weather suction values ranging from about 7 kPa to about 40 kPa, typically increasing with time gradually as the soil has dried out. The readings also indicate a modest increase in suction between the upper and lower colluvium and a decrease in the middle zone which is relatively silty, soft and wet compared to the soil above and below. However, evaluation of the soil suction response to rainfall has not been possible to date, as there has been no significant rainfall during the monitoring period.

The results of the constant head permeability tests in drillhole No. DHH1 indicated that the colluvium at shallow depth (between 1.0 and 2.5 m below ground surface) has a higher permeability of 1.02×10^{-5} m/s than that of the lower colluvium with a value of 5.53×10^{-7} m/s (between 2.8 and 4.3 m from below ground level). The field permeabilities of CDG/T generally range from 2.5×10^{-6} m/s to 2.5×10^{-8} m/s.

5.7 Laboratory Testing

A series of laboratory tests was conducted by Gammon Construction Ltd. and Soil & Materials Engineering Co. Ltd. on samples retrieved during the ground investigation. The tests conducted included moisture content tests, particle size distribution (PSD), Atterberg limits tests, single stage isotropically consolidated undrained triaxial compression tests (referred to as CIU tests), and direct shear box tests on 60 mm samples. The tests were carried out in accordance with Geospec 3 (GEO, 2001).

The shear strengths of young and old colluvium (Sections 5.4.1 & 5.4.2), residual soil and completely decomposed tuff were assessed by CIU tests. The shear strength parameters of both young and old colluvium correspond to c' = 2 kPa and ϕ' = 35°. A total of twelve CIU tests were carried out on ten samples located within or in the vicinity of the primary source area of the 7 June 2008 landslide. The tests results are summarised in Figure 15. Another nine CIU tests were carried on nine samples of residual soil and the shear strength corresponds to c' = 1 kPa and ϕ' = 35° (Figure 16). The shear strength parameters of completely decomposed tuff correspond to c' = 1 kPa and ϕ' = 35°, based on six CIU tests carried out on six samples (Figure 16).

Direct shear box tests were also carried out on eight samples of colluvium from block samples and the shear strength parameters of young and old colluvium correspond to c' = 0 kPa and ϕ' = 46°, and c' = 0 kPa and ϕ' = 42° respectively (Figure 15). Two of the samples were taken from the softened silty clay layer within the old colluvium. The results of laboratory testing on these two samples show no significant difference from those of other old colluvium samples. The ϕ' value obtained from the direct shear box tests for the colluvium appeared to be significantly higher than that of the triaxial tests, which may be due to the inherent difference in sampling and the test arrangement.

6. GEOLOGY AND GEOMORPHOLOGY

6.1 Geological and Geomorphological Setting

The study area is characterised by a broad topographic depression, which is probably associated with deeply weathered thermal metamorphic contact between volcanic and granitic rocks with a mantle of colluvium. The colluvium can be separated into an older bouldery

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colluvium, which probably occurs throughout the topographic depression, and a younger localised colluvium probably associated with a specific location and period of activity. The old colluvium is about 2.5 m thick, while the underlying volcanic tuff and granite saprolite is up to 40 m thick. The deep weathered profile appears to have developed regular zones of more indurated or resistant material, possibly associated with hornfels alteration or quartz re-crystallisation. Relatively few relict joints were exposed, and slickensides were rarely observed (only in drillhole No. DHH1).

The location of the 7 June 2008 landslide, which is within a broad topographic depression and below a local break-in-slope on a locality previously affected by natural terrain landslides, does not appear to be typical of retrogression of existing relict scars or hillside retreat, such as that postulated by Hansen (1984). The 7 June 2008 landslide is much larger in extent and scale than that of previous instabilities within the relatively active catchment. Despite the large extent, the landslide is relatively shallow with the surface of rupture occurring at the interface between old colluvium and RS/CDT. As the depression coincides with much of the line of contact, it may be the case that the materials along the contact are associated with preferential weathering, although bands of indurated or resistant rock may occur in the weathered profile due to localised metamorphic effects such as hornfelsic alteration or quartz re-crystallisation.

6.2 Hydrogeology

Seepages were observed on the upper and lower portions of the primary source area at the time of field inspection made on 8 June 2008, and evidence of soil pipes were found in the GI carried out (Plate 14). Erosion gullies were observed predominantly within the secondary source area, as well as within the soft remoulded debris deposits along the debris trail.

Existing drillholes Nos. DH24 and AIDH5 located near the toe area of the landslide site indicated that the water levels were respectively 3.8 m and 4.3 m below the ground surface within insitu weathered materials. The groundwater monitoring carried out at drillhole No. DHH1 (located near the crest of the primary source area) and drillhole No. DHH2 (near the toe of the primary source area) between November 2008 and January 2009, has indicated a groundwater level of 15 m or more below the ground surface.

Soil pipes were observed in the main scarp and in trial trench TTH1 although no seepage was observed at the time of inspection. However, some wetted zones within the old colluvium were observed in some trial pits above the underlying CDT (e.g. trial pits Nos. TPH5, TPH7 & THH2), possibly indicating zones of groundwater perching or preferential groundwater flow zones.

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from two nearest GEO automatic raingauges Nos. H02 and H04, which are located about 370 m to the north at Knowles Building, Hong Kong University, Pokfulam and 760 m to the west at Blocks C & D, Kwun Lung Lau Estate, Lung Wah Street, Kennedy Town (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the GEO and the Hong Kong Observatory (HKO). The daily rainfall recorded

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by raingauges Nos. H02 and H04 over the month preceding the 7 June 2008 rainstorms, together with the hourly rainfall readings for the period between 5 and 7 June, 2008, are presented in Figures 17 and 18.

The short-duration rainfall up to duration of about 24 hours recorded at raingauge No. H02 was more intense than that recorded at raingauge No. H04, while the longer-duration rainfall was less intense at raingauge No. H02.

According to the eyewitness account, the main phase of the landslide occurred between 8:45 a.m. to 9:00 a.m. on 7 June 2008. For the purposes of rainfall analysis, the landslide was assumed to have occurred at 9:00 a.m. on 7 June 2008. The Black Rainstorm Warning was hoisted on 7 June 2008 between 6:40 a.m. and 11:00 a.m. The rainstorm started at about 2:00 a.m. on 7 June 2008 and the maximum 1-hour rolling rainfall at raingauge Nos. H02 and H04 was 142 mm and 129.5 mm respectively, which were recorded between 7:45 a.m. and 8:45 a.m. at raingauge No. H02 (Table 1) and between 8:00 a.m. and 9:00 a.m. at raingauge No. H04 (Table 2).

An analysis of the return periods for various durations of rolling rainfall recorded by raingauge Nos. H02 and H04, with reference to historical rainfall data at the HKO in Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994), shows that a rainfall duration of 15 minutes was the most severe at raingauge No. H02, with a corresponding return period of about 100 years. The maximum return periods for rainfall recorded at the closer raingauge No. H04 is 46 years corresponding to the 4-hour duration (Tables 1 & 2).

The 7 June 2008 rainstorm was also assessed with local rainfall data to evaluate the spatial variability of rainfall. The return periods were assessed based on the statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by raingauge Nos. H02 and H04 between 1984 and 1997. The results show that the return periods are comparable to those estimated by the historical rainfall data at Tsim Sha Tsui (Table 1) with a maximum return period of over 100 years and 49 years for raingauges Nos. H02 and H04 respectively. The rainfall distributions for the periods of 1 hour to 8 hours are shown in Figure 19. It indicates the rainfall intensity decreased gradually from raingauges No. H02 to the east towards raingauge No. H04, near the 7 June 2008 landslide location.

The maximum rolling rainfall for the 7 June 2008 rainstorm has been compared with the previous major rainfall recorded by raingauge No. H04, which came into operation in August 1978 (Figure 18). The 7 June 2008 rainstorm is more severe than the previous major rainstorms for rainfall durations of 1 hour to 4 hours and 24 hours. The 7 June 2008 rainstorm was also compared with the rainfall data recorded at the HKO in Tsim Sha Tsui in June 1966 (Figure 18). The 7 June 2008 rainstorm is the heaviest ever recorded for rainfall durations of 1 hour and 2 hours.

8. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses were carried out to assist in the diagnosis of the mechanisms and causes of the failures in the primary source area. These analyses were aimed at investigating the likely operative range of shear strength parameters along the potential failure surfaces corresponding to different possible transient groundwater levels.

The information used in these analyses was obtained from the pre-incident LIDAR survey, post-incident topographic survey, pre- and post-incident ground investigations and laboratory tests, together with field observations and measurements.

Section B-B (Figure 11) was adopted in the analysis and two failure modes were considered. Failure mode 1 corresponds to a phased failure where the upper part of the main source area failed first as reported by one of the eyewitnesses (slip surface No. 1 in Figure 20). Failure of the lower part of the main source area was subsequently triggered because of the surcharging by the debris, which came from the upper part of the source area (slip surface No. 2 in Figure 20). Failure mode 2 corresponds to a failure extending over the entire main source area (Figure 21). The potential failure surfaces in both failure modes are located predominately along the old colluvium/residual soil interface and within the residual soil layer. A range of possible transient groundwater profiles was examined in the analyses. The groundwater levels recorded in the primary source area following the 7 June 2008 landslide indicate that the baseline levels are low (> 15 m). However, ‘moist’ colluvial soil horizons and soil pipes observed in some of the trial pits within the upper 2 m of the regolith indicate that transient perched water levels may have reached the upper regolith layers during heavy rain. It is likely that soil suction reduced to zero in the near-surface groundmass during heavy rainfall and therefore no soil suction was allowed for in the stability analyses.

The results of the analyses for failure mode 1 and 2 are presented in Figures 20 and 21 respectively for shear strength parameters of c' = 0 kPa to 3 kPa and ϕ' = 30° to 40° for the colluvium/residual soil interface and residual soil. The results indicate that with the shear strength parameters derived from triaxial tests (c' = 2 kPa and ϕ' = 35° for colluvium and c' = 1 kPa and ϕ' = 35° for residual soil), together with a perched water level of about 1.1 m to 1.5 m below ground surface (i.e. about 0.7 m to 0.3 m above the slip surface), it would have been sufficient for both failure modes 1 and 2 to occur. There was no significant difference in the perched water level profile required to trigger the two failures.

9. DEBRIS MOBILITY

9.1 General

The debris from the primary and secondary source areas travelled for distances of about 210 m and 150 m respectively. Most of the debris from both source areas was deposited on the western side of CYC Building along the lower portion of the drainage line, which is inclined at an angle of about 15°.

The travel angle of the debris from the primary source area, which had a greater runout distance, was about 29°. Travel angles for some historic landslides on natural terrains were presented by Lo (2000). The travel angles of those historic landslides involving failure volumes similar to that of the primary source area of the 7 June 2008 (approximately 1,400 m^3) were typically between 15° and 25°, which is below the travel angle of the 7 June 2008 landslide (29°). This suggests that the 7 June 2008 landslide was not particularly mobile in comparison. This may be partly due to the relatively high basal friction of the insitu materials below the primary source area (see Section 9.2) and partly due to the restraints provided by CYC Building.

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The debris mobility was also assessed with an empirical method, which considers both the travel angle and the horizontal distance downslope where an overall gradient is 15° or less (Wong et al, 2006). For the 7 June 2008 landslide, the debris travelled a horizontal distance of about 30 m downslope of 15° or less, and the travel angle was about 29° (from the primary source area). The debris mobility is classified as 'Zone 4', indicating that the debris was not particularly mobile (Figure 22).

9.2 Theoretical Modelling of Debris Runout

Theoretical analyses of the mobility of the landslide debris trail resulting from the primary source area was carried out using GEO's numerical simulation package, the 3-dimensional Debris Mobility Model (3dDMM). Details of the analyses are given in Appendix C.

The topography adopted for the modelling was based on the pre-failure LiDAR survey. The initial thickness of the displaced material within the primary source area was estimated based on the pre-failure LiDAR survey, and the post-failure topographical survey and field measurements (see Section 4.2). For simplicity, it has been assumed that all the materials in the primary source area displaced simultaneously. Frictional rheology was adopted in the model. A parametric study was carried out in order to provide a reasonable fit to the extent and shape of the debris trail, deposition of debris and mass balance.

The results of the parametric study show that a combination of base friction angles of 22° for the colluvium in the primary source area and 27° for the downhill area where insitu materials were incised by the debris, could provide a reasonable fit to the debris trail. A constant entrainment coefficient of 0.0025 was also adopted to give a reasonable fit to the overall mass balance.

The average velocity profile generated by the 3dDMM (Figure C1) indicates that the debris flow would accelerate from the primary source area and reach its peak average velocity of about 11 m/s after 7 seconds of initiation, when the debris front reached approximately Chainage CH 110 (Figure C2). The debris would then start to reduce in speed at about 8 second as it entered the drainage line DL1 where the debris became partially confined and channelised. The average velocity would be reduced further to about 6 m/s when the debris reached the temporary steel footbridge adjacent to CYC Building after 13 seconds. The momentum and thickness of debris at that time were calculated to be 2×10^7 kg m/s and 1.5 m respectively, which might be sufficient to knock down the temporary steel footbridge. At about 18 second, the debris would come to a halt between Chainage CH 130 and CH 200 near the western side of CYC Building where the slope gradient is gentle (15°). The calculated maximum thickness of the debris deposited there was about 3 m, which is comparable to that observed on site.

10. DIAGNOSIS OF THE PROBABLE CAUSES OF THE 7 JUNE 2008 LANDSLIDE

10.1 Sequence of Failure

The probable sequence of events has been reconstructed from accounts given by eyewitnesses and photographic records, together with detailed field mapping of the

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7 June 2008 landslide. Based on a synthesis of the available information and corroboration of evidence from various sources, it is considered that the landslide probably occurred in four phases in a progressive manner over a period of about two hours between about 7.30 a.m. and 9.30 a.m. (Figure 9).

The first phase of the failure probably occurred between 7:30 a.m. and 8:00 a.m. on 7 June 2008, initiating a detachment in the uppermost part of the primary source area. This detachment comprised an estimated volume of about 500 m^3, much of which probably came to rest on the lower part of the primary source area as no debris was observed at the lower slope at that time.

The second phase of the failure probably occurred at around 8:30 a.m. in the secondary source area. At this time, the temporary steel footbridge was still intact, although some debris might have accumulated behind it, but there was no debris adjacent to CYC Building.

The third phase of the landslide likely occurred at around 8:45 a.m. at the lower part of the primary source area following the initial failure, in areas between the initial detached area and the uphill side of Pik Shan Path. The third phase of the landslide was possibly precursory movement to the main detachment (fourth phase), as trees were observed to have leaned forward and progressively move downhill. The fourth phase of the landslide occurred around 9:30 a.m. and involved the main detachment from the primary source area.

Several further minor detachments involved the extension of the flank of the primary main scarp and reactivation within the lower portion of the primary source area occurred between 12 and 30 June 2008.

10.2 Causes and Mechanisms of Failure

The close correlation between the 7 June 2008 landslide and the preceding heavy rainstorm suggests that the failure was probably triggered by rainfall. The rainstorm was more severe than the previous major rainstorms for rainfall duration of 1 hour to 4 hours and 24 hours.

The mode of failure of the primary source area comprised an open hillside failure becoming channelised at the confluence with the secondary source debris trail at about chainage CH 120 m. Direct infiltration during heavy rainfall and possibly subsurface seepage from the upper part of the landslide catchment would have wetted up the groundmass, leading to the reduction of soil suction and possible build-up of transient perched water above the old colluvium/CDT interface. The failure scarps and exposed rupture surface of the initial failure may have promoted further infiltration into the groundmass. Theoretical stability analyses of the 7 June 2008 landslide indicate that a transient perched water table of about 0.9 m above the old colluvium/CDT interface would have been sufficient for failure to occur.

The smaller secondary source area also involved a rain-induced open hillside failure, which became channelised at the confluence with the primary debris trail. Direct infiltration during heavy rainfall would have wetted up the groundmass and led to a reduction of the soil suction. This would in return result in gradual reduction of the shear strength of the

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groundmass. Transient perched water pressure could have also built-up locally above the RS/CDT interface, which further contributed to reducing the shear strength of the soil. Although relict structure was observed within the tuff saprolite at the source area, they were not adversely orientated with respect to the setting.

The primary and secondary source areas are not considered to have any influence on the initiation of each other, given their considerable distance apart.

10.3 Contributory Factors to Failure

10.3.1 General

Based on a diagnosis of the findings of the landslide investigation, the key factors that probably contributed to the failure include the following:

(a) adverse geomorphological and geological setting, and
(b) progressive deterioration of accumulated colluvial material.

10.3.2 Adverse Geomorphological and Geological Setting

The setting of the 7 June 2008 landslide primary source area is adverse in that it is located within a broad topographical depression below a local break-in-slope on a locality with landsliding evident in the past, together with a relatively thick accumulation of colluvium on a fairly steep terrain (> 30°). The broad depression may have resulted in convergent surface runoff and subsurface seepage during periods of heavy rainfall. The soil pipes encountered in the main scarp and in trial pit No. TTH1 could have also promoted water ingress towards the landslide area through preferential groundwater flow.

The 7 June 2008 landslide primary source area involved failure of the shallow materials of young and old colluvium, with the surface of rupture primarily along the old colluvium/CDT interface. The angular morphology of the rupture surface may suggest that the landslide initiation might have been influenced by adverse structural geological features. However, neither site observations nor the GI exposed any continuous discrete shear surface at the old colluvium/CDT interface.

Although no definite slip planes could be observed, some zones of ‘wetted’ sandy silt/clay were present within the old colluvium, either above the interface with insitu tuff or locally where the colluvium composition changes. These zones of ‘wetted’ material had a relatively higher water content, and may be more susceptible to the development of a positive pore water pressure, leading to a reduction in the shear strength of the material.

10.3.3 Progressive Deterioration of Accumulated Colluvial Material

Available information indicates that the rupture surface of the 7 June 2008 landslide is typically at the base of the old colluvium. The lower colluvial soil horizon is probably derived from variably altered tuff and consequently contains localised zones of relatively high mica content and changes in sand component grain size, potentially resulting in variable

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permeability and shear strength along these zones. Also, this colluvium was probably accumulated over time as a result of past moderate-scale landslide activities, which are mainly located along a line or erosion front around the upper catchment area. The accumulated colluvial material may be susceptible to long-term movement during rainstorms and progressive deterioration.

Given the particular hillside setting of the 7 June 2008 landslide, it is likely that progressive deterioration and deformation within the colluvial materials has occurred over time, as evidenced by the pre-existing tension cracks observed in the old colluvium in trial pit No. TPH5 (Plate 20) and 'disturbed' (dilated and infilled) partially weathered rock mass zones at the base of trial trench No. TTH1 and trial pit No. TPH3. The progressive deterioration and deformation may have resulted in development of shear and volumetric strains due to past heavy rainstorms, leading to the formation of local tension cracks (without resulting in a distinct or discrete rupture surface at depth), which would have made the hillside more vulnerable to water ingress during subsequent rainfall. However, the available data did not reveal evidence of a deep-seated failure.

10.4 Extent of Failure

The scale of the 7 June 2008 landslide is unusual in that although relatively shallow, it is spatially far more extensive than any previously recorded landslides in the catchment. This may be partly due to the different failure processes involved and the characteristics of the rainstorm. The previous instabilities in this locality were relatively frequent with moderate magnitude, and involved retrogressive failures within a thin layer of superficial colluvium at the upper part of the catchment. By comparison, the 7 June 2008 landslide process produced a relatively infrequent and larger magnitude event at the middle part of the catchment, where there are extensive colluvial accumulations. Thus there appears to be two different processes operating within the same catchment, with differing vulnerability to time-dependant deterioration and rainstorm intensity.

Furthermore, the unusual extent of the primary source area in the June 2008 event was probably controlled by its geomorphological setting and localised geological material variations which would have affected the susceptibility to failure. The crown of the primary source area is located below a convex break-in-slope, and the extent of the east flank was controlled by the proximity to the spurline forming the landslide catchment boundary and where the thickness of colluvial accumulation was likely to decrease. The west flank of the primary source area was probably controlled by local shallow areas of hard material typically described as a partially weathered tuff rock mass PW 30/50 to PW 50/90 (TTH1 & TPH3), although the rockhead may be at significant greater depth (> 40 m in DHH1). The solid geology of the landslide catchment may not have directly influenced the shallow failures. However, the localised effects of the granite/tuff contact may result in variations in the depth of the detached materials in the primary source area, as evidenced by deep weathered soil profile and presence of partially weathered rock bands.

Dense vegetation present in the middle to upper area of the 7 June 2008 landslide may also have influenced the extent of the failure. The dense vegetation and associated effects of root binding of the near-surface groundmass may have contributed to stabilise the surface material and prevent the frequent occurrence of smaller scale instabilities until the stability of

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the groundmass reached a critical triggering point for a large scale failure.

10.5 Potential Anthropogenic Influences

The construction site for the HKU's Centennial Campus is located at the toe of a natural hillside adjacent to the 7 June 2008 landslide catchment. The associated tunnel excavation works mainly adopted a drill and break technique using hydraulic splitting/breaking, without blasting. The excavation works would unlikely have contributed to the shallow failure in the 7 June 2008 landslide event. Also, the tunnelling works would not have affected the surface hydrogeological setting of the failed natural hillside since the landslide is located within another topographic catchment separated from that of the tunnels by a spur (Section 2.3).

Along the uphill side of Pik Shan Path are several small cut slopes typically about 3 m high. Some of these slope features failed in the 7 June 2008 landslide, mainly on the eastern side of the primary source area. The failures may have been a result of the erosive action of the landslide debris from the primary source area above. Retrogressive failure induced by initial instability of these small cut slopes is considered unlikely, given the large extent of the 7 June 2008 landslide event and that no major past instabilities occurred on these slopes. Furthermore, eyewitness accounts indicated that the first obvious signs of failure originated within the upper part of the primary source area above the cut slopes (Section 4.1).

A small trench (probably military in origin) was observed adjacent to a ridgeline about 50 m above the crest of landslide catchment (Section 3.3.6, Plate A3). The base and sides of the trench are paved and the paving appears to be in relatively good condition. Therefore, water ingress from the trench into the groundmass would likely be minimal and confined to local area.

A 200 mm diameter water main was present along Pik Shan Path and was ruptured by the landslide. Subsequent discharge from the ruptured pipe probably caused an increased washout of landslide debris down the drainage line and exacerbated local surface erosion along the debris trail (Section 4.4). However, there is no evidence indicating leakage from the water main prior to the 7 June 2008 landslide (Section 2.2).

11. CONCLUSIONS

The 7 June 2008 landslide was probably triggered by the preceding intense rainstorms. It involved two separate source areas and occurred in phases. The 7 June 2008 rainstorm was more severe than the previous major rainstorms since 1978 for short to medium duration rainfall (1 hour to 4 hours, and 24 hours).

Although spatially extensive, the 7 June 2008 landslide is relatively shallow. The surface of rupture was primarily along the old colluvium/CDT interface. Possible build-up of transient perched water above this interface due to direct infiltration and subsurface seepage and subsequent reduction of the shear strength of the groundmass was probably the primarily cause of the landslide. Progressive deterioration and deformation within the colluvium over time due to past heavy rainstorms, likely made the hillside more vulnerable to water ingress.

The shallow but spatially extensive landslide of 7 June 2008 is not typical of the previous landslides in the catchment. This may partly due to the different failure processes involved and the characteristics of the rainstorm. The previous instabilities in this locality involved retrogressive failures within a thin layer of superficial colluvium at the upper part of the catchment. By comparison, the 7 June 2008 landslide process involved areas at the middle part of the catchment, where there are extensive colluvial accumulations. Furthermore, localised effects of the granite/tuff contact in the primary source area as well as the adverse geomorphological setting, which comprises relatively steep-inclined broad topographical depression and extensive but shallow colluvial accumulations, may have influenced the extent of the failure.

However, the above-mentioned factors are not uncommon in other hillside settings. Although the detailed investigation has provided some useful information on the hillside behaviour, it remains uncertain as to why a landslide with such unusual characteristics would occur at this particular location. This uncertainty also highlights the difficulty involved in a natural terrain hazard study, especially in predicting large magnitude low-frequency events.

A number of anthropogenic activities have been identified in the area, including the construction works at the toe of the adjacent hillside. However, none of them are considered to have affected the initiation of the 7 June 2008 landslide.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. H02 for Selected Durations Preceding the 7 June 2008 Landslide and the Estimated Return Periods

Duration	Maximum (1) Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)	
			Lam & Leung (2) (1994)	Data of H02 (3) from Evans & Yu (2001)
5 Minutes	19.0	7:55 a.m. on 7 June 2008	18	11
15 Minutes	50.0	8:05 a.m. on 7 June 2008	100	40
1 Hour	142.0	8:45 a.m. on 7 June 2008	89	> 100
2 Hours	193.0	9:00 a.m. on 7 June 2008	53	> 100
4 Hours	270.0	9:00 a.m. on 7 June 2008	65	> 100
12 Hours	293.0	9:00 a.m. on 7 June 2008	11	10
24 Hours	425.0	9:00 a.m. on 7 June 2008	19	25
48 Hours	431.5	9:00 a.m. on 7 June 2008	10	7
4 Days	479.0	9:00 a.m. on 7 June 2008	7	5
7 Days	537.5	9:00 a.m. on 7 June 2008	7	6
15 Days	675.5	9:00 a.m. on 7 June 2008	7	5
31 Days	761.0	9:00 a.m. on 7 June 2008	3	3

Notes :
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(3) Return periods were also derived from the statistical parameters of raingauge No. H02 extracted from Appendix B of Evans & Yu (2001) to assess the spatial variability of rainfall.
(4) Raingauge No. H02 situated at about 760 m to the west of the landslide site. The nearest GEO raingauge to the landslide site is raingauge No. H04 situated at about 370 m to the northeast of the landslide site.

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Table 2 - Maximum Rolling Rainfall at GEO Raingauge No. H04 for Selected Durations Preceding the 7 June 2008 Landslide and the Estimated Return Periods

Duration	Maximum [(1)] Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)	
			Lam & Leung (2) (1994)	Data of H04 (3) from Evans & Yu (2001)
5 Minutes	15.5	7:55 a.m. on 7 June 2008	5	5
15 Minutes	38.0	8:15 a.m. on 7 June 2008	10	8
1 Hour	129.5	9:00 a.m. on 7 June 2008	44	45
2 Hours	170.0	9:00 a.m. on 7 June 2008	23	24
4 Hours	255.5	9:00 a.m. on 7 June 2008	46	49
12 Hours	281.5	9:00 a.m. on 7 June 2008	9	6
24 Hours	424.0	9:00 a.m. on 7 June 2008	18	13
48 Hours	430.5	9:00 a.m. on 7 June 2008	10	5
4 Days	547.0	9:00 a.m. on 7 June 2008	12	5
7 Days	613.0	9:00 a.m. on 7 June 2008	13	7
15 Days	753.0	9:00 a.m. on 7 June 2008	11	5
31 Days	839.0	9:00 a.m. on 7 June 2008	5	3

Notes :
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(3) Return periods were also derived from the statistical parameters of raingauge No. H04 extracted from Appendix B of Evans & Yu (2001) to assess the spatial variability of rainfall.
(4) The nearest GEO raingauge to the landslide site is raingauge No. H04 situated at about 370 m to the northeast of the landslide site.

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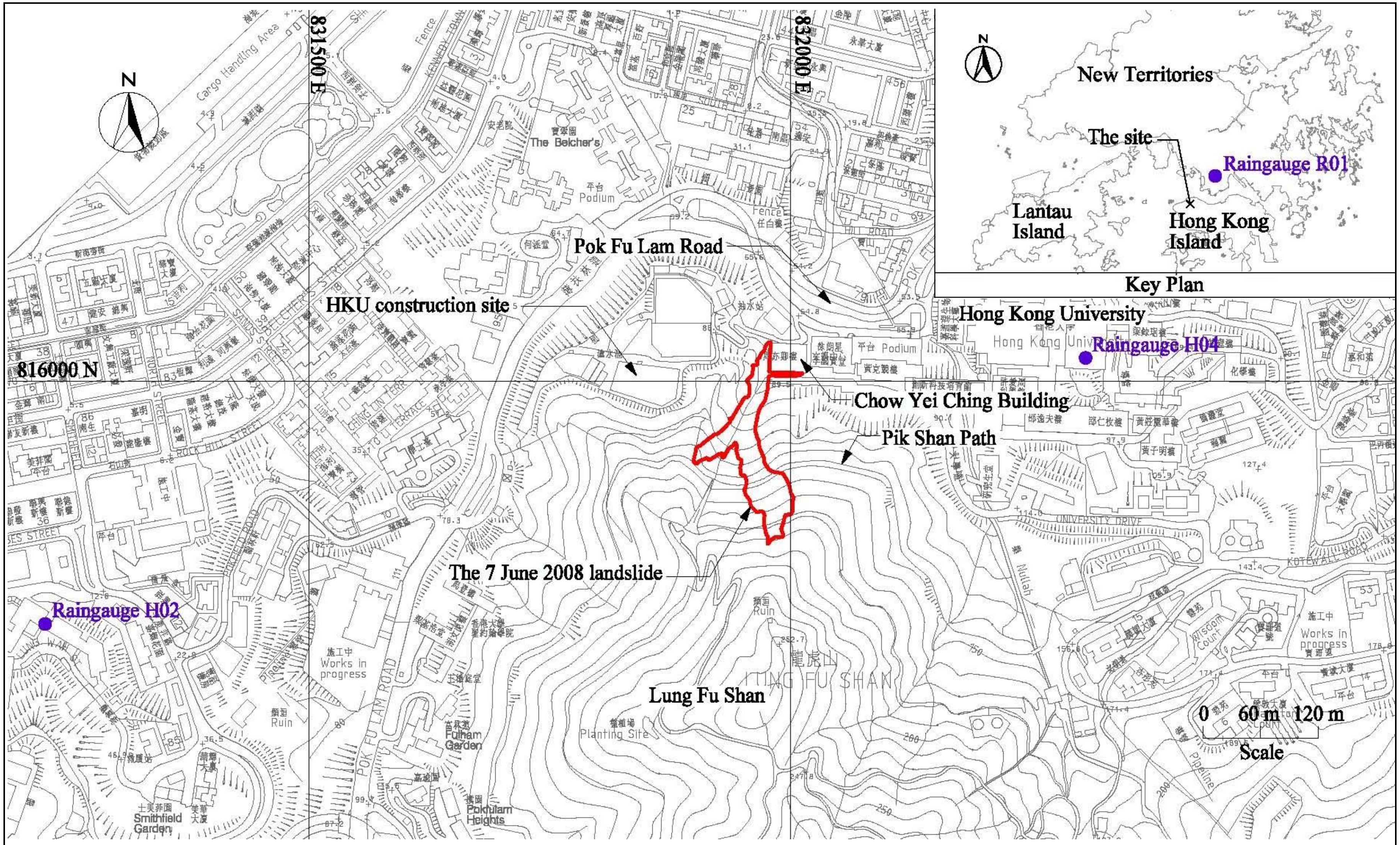

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C, 11SW-7D, 11SW-12A and 11SW-12B dated March 2008.

Figure 1 - Locations Plan

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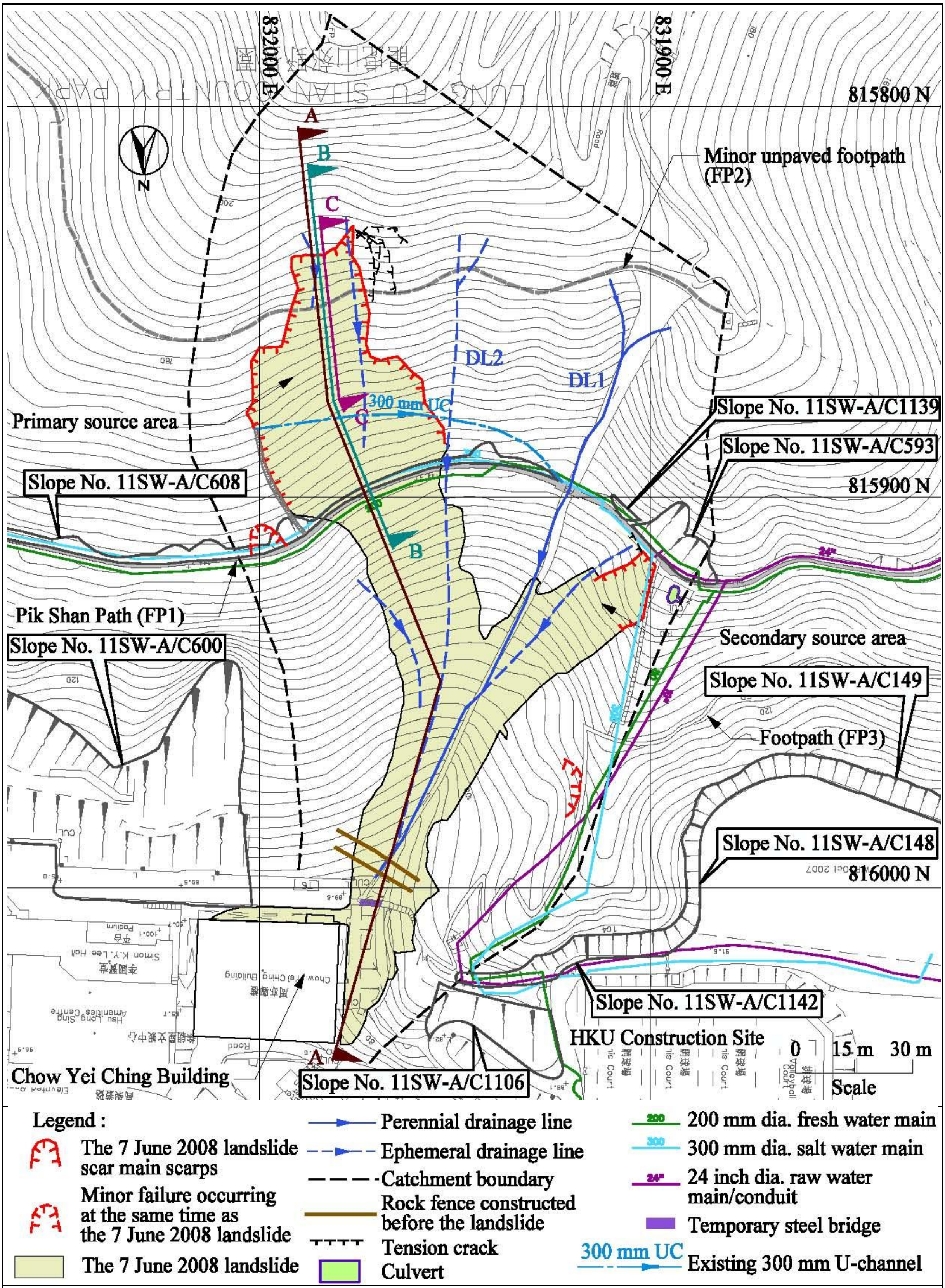
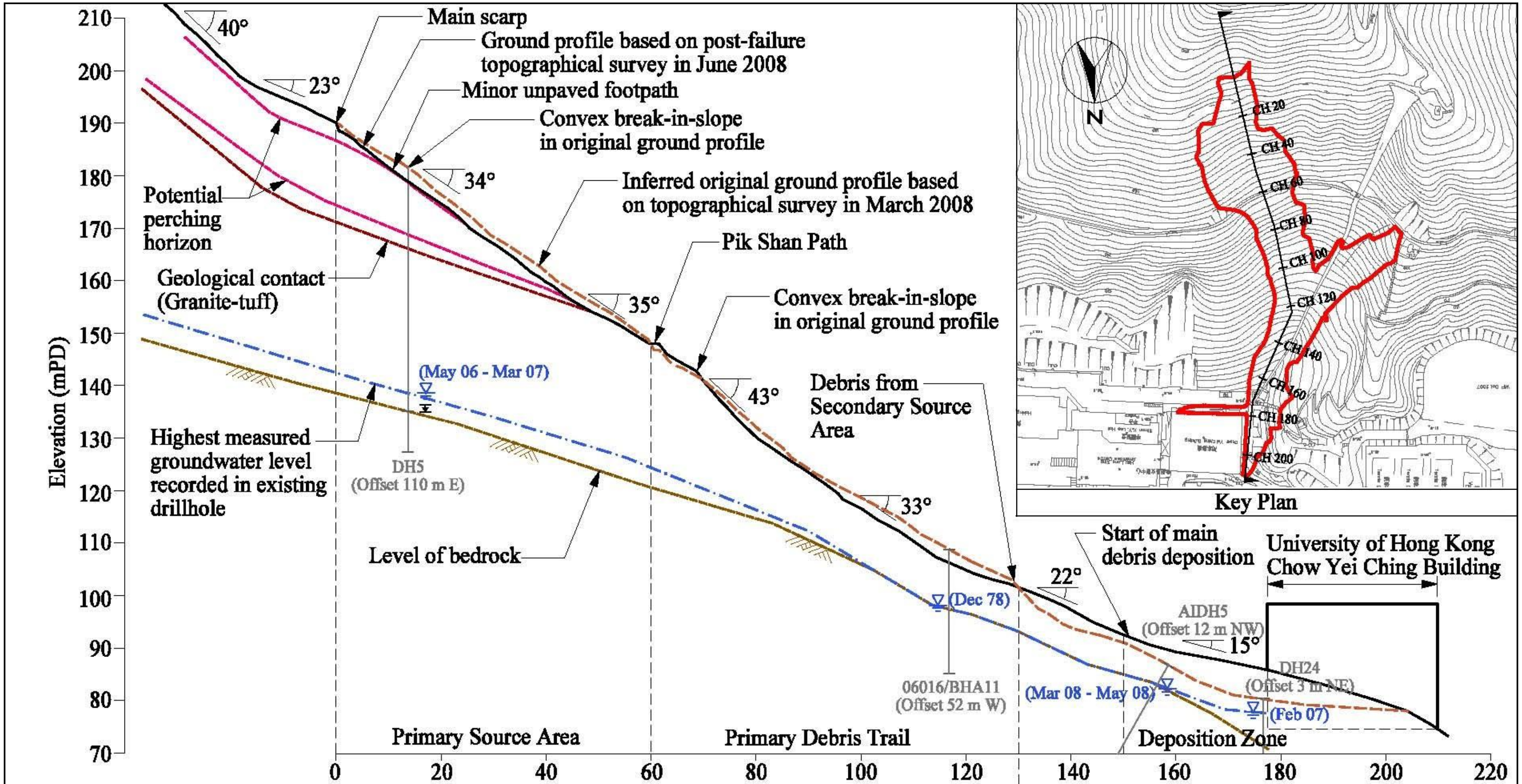


Notes: (1) Base plan is extracted from 1:1000 survey sheet No. 11SW-7C dated March 2008.

(2) Locations of the water mains are approximate only and are based on utilities records provided by WSD.

Figure 2 - Site Layout Plan and Utilities



Erosion (m³)	1750	590	400	0
Deposition (m³)	220	255	50	2127
Mass Balance (m³)	1530	1865	2215	88 (Outwash)

Legend ⊽ (Dec 78) Highest measured groundwater level recorded in existing drillhole in December 1978.

Note: See Figure 2 for location of section and location of water main adjacent to Pik Shan Path; and Figures 11 & 12 for detailed geological sections.

Figure 3 - Section A-A through the Primary Source Area of the 7 June 2008 Landslide

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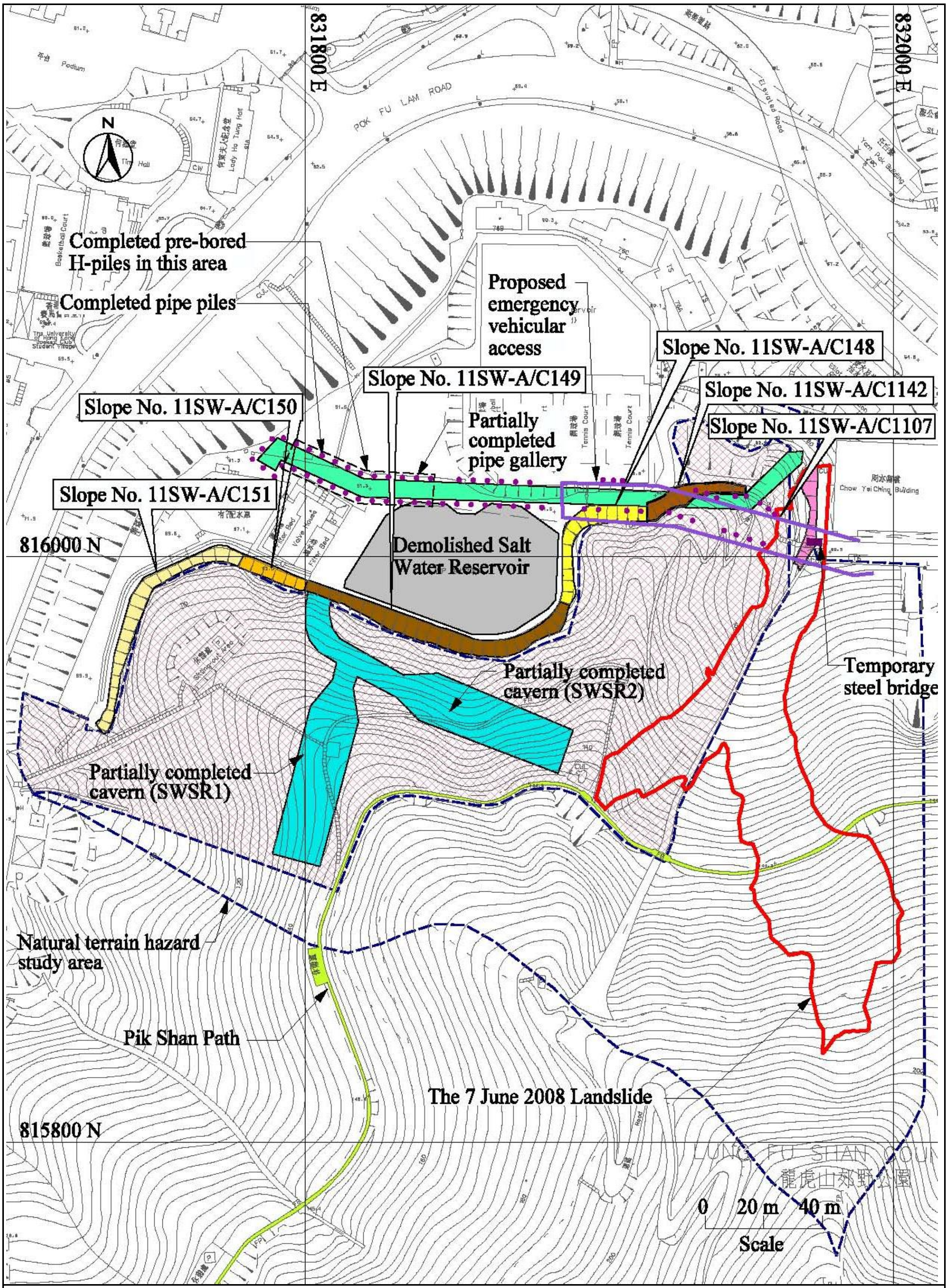

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C, 11SW-7D, 11SW-12A and 11SW-12B dated March 2008.

Figure 4 - Construction Site for HKU Centennial Campus

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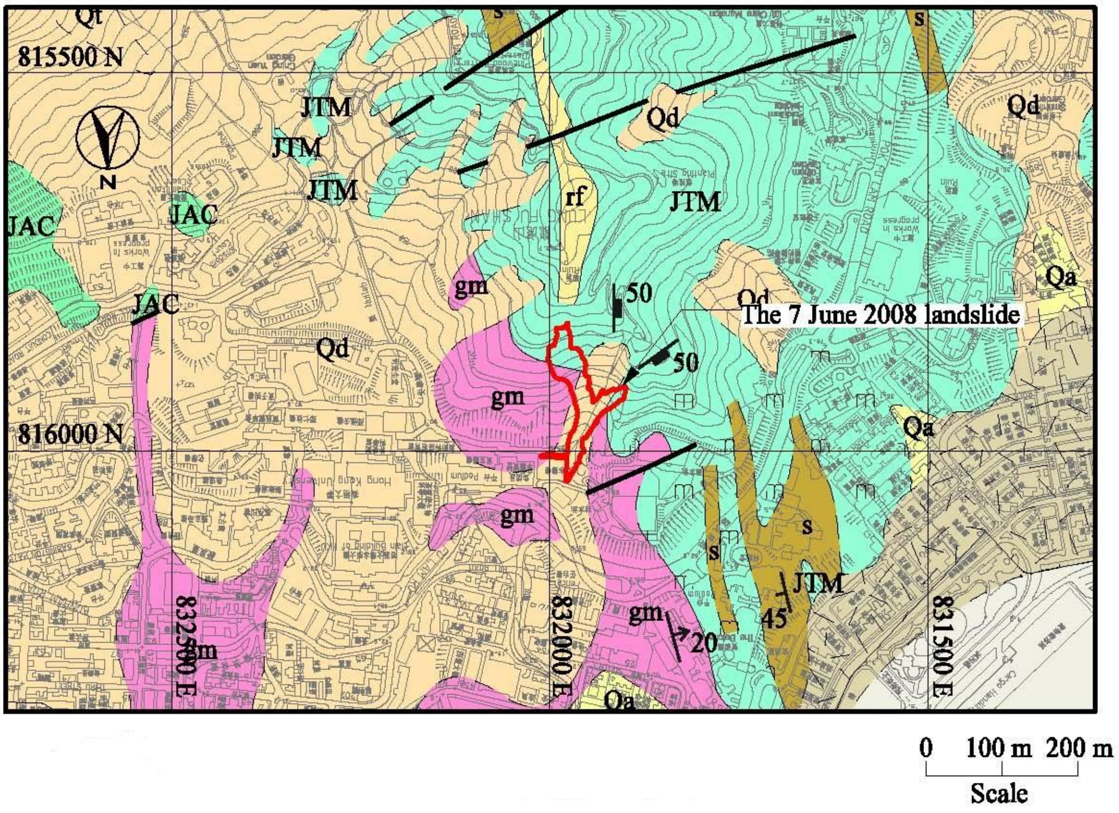

Legend:

Superficial deposits

Qa	Alluvium	Clay/silt, sand and gravel; well-sorted to semi-sorted
Qd	Debris flow deposits	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix

Solid geology

gm	Medium-grained granite, 2 - 6mm
JTM	Coarse ash crystal tuff
JAC	Fine ash vitric tuff
s	Sandstone

Geological lines

— - — -	Photogeological lineament
—— ——	Fault
– – – –	Geological boundary, superficial deposits

Structual symbols

20	Intrusive contact
50	Jointing
45	Bedding

Note: Extracted from Hong Kong Geolgical Survey, Map Series HGM 20, Sheet 11. 1:20 000 scale (GCO, 1986).

Figure 5 - Regional Geology

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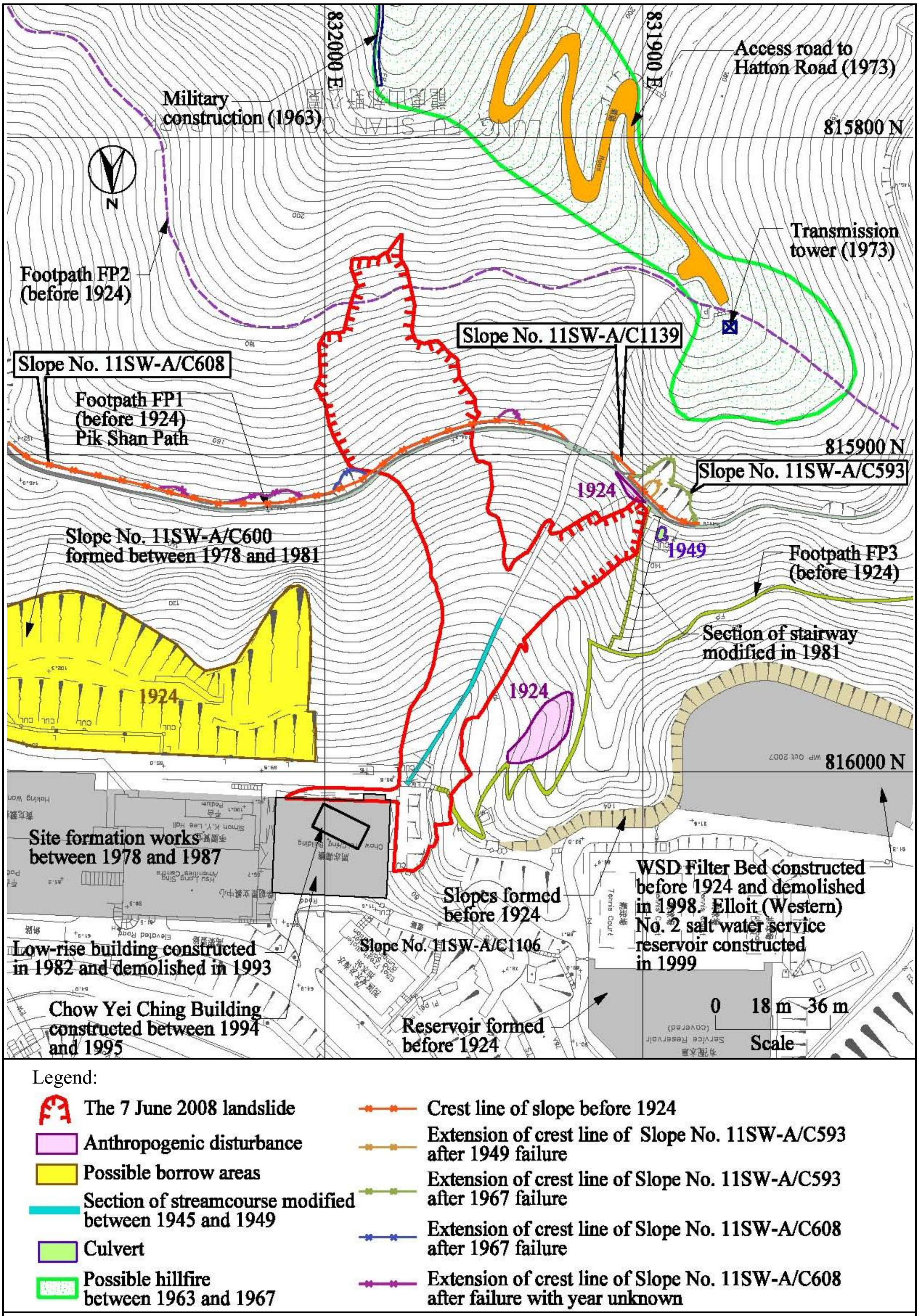

Note: Base plan is extracted from 1:1000 survey sheets No. 11SW-7C dated March 2008.

Figure 6 - Site History

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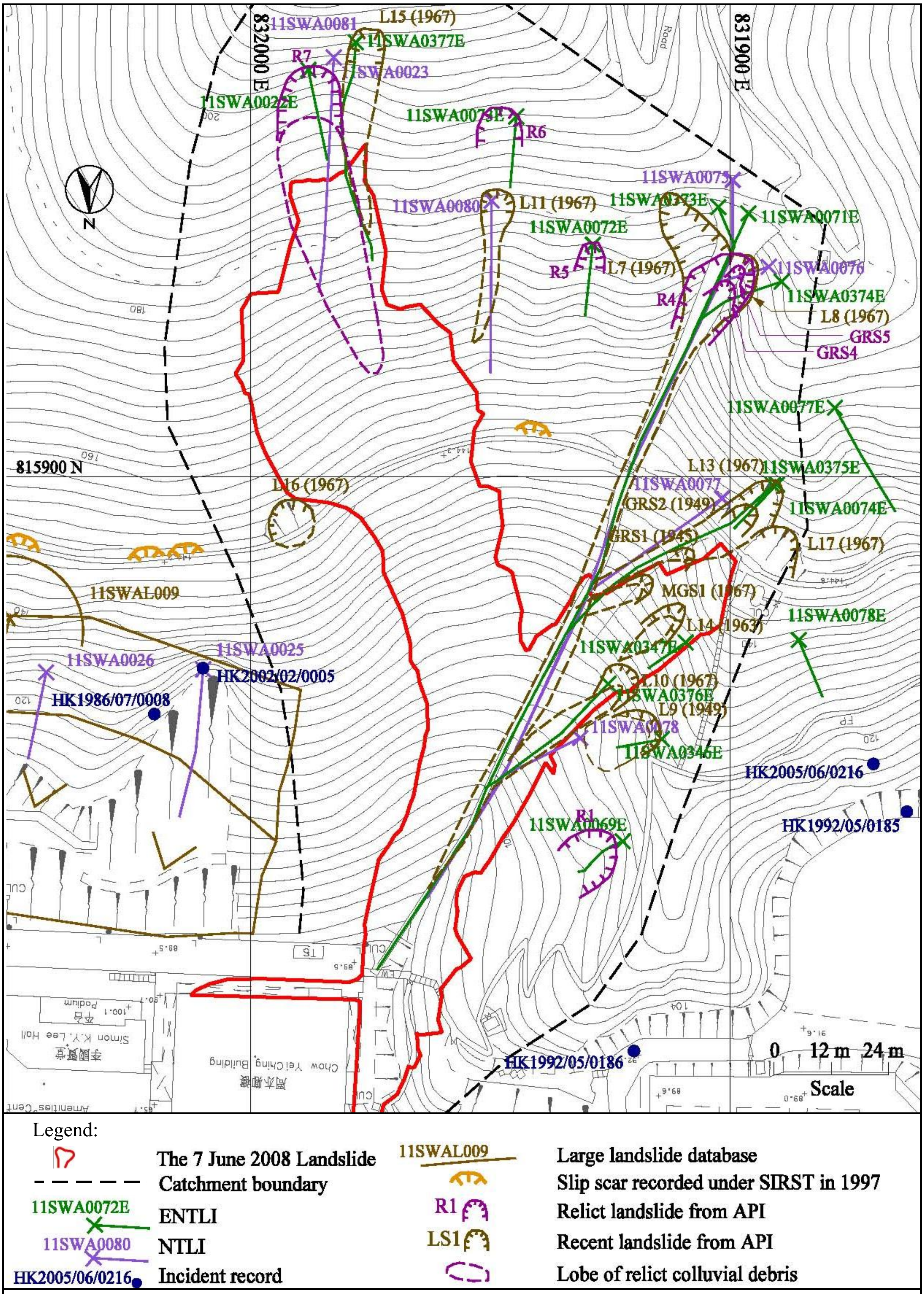
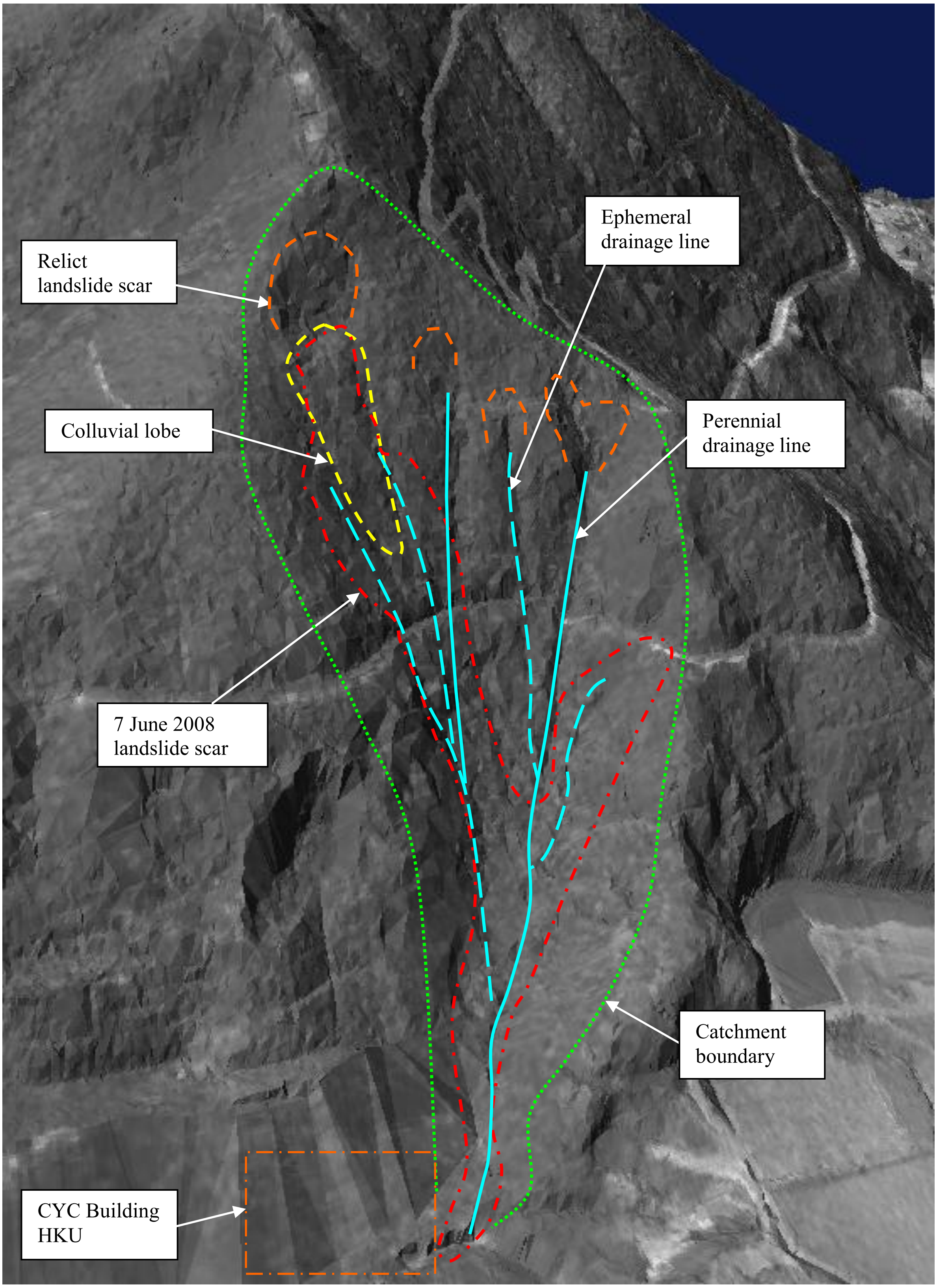


Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C and 11SW-7D dated March 2008.

Figure 7 - Past Instabilities



Note: 3D Digital Terrain Model, composed of 2006 LiDAR survey data and overlayed with 1963 aerial photograph, shows the geomorphological characteristics of the landslide catchment.

Figure 8 - 3D Digital Terrain Model Generated Using LiDAR Survey

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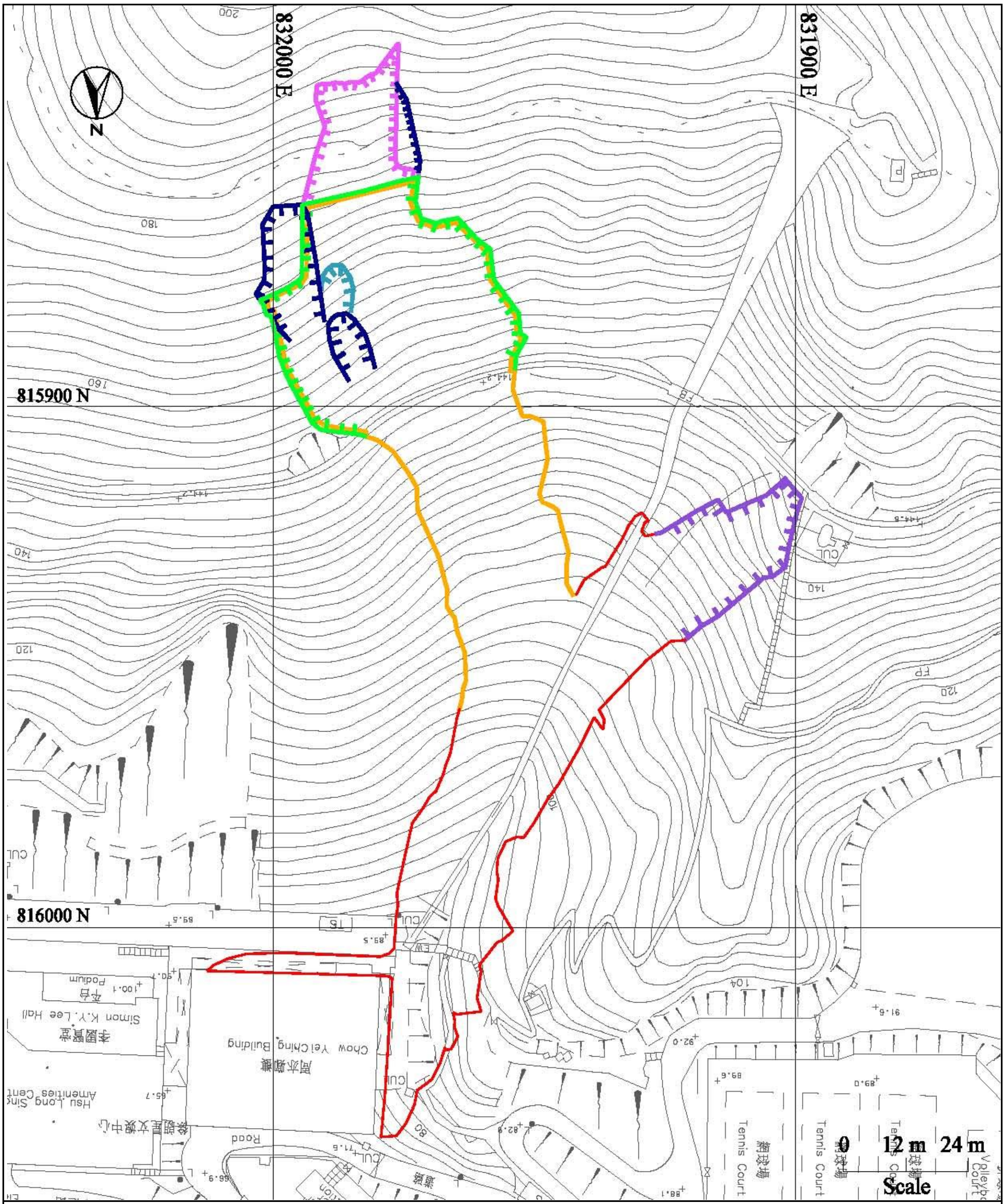

Legend:

🟥 The 7 June 2008 Landslide

🟪 Initial failure (7:30 am - 8:00 am, 7 June 2008)

🟪 Second phase (8:30 am, 7 June 2008)

🟩 Third phase (possibly pre-cursor movement to the upper source area) (8:45 am - 9:00am, 7 June 2008)

🟧 Fourth phase (9:30 am, 7 June 2008)

🟦 Reactivated between 12 June and 14 June 2008

🟦 Reactivated between 26 June and 30 June 2008

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C and 11SW-7D dated March 2008.

Figure 9 - Probable Sequence of Failure

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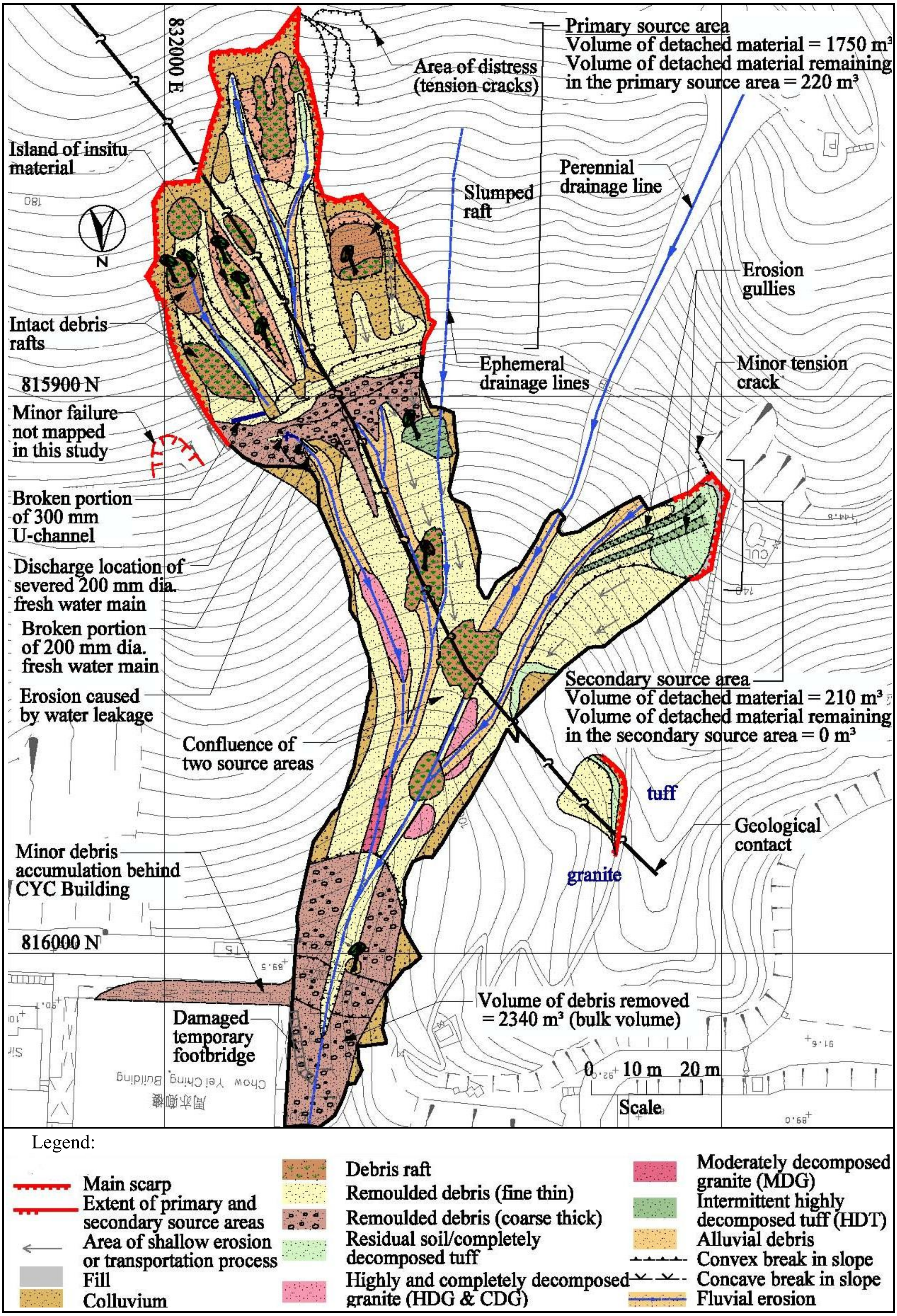
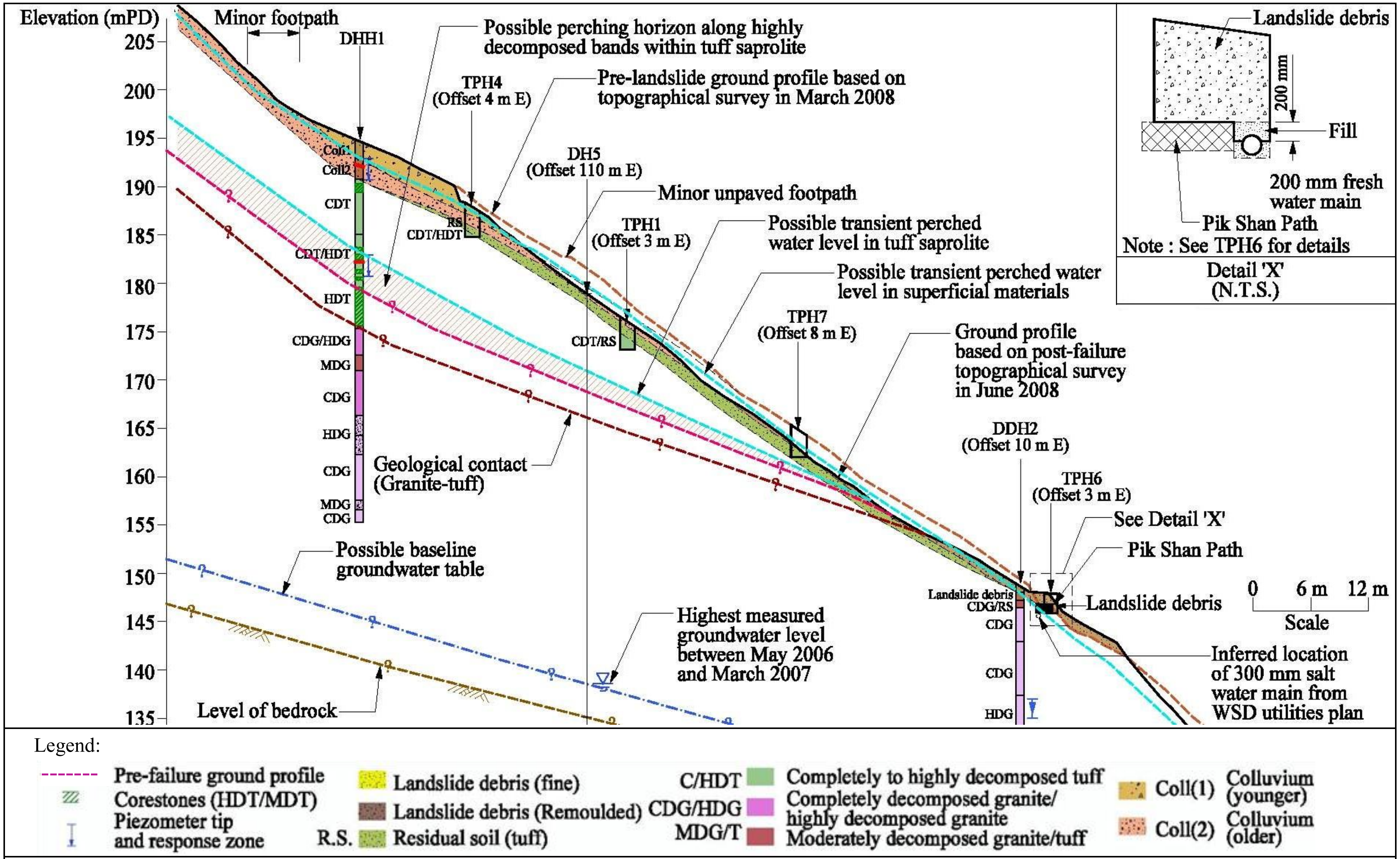


Figure 10 - Landslide Mapping



Note: See Figure 2 for location of section.

Figure 11 - Geological Section 'B-B' through the Primary Source Area

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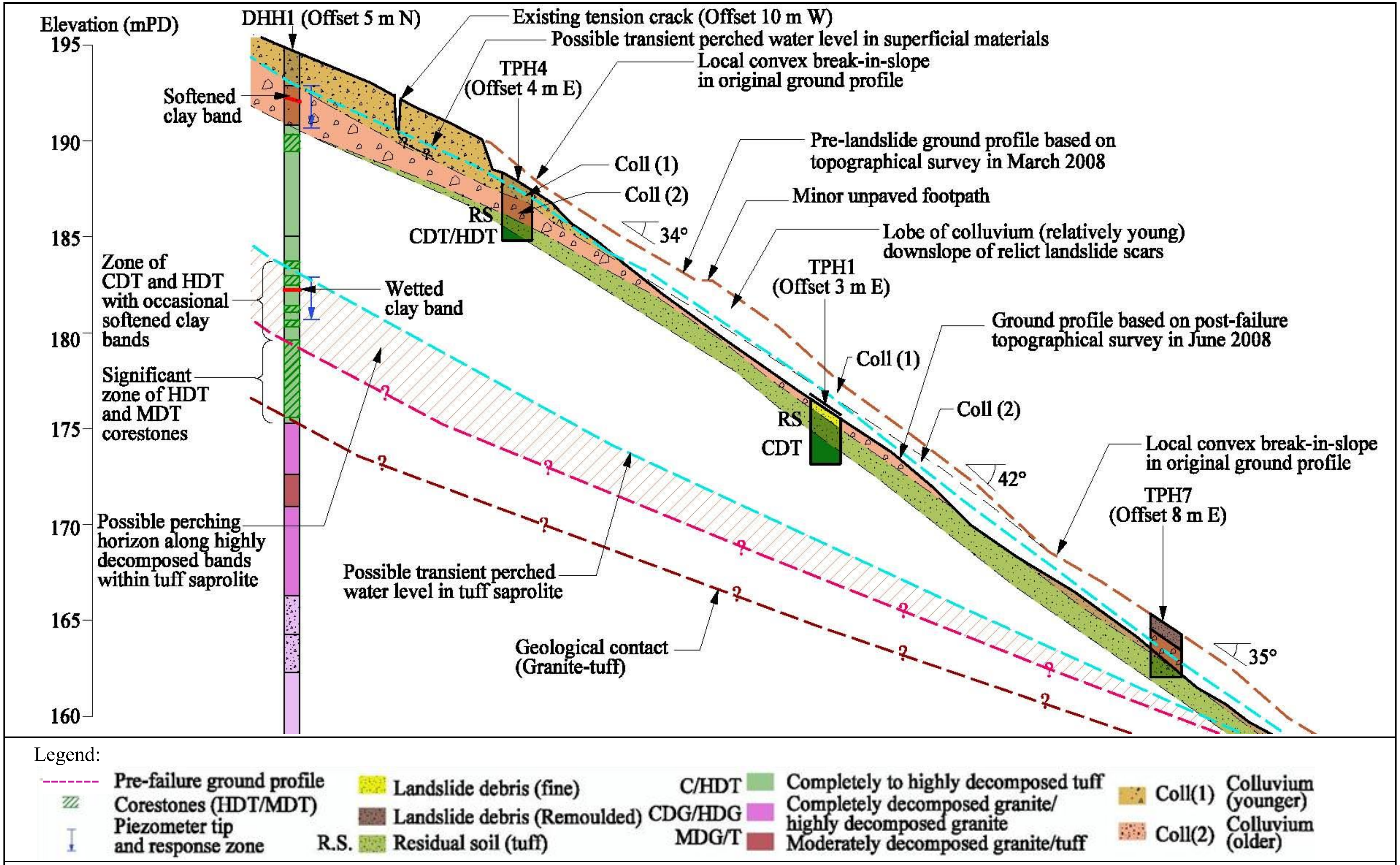
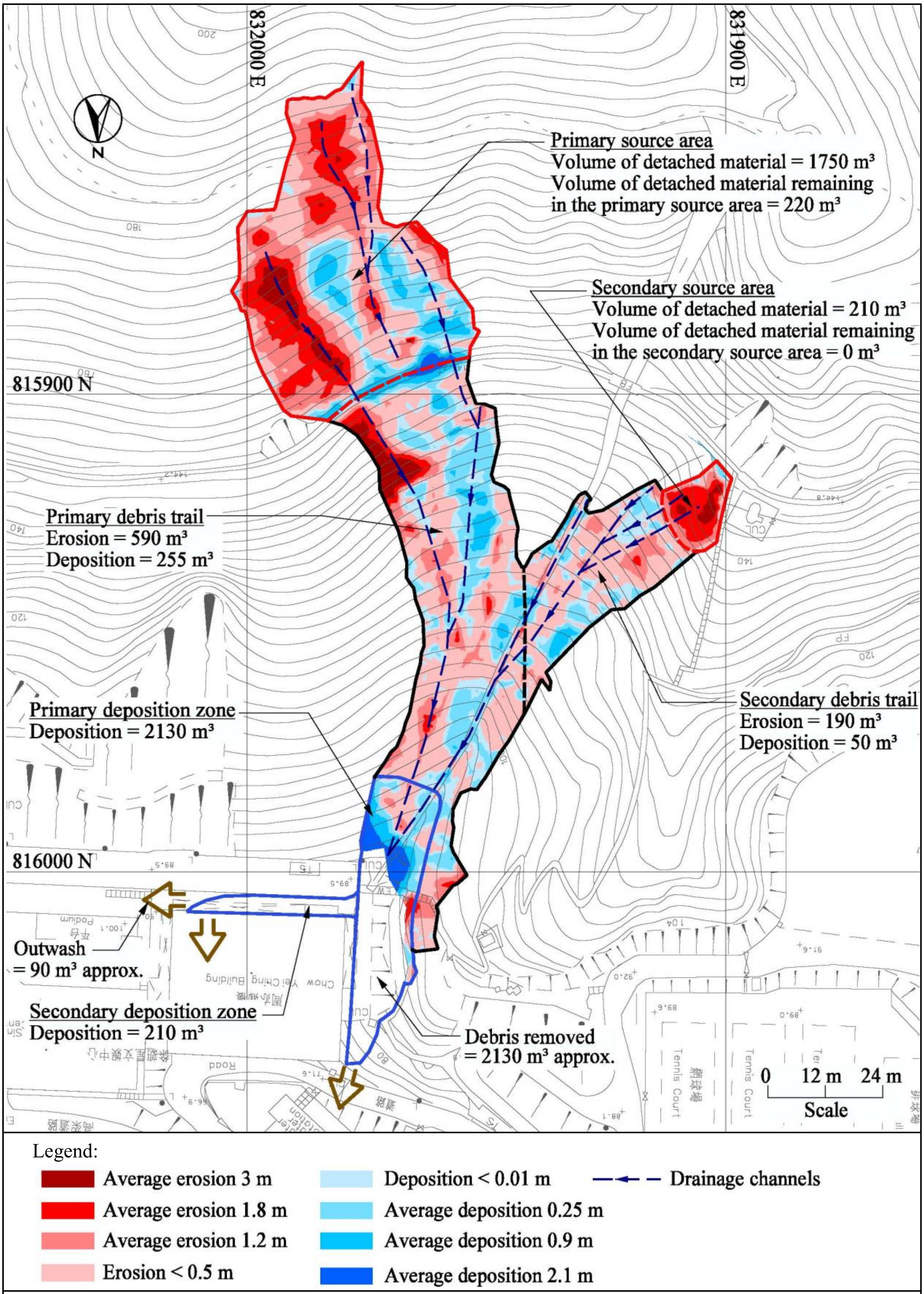


Note: See Figure 2 for location of section.

Figure 12 - Geological Section 'C-C' through the Main Scarp of the Primary Source Area



Note: Base plan is extracted from 1:1000 survey sheets No. 11SW-7C dated March 2008.

Figure 13 - Mass Balance Plan Derived from Pre-failure LiDAR Survey and Post-faillure Topographic Survey

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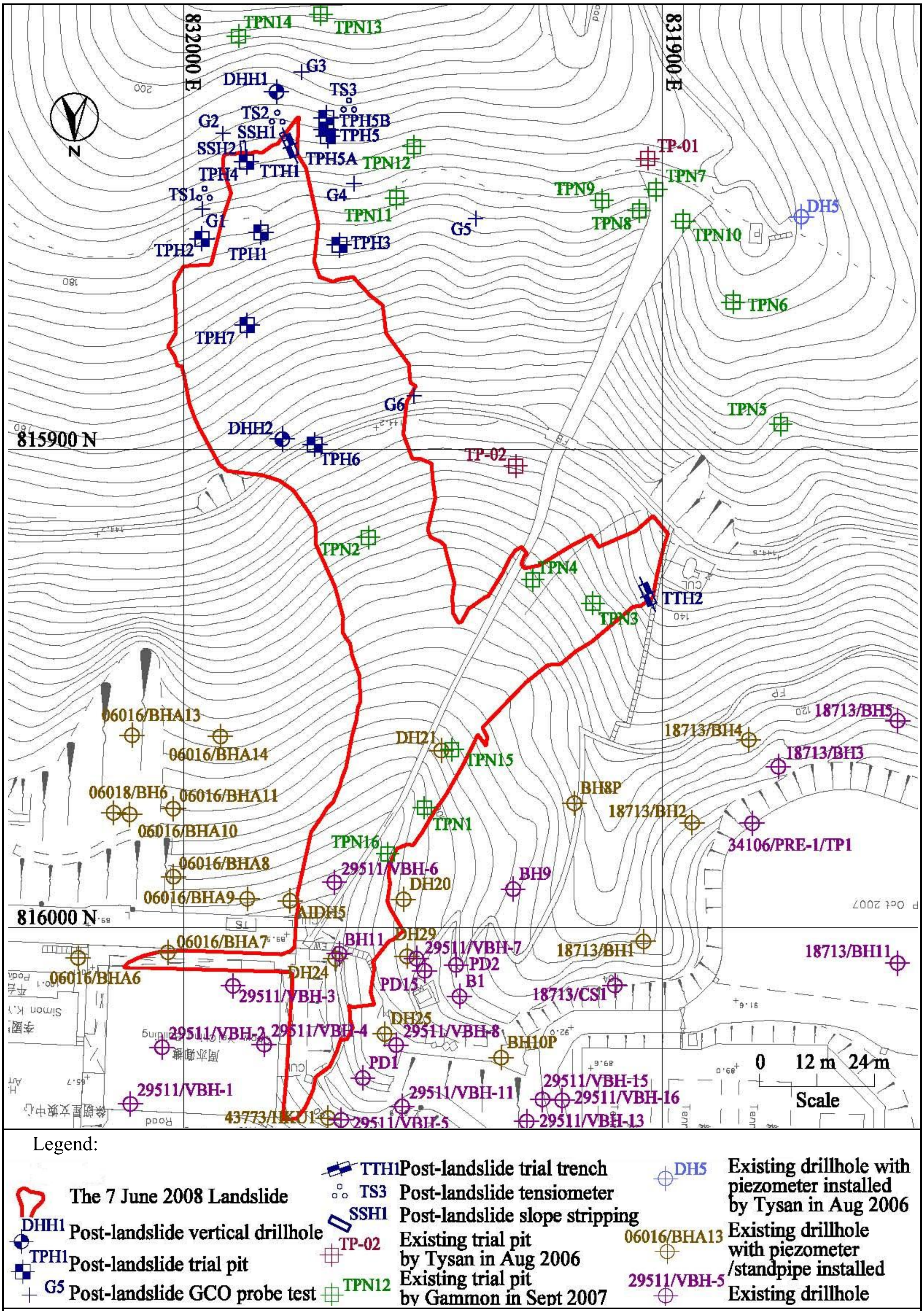
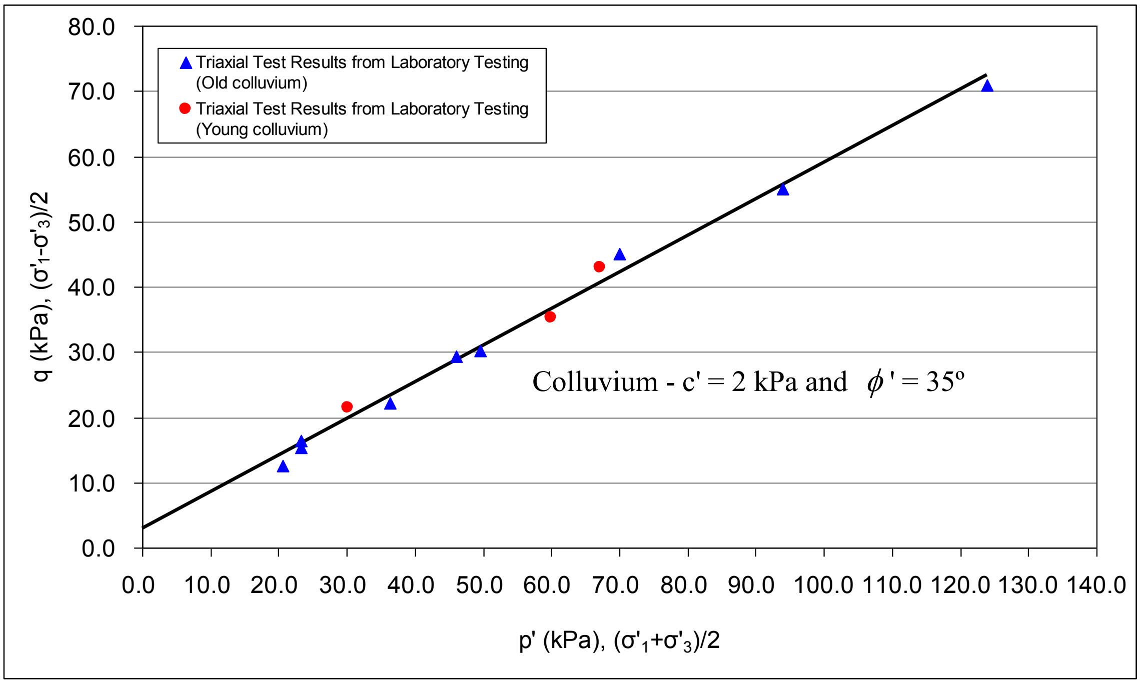
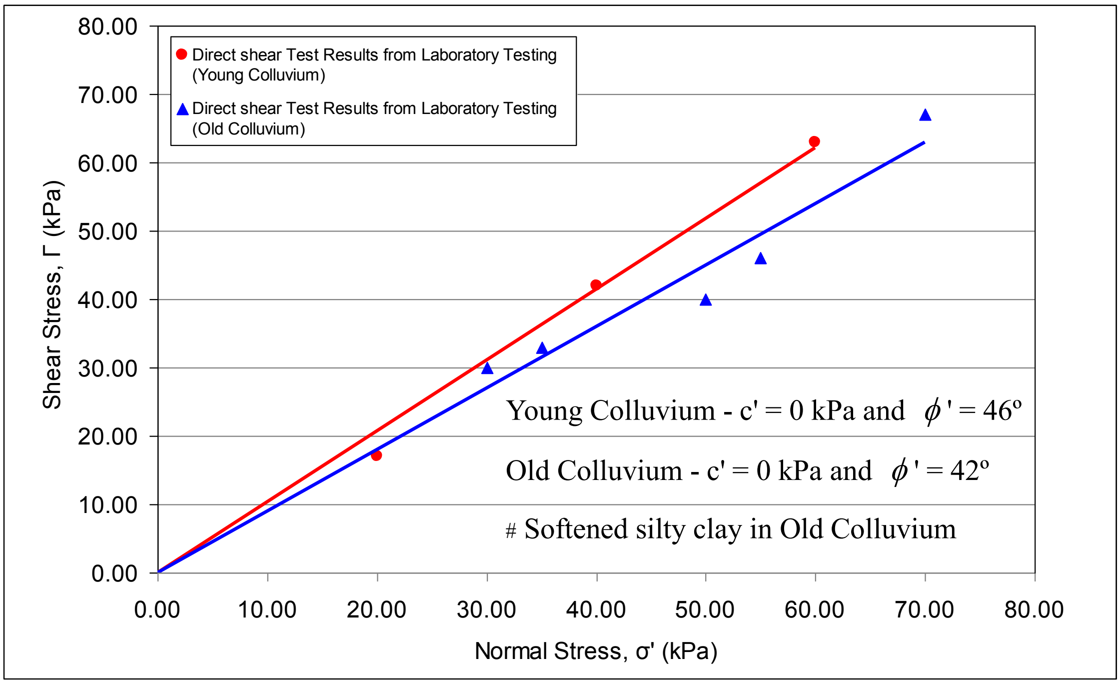


Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C and 11SW-7D dated March 2008.

Figure 14 - Plan of Ground Investigation Works



(a) Colluvium - Triaxial Test



(b) Colluvium - Direct Shear Box Test

Legend:

c'	Cohesion	ϕ'	Angle of shearing resistance
σ'_1	Major principal stress	σ'_3	Minor principal stress

Figure 15 - p'-q Plots for Colluvium

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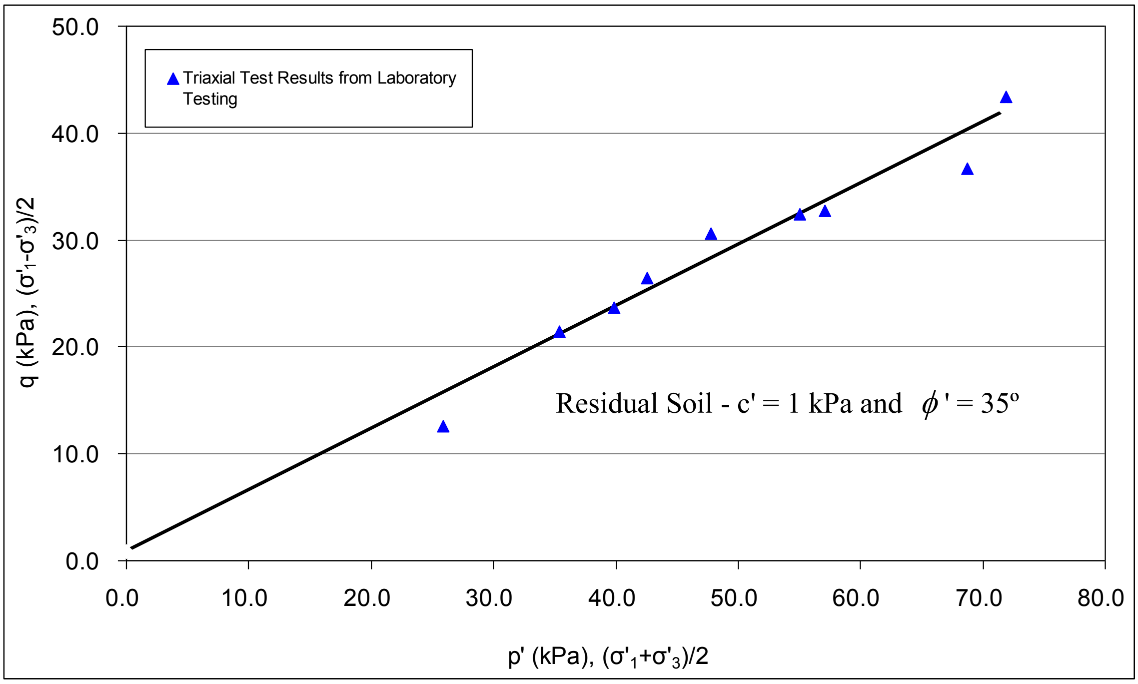
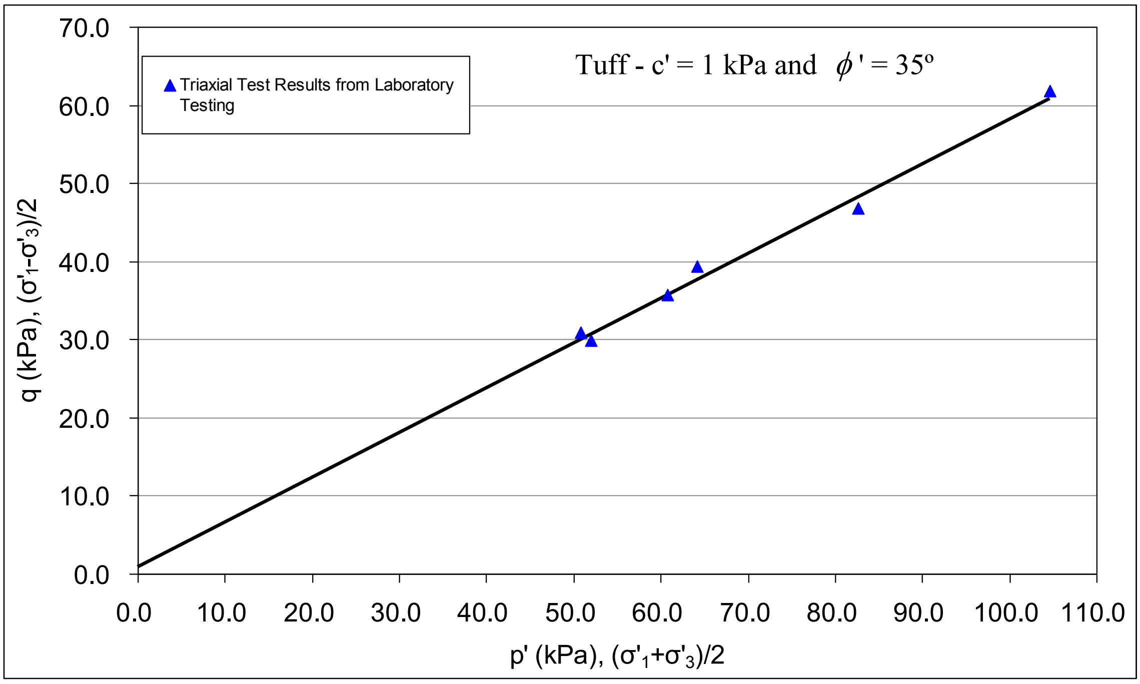


(a) Residual Soil - Triaxial Test



(b) Completely Decomposed Tuff - Triaxial Test

Legend:

c'	Cohesion	ϕ'	Angle of shearing resistance
σ'_1	Major principal stress	σ'_3	Minor principal stress

Figure 16 - p'-q Plots for Residual Soil and Completely Decomposed Tuff

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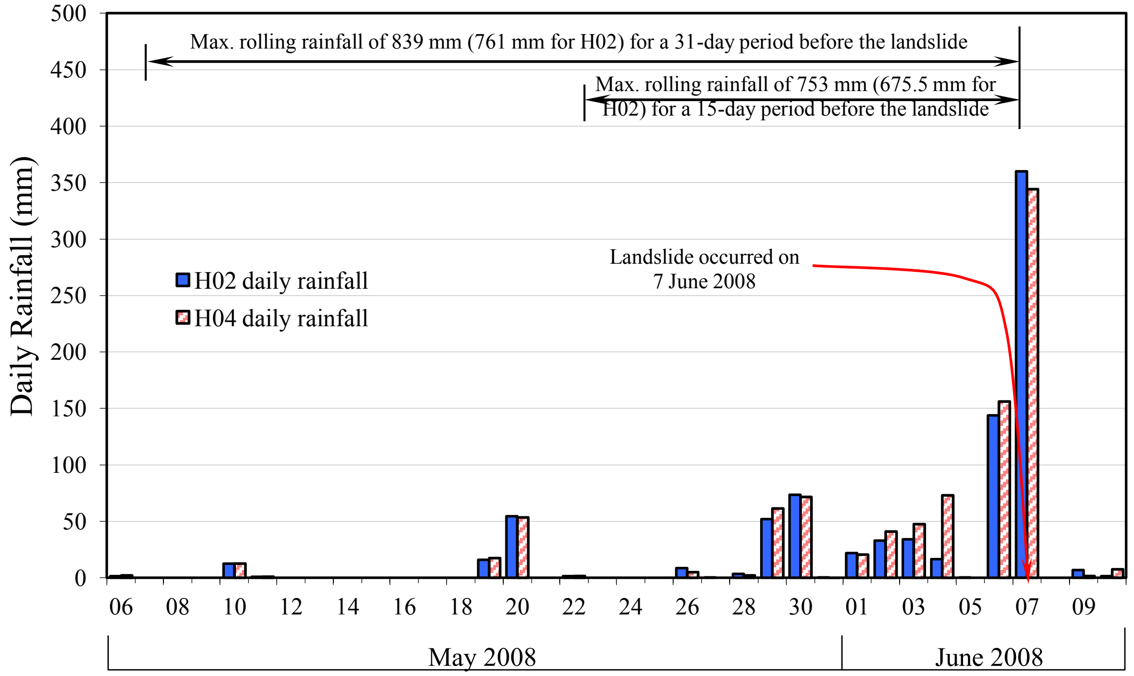
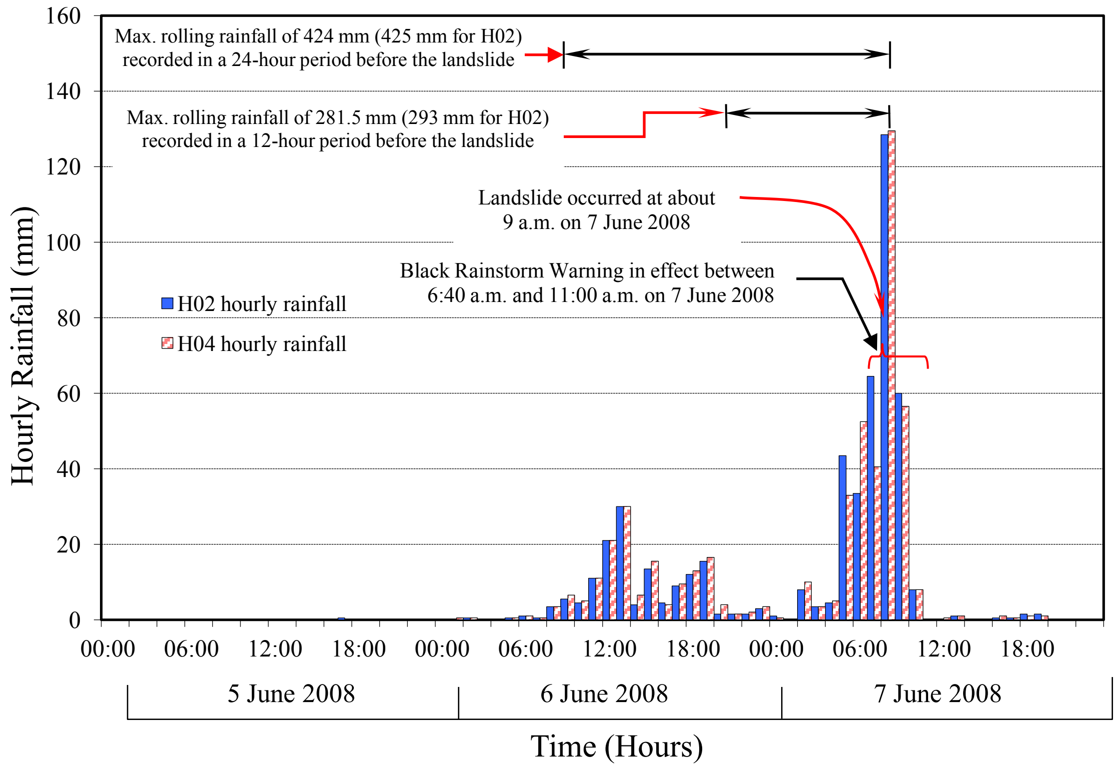


(a) Daily rainfall



(b) Hourly rainfall

Figure 17 - Daily and Hourly Rainfall Records at GEO Raingauges Nos. H02 and H04

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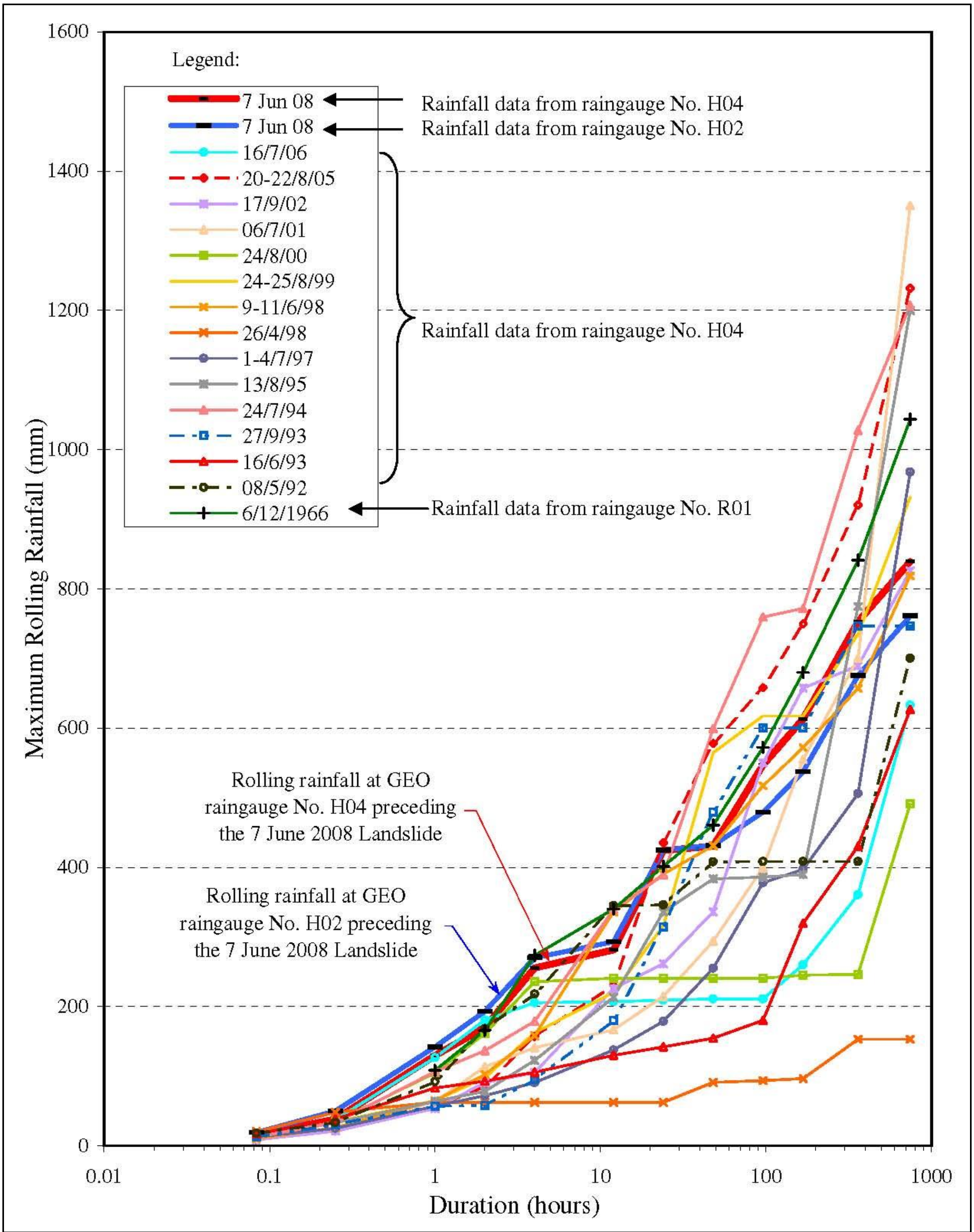

Notes:
(1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. H04 (about 0.4 km to the north of the site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. H04 since Setpember 1978 when the raingauges became operational.
(3) Refer to Figure 1 for locations of raingauges Nos. R01, H02 and H04

Figure 18 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. H04

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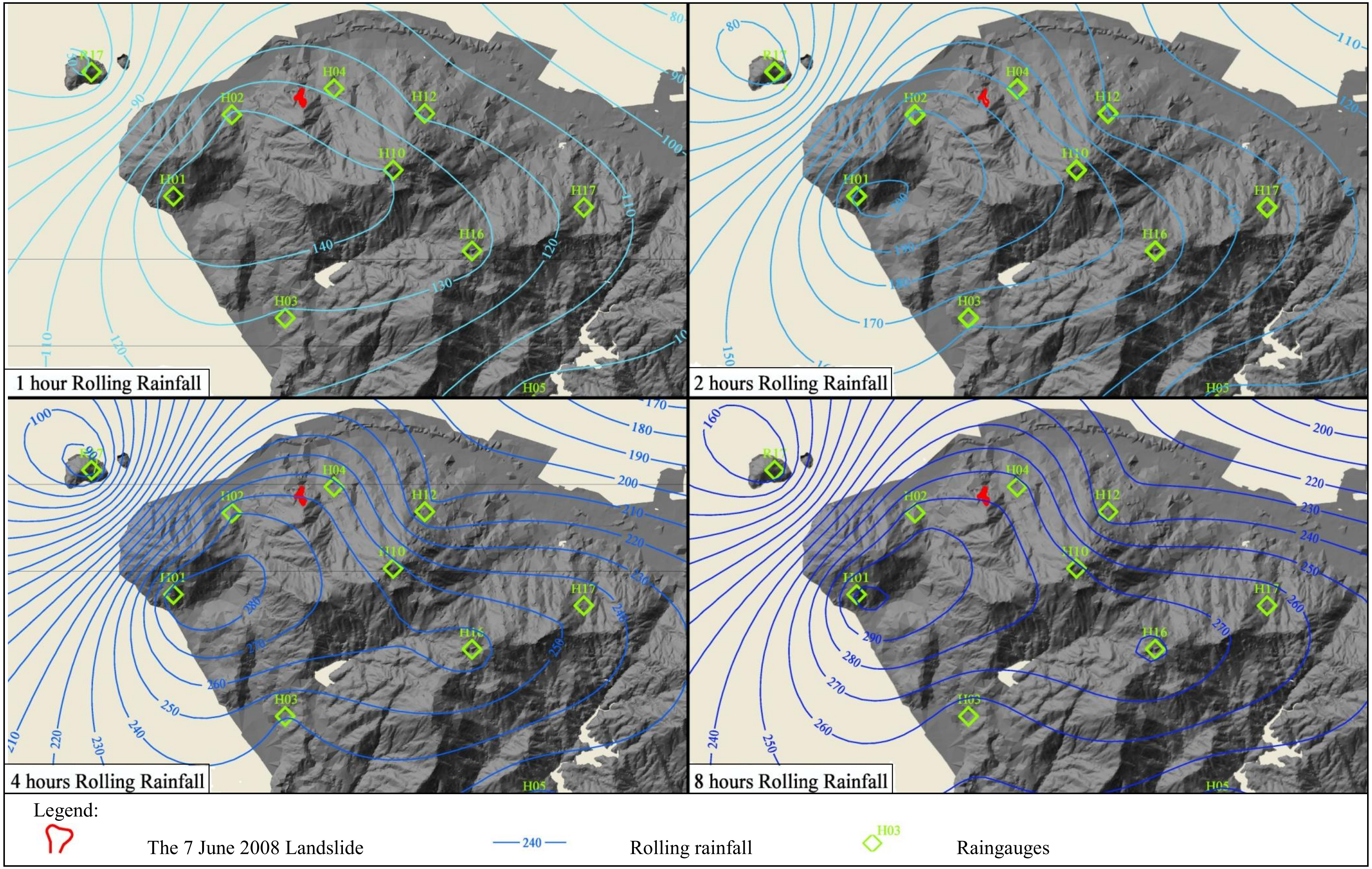

Figure 19 - Contoured Rainfall Plan of Northwest Hong Kong Island - Maximum Rolling Rainfall for 7 June 2008 Rainstorm

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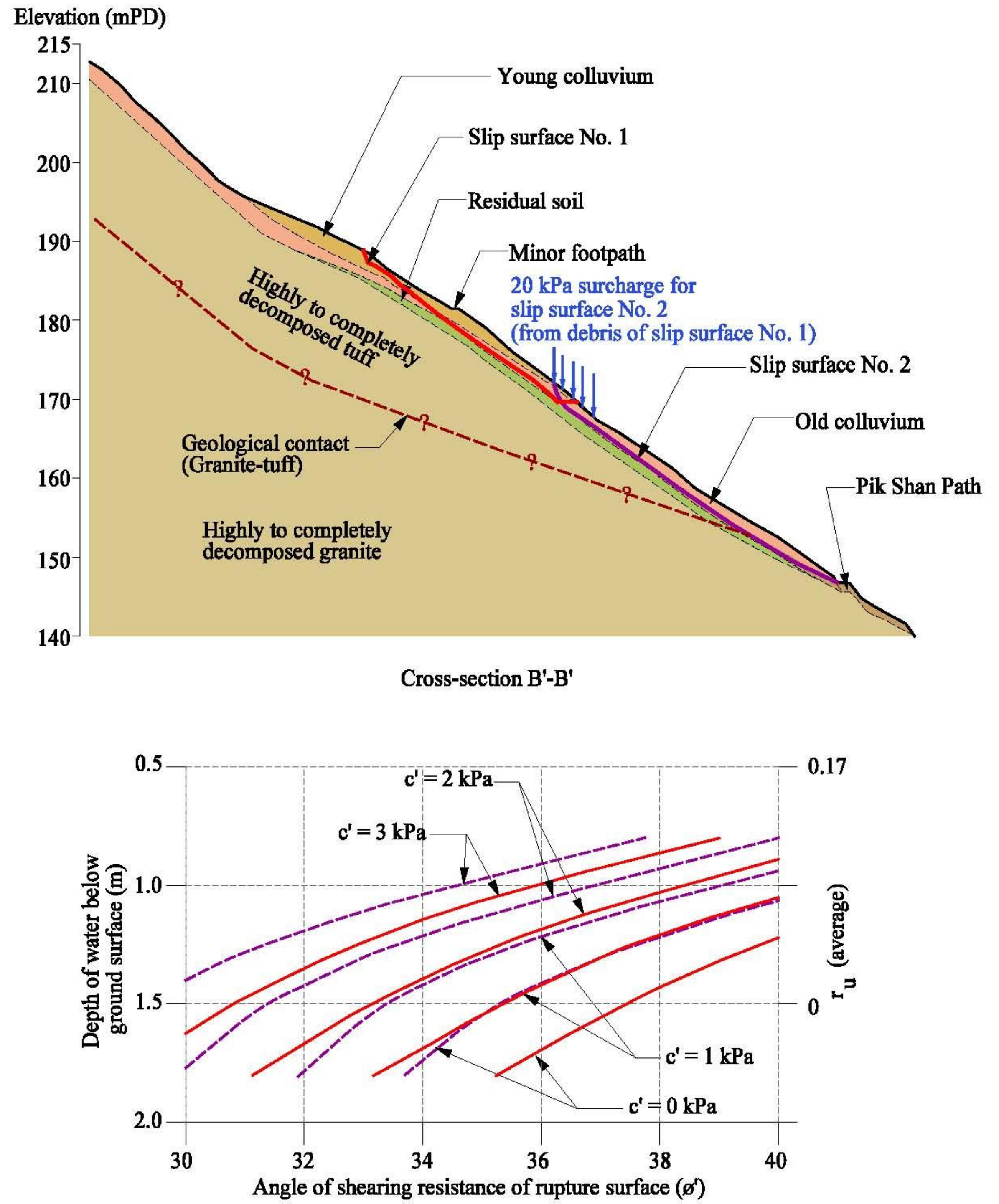

Legend:

——	Factor of safety equal to unity (slip surface No. 1)	- - - -	Factor of safety equal to unity (slip surface No. 2)

Notes:

(1) The rupture surface is based on pre-failure LiDAR survey, post-failure observation, field mapping and topographic survey.

(2) Pore pressure ration (r_u) values shown are the average along slip surface corresponding to each water level.

(3) See Figure 2 for location of cross-section line.

(4) See Figures 15 and 16 for soil parameters adopted.

Figure 20 - Summary of Theoretical Stability Analysis of the Primary Source Area - Failure Mode 1

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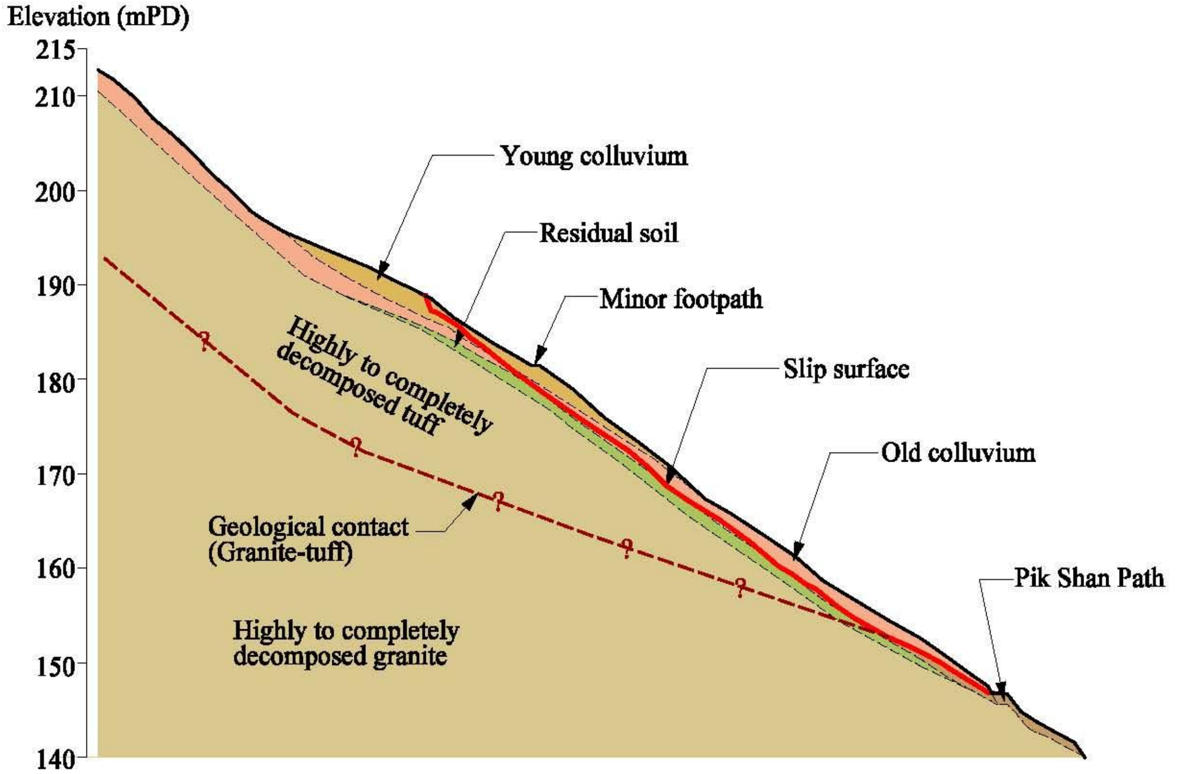
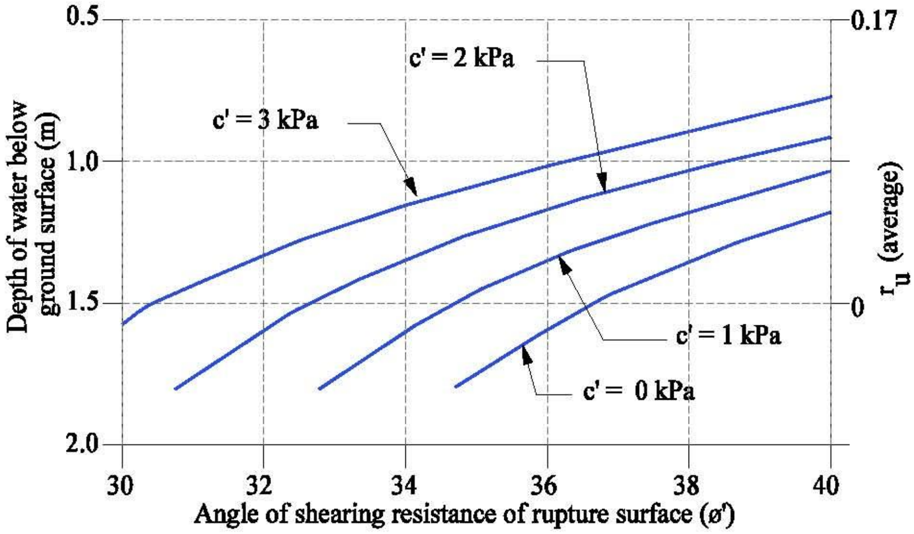


Cross-section B'-B'



Legend:

— Factor of safety equal to unity

Notes:

(1) The rupture surface is based on pre-failure LiDAR survey, post-failure observation, field mapping and topographic survey.
(2) Pore pressure ration (r_u) values shown are the average along slip surface corresponding to each water level.
(3) See Figure 2 for location of cross-section line.
(4) See Figures 15 and 16 for soil parameters adopted.

Figure 21 - Summary of Theoretical Stability Analysis of the Primary Source Area - Failure Mode 2

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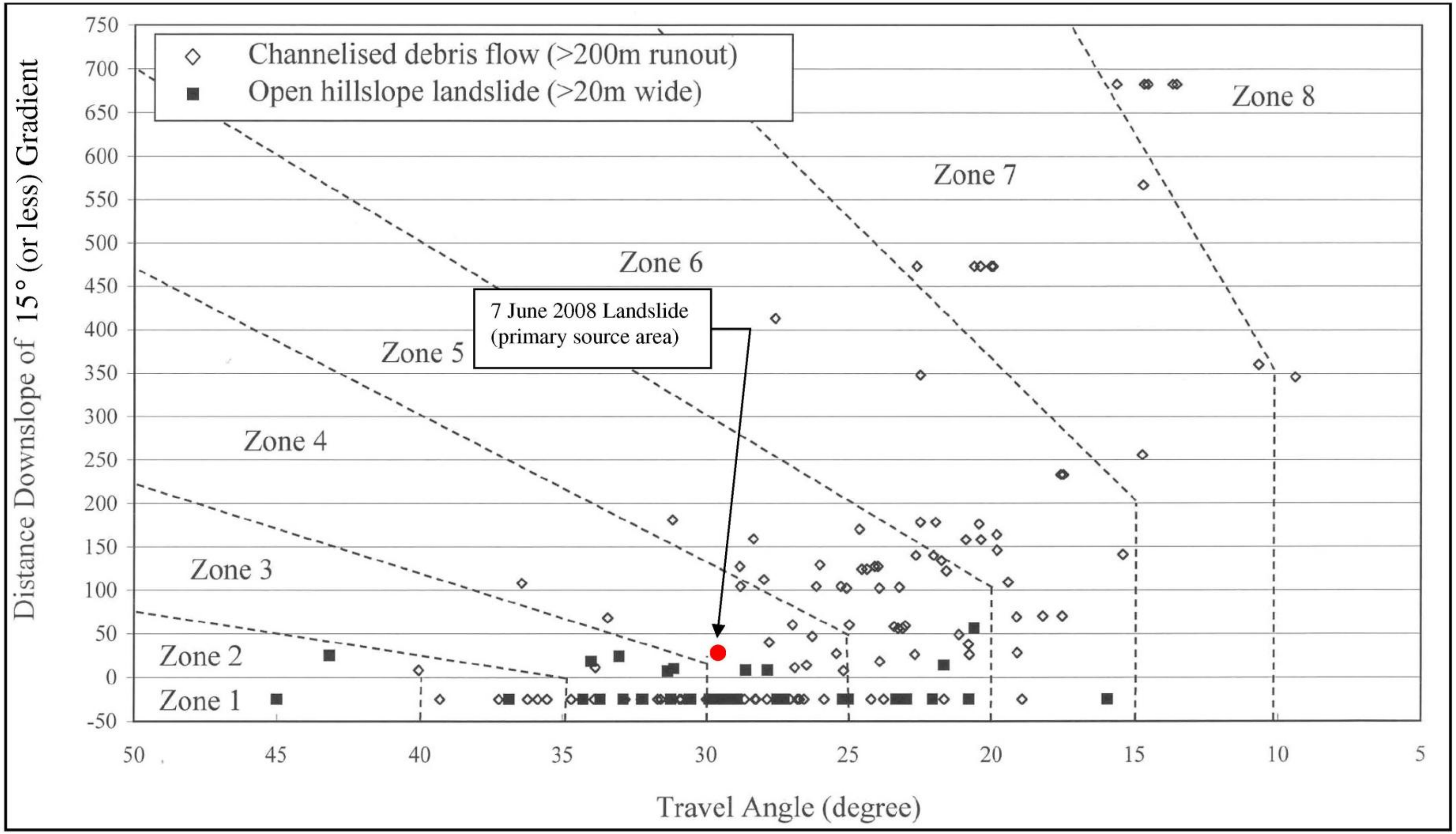

7 June 2008 Landslide (primary source area)

Note: Original Chart extracted from Wong el al (2006).

Figure 22 - Classfication of Proximity Zone

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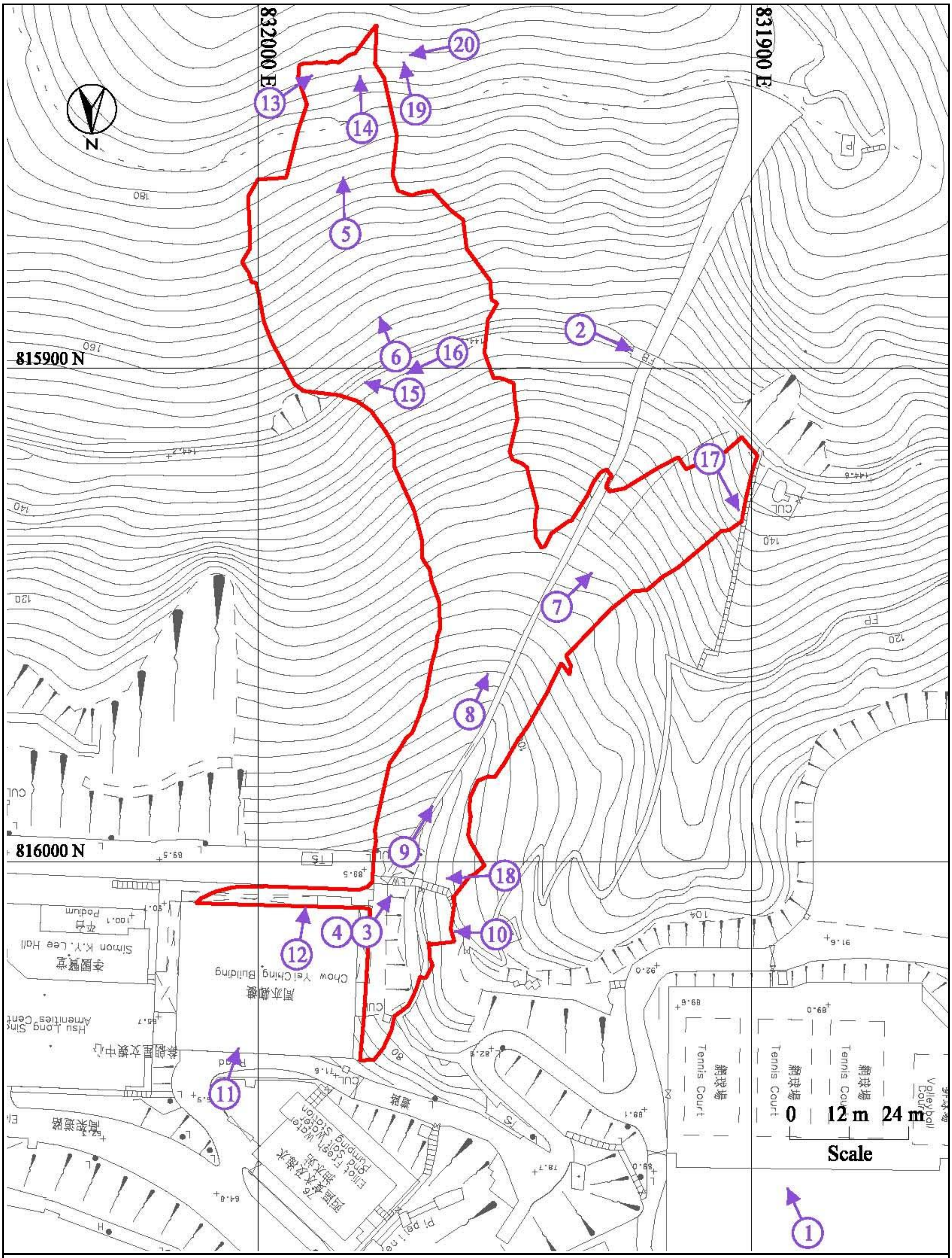

Legend:

▬	The 7 June 2008 Landslide	⑫ ➚	Location and direction of photograph taken

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11SW-7C and 11SW-7D dated March 2008.

Figure 23 - Locations and Directions of Photographs Taken

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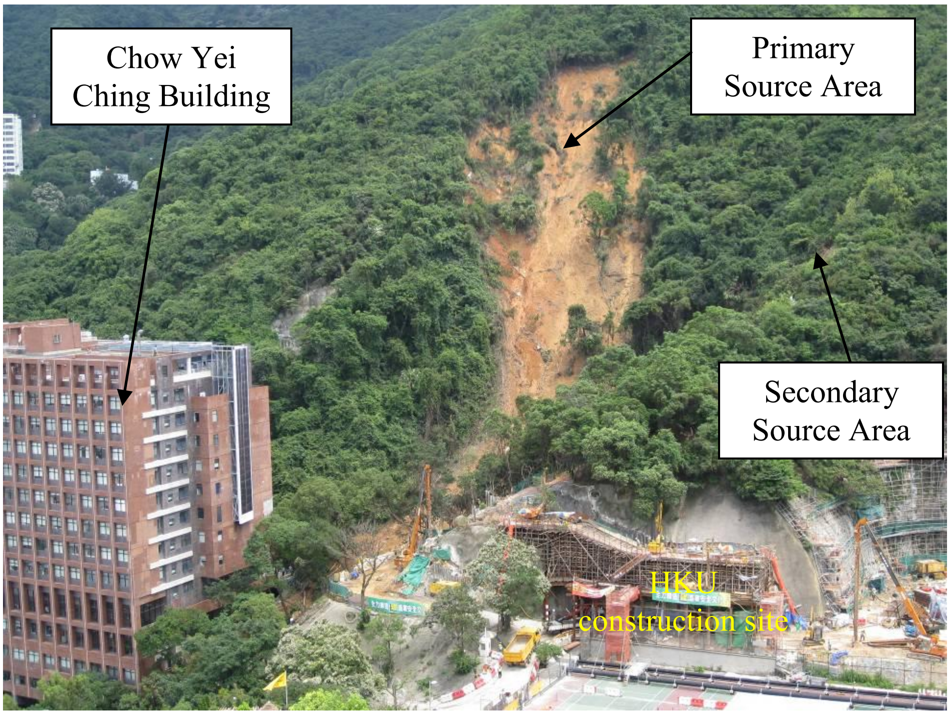

Plate 1 - General View of the 7 June 2008 Landslide from The Belcher's (Photograph taken on 10 June 2008 by BV)

Plate 2 - Water-carrying Services along Pik Shan Path (Photograph taken on 23 September 2008)

Note: See Figure 23 for locations and directions of photographs.

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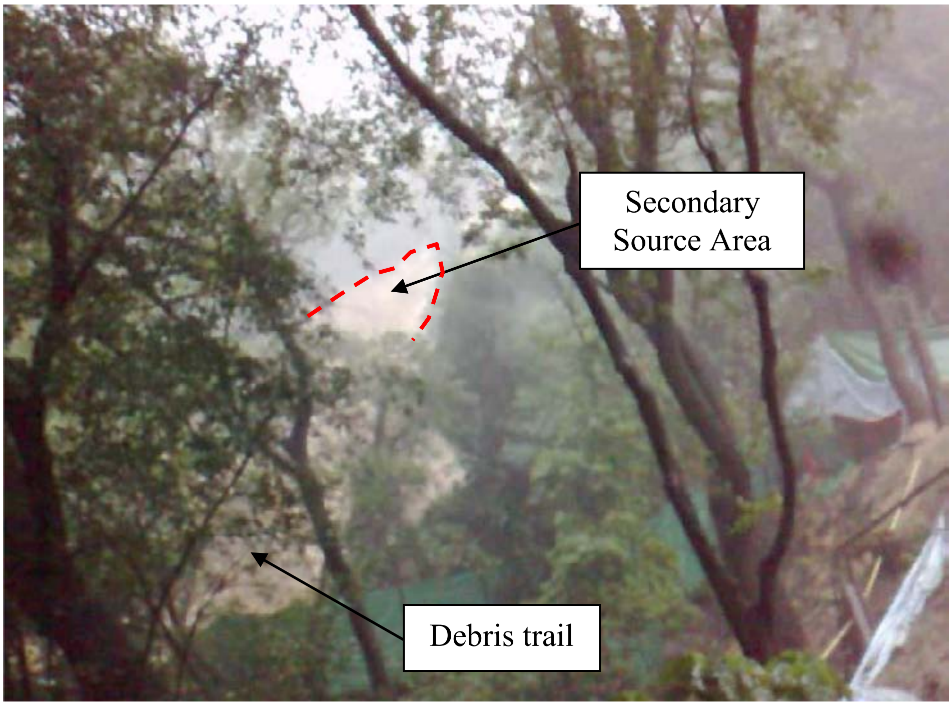

Plate 3 - View of the Secondary Source Area at about 8.42 a.m. on 7 June 2008
(Image captured from video taken by a plant operator)

Plate 4 - View of the Temporary Steel Footbridge with Significant Muddy Water Running through it and Some Debris Piled behind it at about 8.42 a.m. on 7 June 2008
(Image captured from video taken by a plant operator)

Note: See Figure 23 for locations and directions of photographs.

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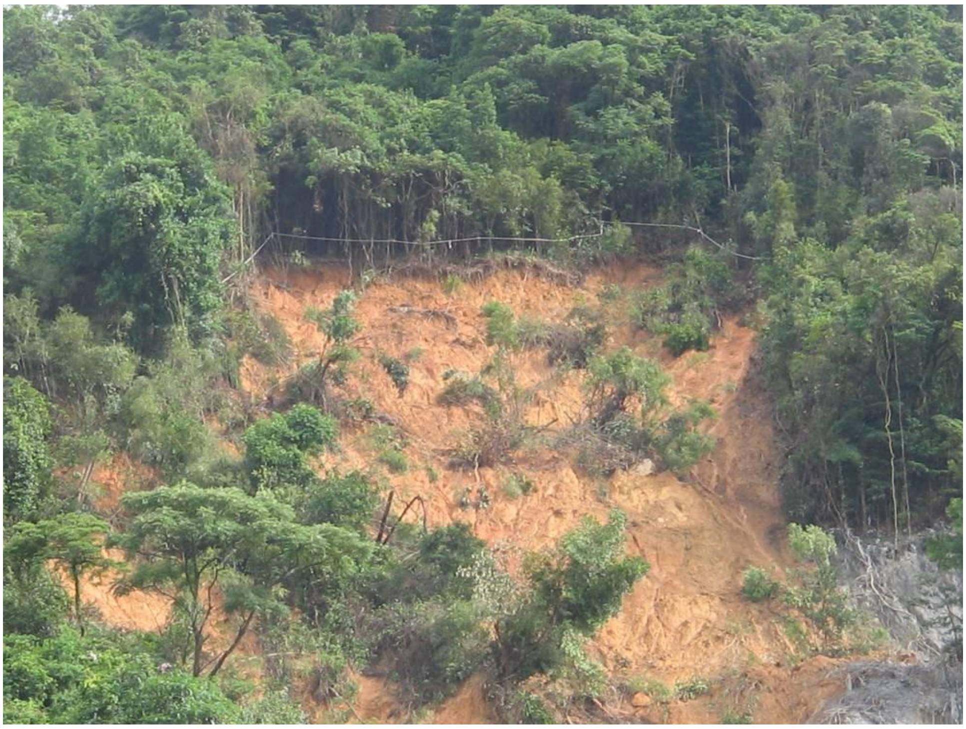

Plate 5 - General View of the Upper Portion of the Primary Source Area
(Photograph taken on 16 June 2008 by FSWJV)

Plate 6 - General View of the Lower Portion of the Primary Source Area
(Photograph taken on 3 July 2008)

Note: See Figure 23 for locations and directions of photographs.

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Plate 7 - General View of the Upper Portion of the Secondary Source Area
(Photograph taken on 10 June 2008 by BV)

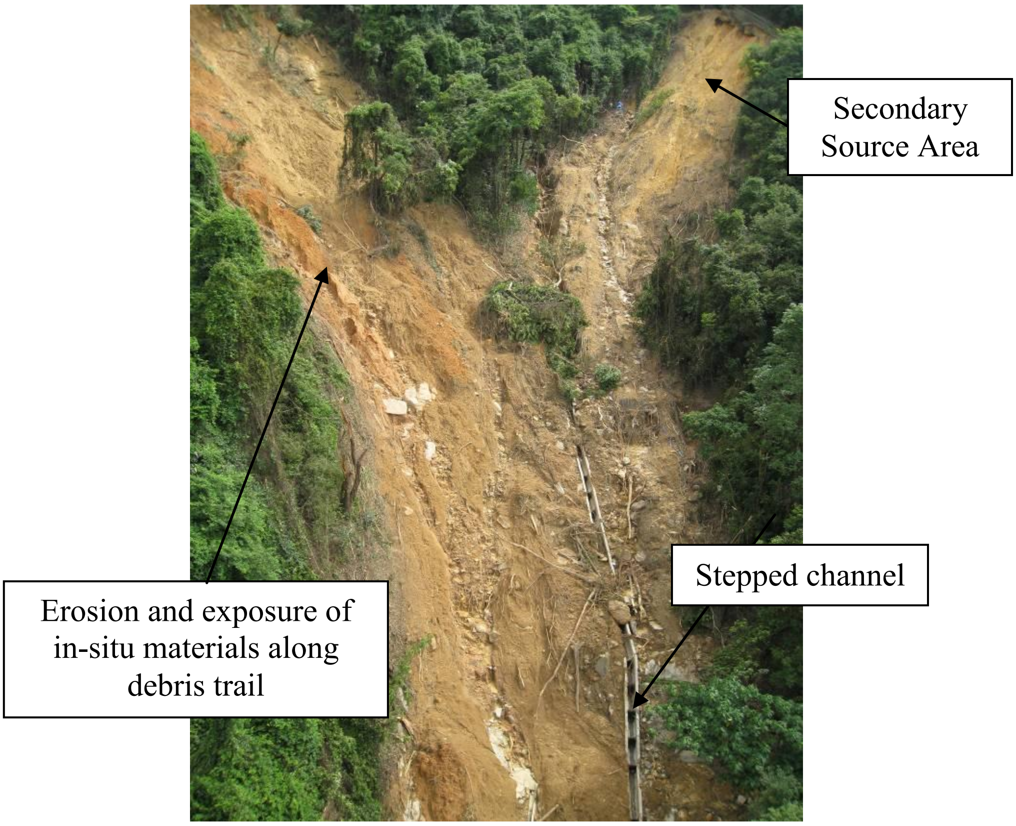

Plate 8 - General View of the Interception of the Debris Trails
(Photograph taken on 10 June 2008 by BV)

Note: See Figure 23 for locations and directions of photographs.

Plate 9 - General View of the Lower Debris Trail
(Photograph taken on 10 June 2008)

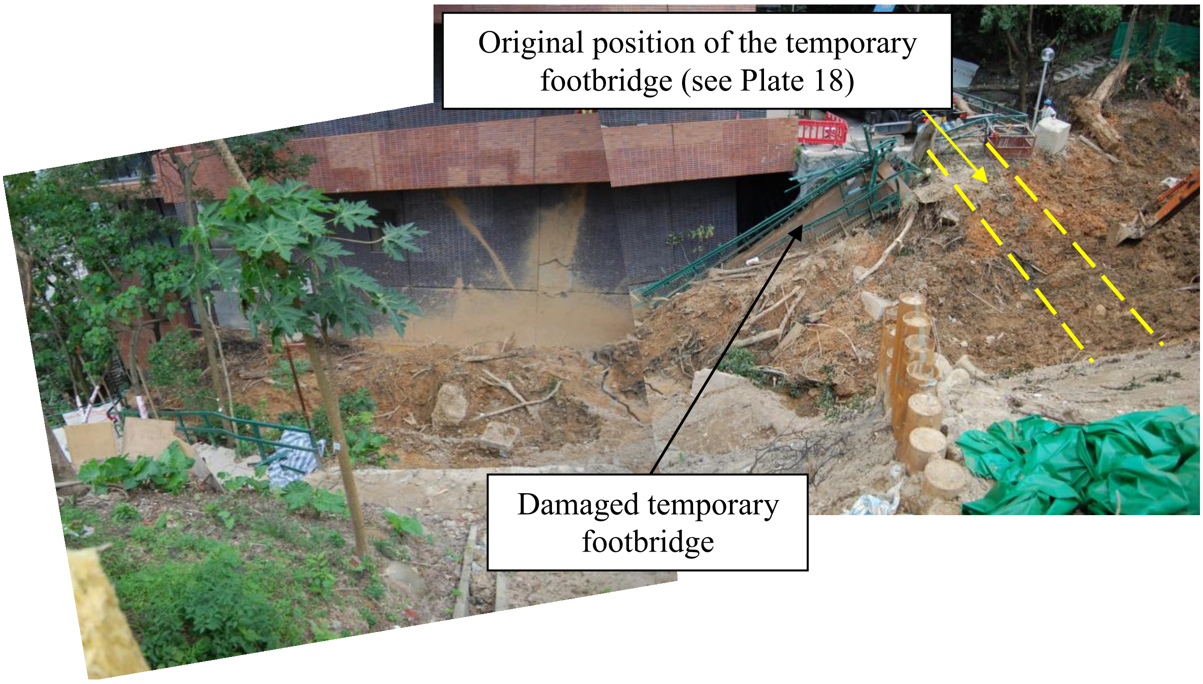

Plate 10 - Debris Accumulation at the Toe Area next to CYC Building
(Photograph taken on 24 June 2008)

Note: See Figure 23 for locations and directions of photographs.

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Plate 11 - Flooding of the Upper and Lower Carpark CP1 Level in CYC Building
(Photograph taken on 8 June 2008 by HKU Estates Officer)

Plate 12 - Debris Flowed into LG3 of a Hydraulics Laboratory in CYC Building
(Photograph taken on 8 June 2008 by HKU Estates Officer)

Note: See Figure 23 for locations and directions of photographs.

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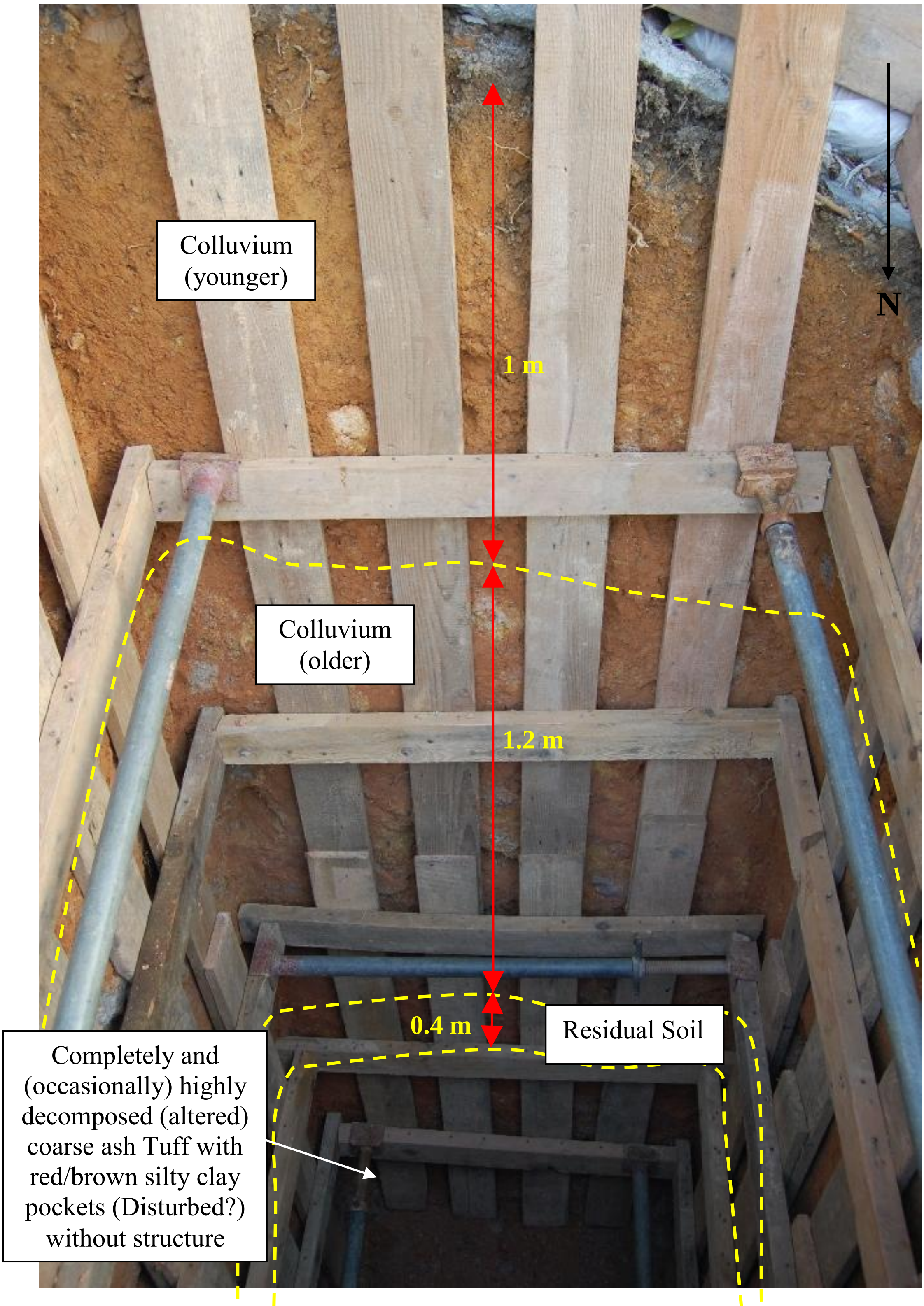

Plate 13 - Trial Pit TPH4 at the Main Scarp Showing Two Layers of Colluvium Overlying a Thin Layer of Residual Soil and then Disturbed C/HDT (Photograph taken on 10 October 2008)

Note: See Figure 23 for locations and directions of photographs, and Figure 14 for location of trial pit/trench.

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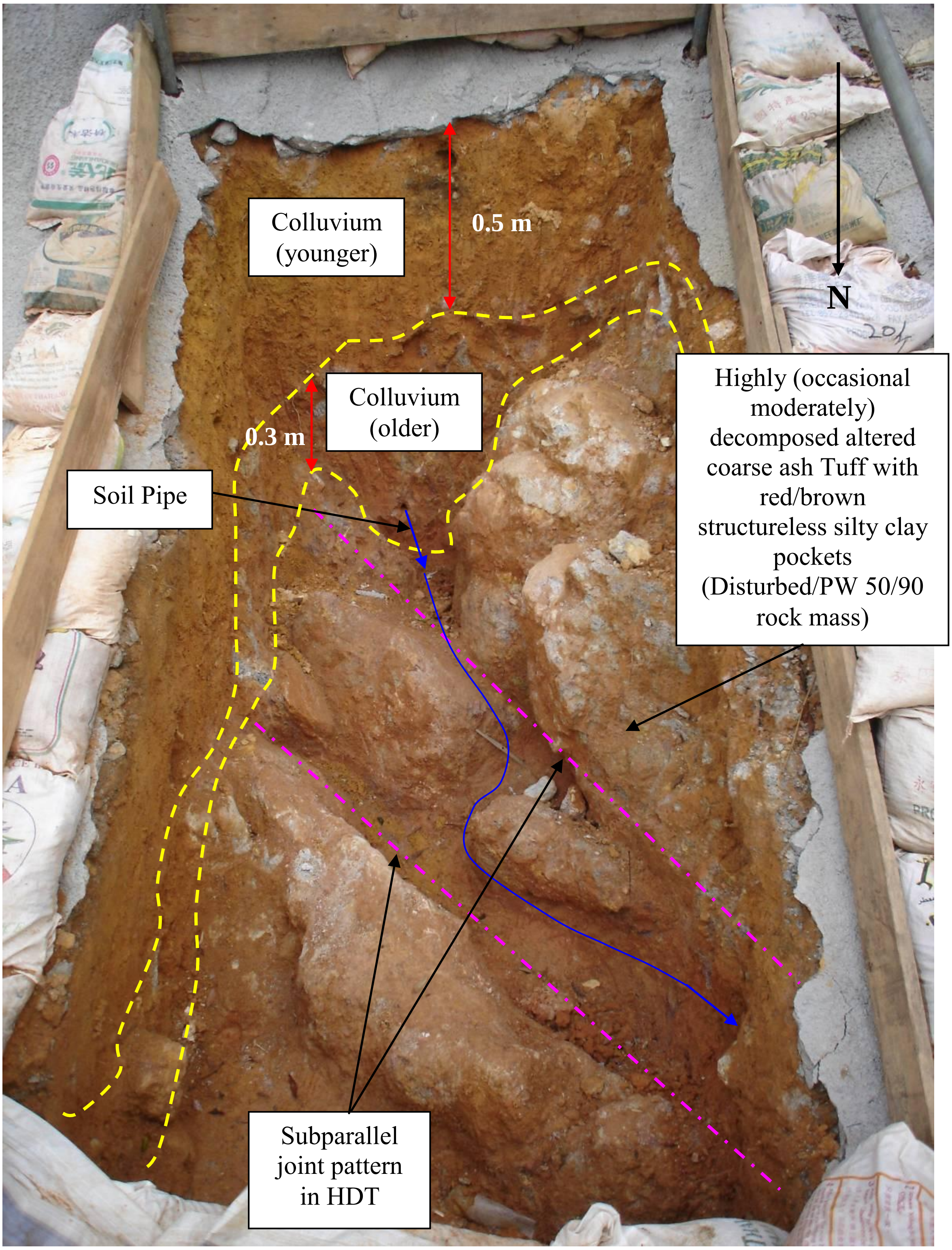

Plate 14 - Trial Trench TTH1 Showing Two Layers of Colluvium Overlying HDT (Photograph taken on 10 October 2008)

Note: See Figure 23 for locations and directions of photographs, and Figure 14 for location of trial pit/trench.

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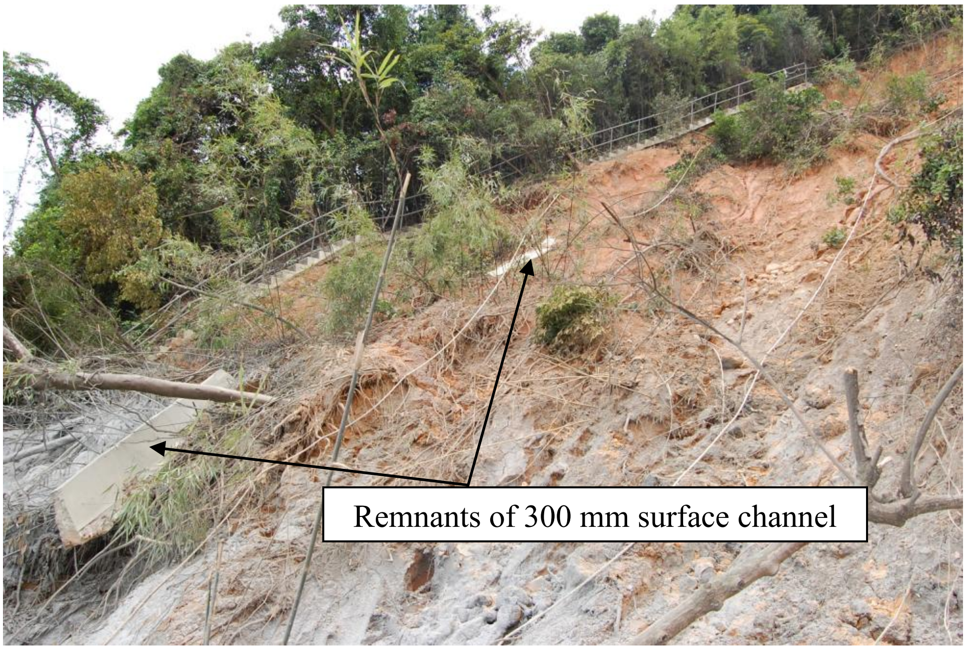

Plate 15 - Remnants of the 300 mm Surface Channel within the Lower Portion of the Primary Source Area
(Photograph taken on 24 June 2008)

Plate 16 - Close-up View of the Damaged 200 mm dia. Fresh Water Pipe below Pik Shan Path which was Displaced Downslope by Landslide Debris
(Photograph taken on 7 June 2008 by BV)

Note: See Figure 23 for locations and directions of photographs.

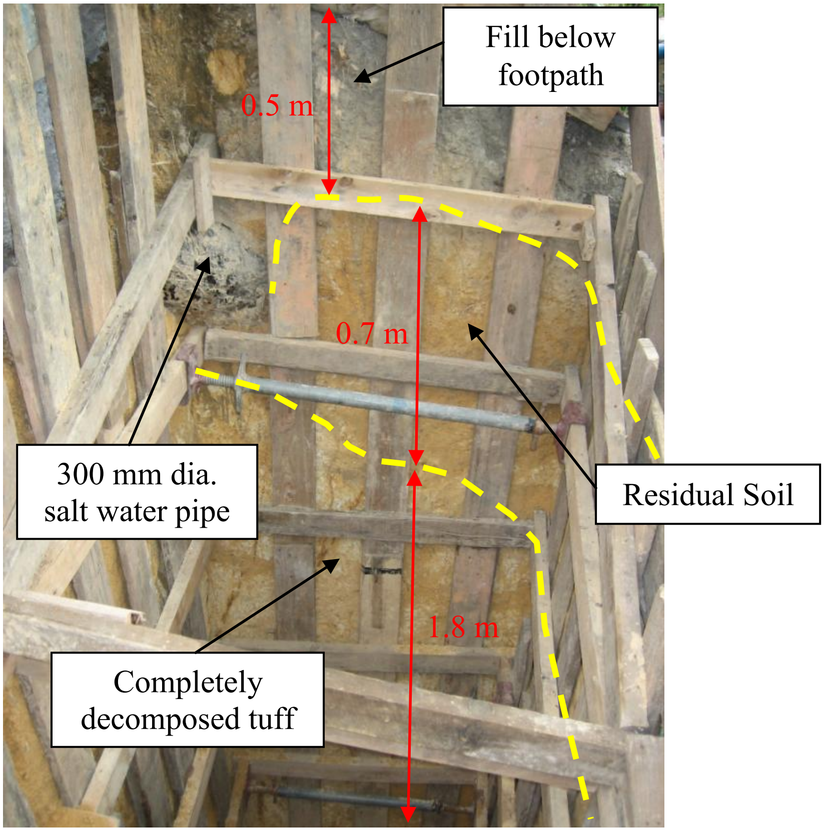

Plate 17 - Trial Trench TTH2 adjacent to the Staircase Leading to Footpath FP3, Showing the Salt Water Pipe Overlying RS and CDT (Photograph taken on 23 September 2008)

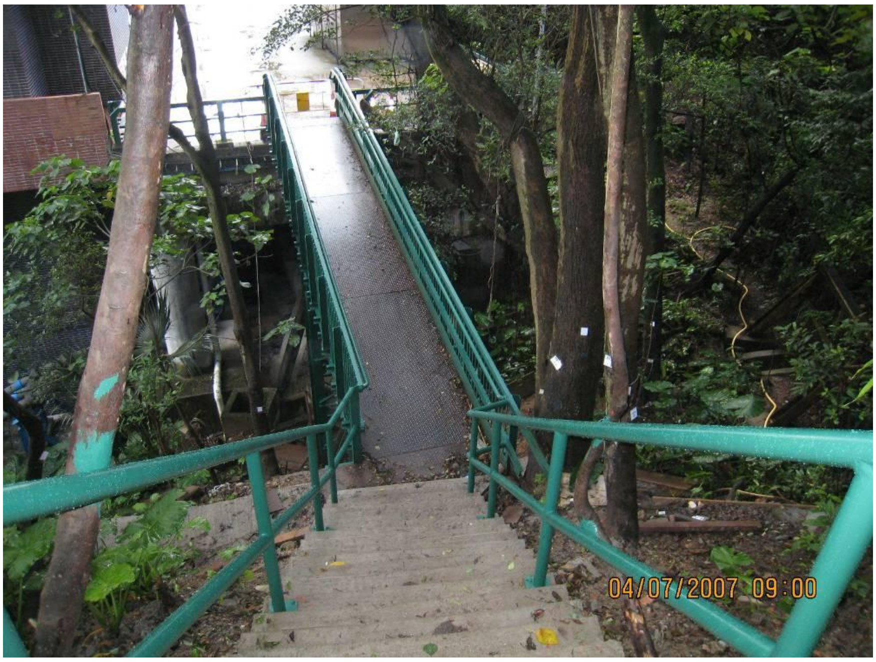

Plate 18 - Pre-failure View of the Temporary Steel Footbridge (Photograph taken on 4 July 2007 by BV)

Note: See Figure 23 for locations and directions of photographs.

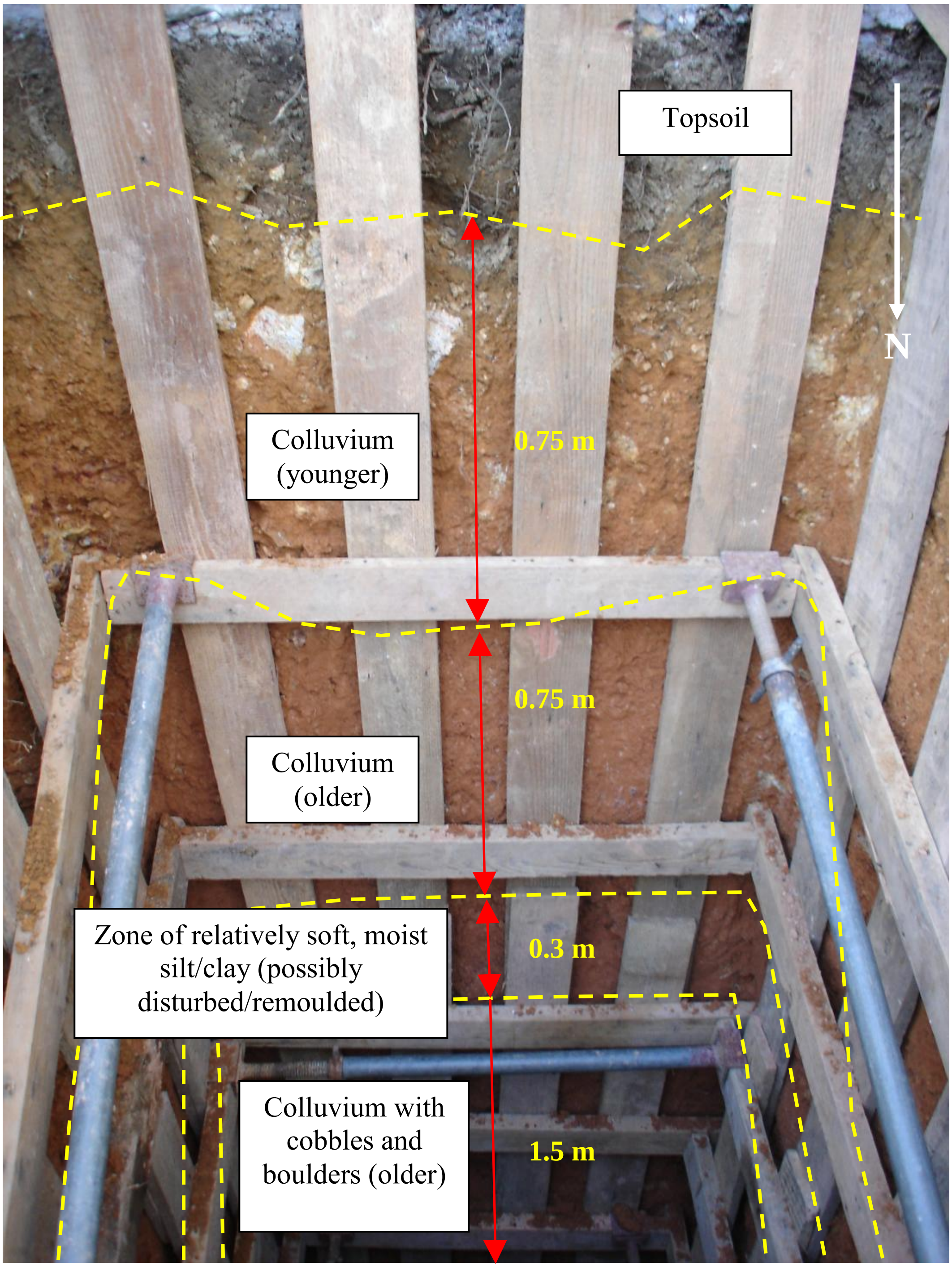

Plate 19 - Trial Pit TPH5 Showing a Zone of Softened, Silt/Clay within the Older Colluvium Layer
(Photograph taken on 18 November 2008)

Note: See Figure 23 for locations and directions of photographs, and Figure 14 for location of trial pit/trench.

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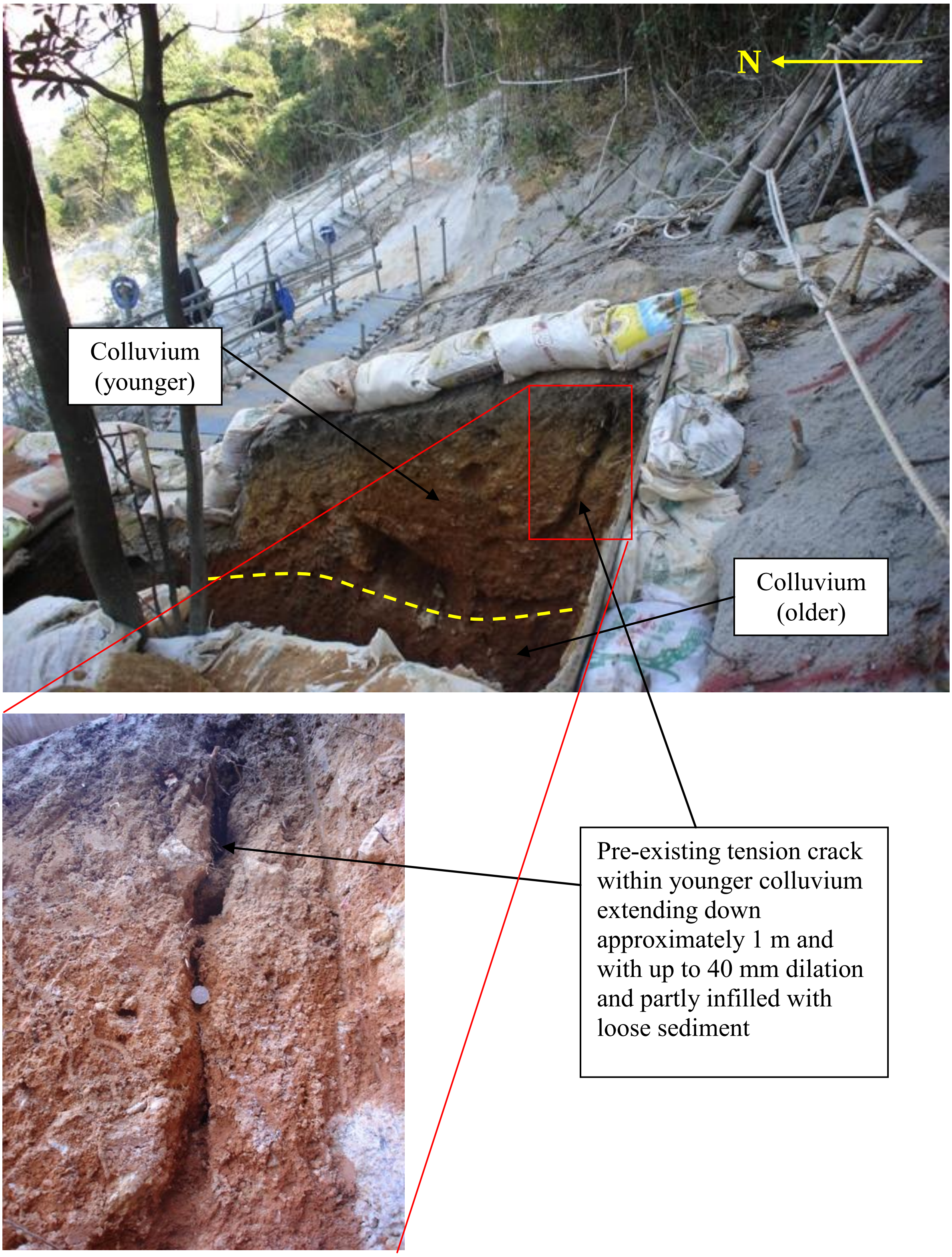

Plate 20 - Trial Pit TPH5 Just to the West of the Main Scarp, Looking East Showing a Tension Crack Exposed within Colluvium
(Photograph taken on 3 December 2008)

Note: See Figure 23 for locations and directions of photographs, and Figure 14 for location of trial pit/trench.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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A1. INTRODUCTION

An Aerial Photograph Interpretation (API) has been carried out as part of the desk study for the purposes of establishing the site history, past instability and geomorphological characteristics of the study area. A review of available aerial photographs taken between 1924 and 2007 was undertaken (see list in Table A1). Based primarily on the 1963 aerial photographs, with some additional observations from other aerial photographs, relevant observations relating to the site history are shown on Figure 6, with the morphology and hydrology shown in Figure A1. Pertinent observations from the 1924, 1949, 1963, 1967, 1978 and 1982 aerial photographs are highlighted in Plates A1 to A6.

A2. SUMMARY

The study area comprises natural terrain. In the earliest aerial photographs reviewed (1924), the area of concern can be seen to be located on a north-facing hillside below Lung Fu Shan, which forms the northern tip of a north-south trending ridge that descends from the higher hills that include Victoria Peak and High West. The study area forms a hillside catchment defined by a broad depression between two rounded spurs trending north-northeast and north (Figure A1 and Plate A3). This broad depression is characterised with increased vegetation and possible unconfined colluvial deposits.

Two main ephemeral drainage lines, DL1 and DL2, are observed adjacent to the west flank and middle of the study area, draining approximately north-northeast and north respectively (Figure A1 and Plate A3). Several minor, discontinuous ephemeral drainage lines are located on the flanks of the study area, two of which are located near the 7 June 2008 landslide primary source area. A convex break-in-slope is discernible near the head of drainage line DLl, which is possibly a relict landslide R4, with two small-scale relict landslides (GRS4 & GRS5) contained within it.

The study catchment shows a history of landslides. About 30 m upslope of the primary source area of the 7 June 2008 landslide, a degraded relict landslide scar R7, approximately 12 m wide by 17 m long is visible, see Figure A1 and Plate A3. Based on the setting and morphology, a lobe of colluvial deposits (about 35 m long) is visible downslope from landslide R7, which forms a footprint to the upper portion of the primary source area. Landslide R7 is identified under the ENTLI as Tag No. 11SWA0022E. Several recent landslides are visible within the study catchment, particularly concentrated on the western flank. After the June 1966 rainstorm, nine recent landslides (L7, L8, L10, L11, L13, L15, L16, L17 and MGS1) are visible on the study area hillside (Plate A4). Landslide L15 (ENTLI Tag No. 11SWA0377E) is located further upslope of the 7 June 2008 landslide primary landslide source area with the debris trail stopping a few metres downslope from footpath FP2.

There is some evidence of anthropogenic disturbance across the subject hillside. Several footpaths cross the site, footpath FP1 (Figure A1) crosses the mid-slope portion along the present-day Pik Shan Path, and footpath FP2 crosses the main scarp of the primary source area, near the head of ephemeral drainage line DL1. Another footpath FP3 is visible along the western spur. A water-carrying structure was constructed on the western flank of the study area, near the secondary source area. Military structures are present along the ridgeline, including chevron shaped wartime trenches, about 60 m above the primary source area of the 7 June 2008 landslide.

There is no observable change to the terrain between 1963 and the present day, other than a general increase in vegetation density.

A3. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1924 and 2006. A list of the aerial photographs studied is presented in Table A1 and a location plan is shown in Figure A1.

YEAR	OBSERVATIONS
1924	High flight aerial photographs, which are of relatively poor resolution. The study area is located on a north-acing hillside below Lung Fu Shan which forms the northern tip of a north-south trending ridge that descends from the higher hills that include Victoria Peak and High West. Topographically, the study area forms a hillside catchment defined by a broad depression between two rounded spurs trending north-northeast and north (see Figure A1). The broad depression appears asymmetric in shape with a steeper and sharper western flank. The study area hillside is generally sparsely vegetated. Two main ephemeral drainage lines DL1 and DL2 are located adjacent to the west flank and middle of the study area, draining approximately north-northeast and north respectively. Several minor, discontinuous ephemeral drainage lines are located on the flanks of the study area, two of which are located near the 7 June 2008 landslide primary source area. A northeast-southwest trending photo-lineament is apparent along the ephemeral drainage line DL1 and defines the general course of the drainage line. The Western Fresh Water Service Reservoir and the Filter Beds (present-day location of Elliot No. 2 Salt Water Service Reservoir) have been constructed to the northwest of the toe of the study area. Associated slopes, including slope Nos. 11SW-A/C148, 11SW-A/C149 and 11SW-A/C1142, have been formed by cutting into the natural hillside northwest of the study area. Two footpaths (FP1 and FP2) traverse the hillsides, FP1 is located on the mid-slope along the present-day Pik Shan Path, and FP2 is located further upslope near the head of ephemeral drainage line DL1. The WSD water conduit along Pik Shan Path was probably constructed at the same time as footpath FP1. A ‘zig-zag’ footpath FP3 is visible along the western spur, leading from the Western Fresh Water Service Reservoir to the upslope terrain. A highly reflective area interpreted as a patch of bare soil surface can be seen generally along the lower portion of the footpath, possibly related to anthropogenic disturbance.

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A lighter tone is noted below Pik Shan Path, which is located adjacent to the 7 June 2008 landslide secondary source area, is probably anthropogenic disturbance due to its proximity to the footpath.

A deep and sharply defined topographic depression is visible east of the study area. It appears to be related to anthropogenic disturbance, possibly borrow areas.

1945 A highly reflective area can be observed adjacent to the downslope side of Pik Shan Path, possible a recent landslide scar GRS1.

1949 An apparent recent landslide scar L9, labelled in the ENTLI database as Tag No. 11SWA0346E, with highly reflective material is noted on the western flank next to a sharp bend of footpath FP3.

An area of high reflectivity can be seen on the eastern portion of slope No. 11SW-A/C593, possibly a cut slope failure GRS2. A reflective patch is evident downslope of landslide GRS2, it appears to be remnant debris from the landslide.

The lower section of drainage line DL1 appears to have been modified into a man-made drainage channel.

A water-carrying structure has been constructed on the western flank of the study area.

1956 No observable changes, except that the vegetation density of the study area continues to increase.

1963 These photographs are of excellent clarity and resolution.

Seven relict landslides (R1, R4 to R7, GRS4 and GRS5) are identified on the hillside. Relict landslides R1, R4 to R7 coincide with those identified under the ENTLI with Tag Nos. 11SWA0069E, 11SWA0071E to 11SWA0073E, and 11SWA0022E respectively. Landslide R7 is located about 30 m upslope of the 7 June 2008 landslide primary source area and is identified as a broad depression with downslope debris. Landslides R4 and R6 are located at the head of ephemeral drainage lines DL2 and DL1 respectively. They are bounded by distinct convex breaks-in-slope and are covered with thin vegetation. Two small-scale relict landslides GRS4 and GRS5 are visible within R4. Landslide R5 is located below footpath FP2, about 25 m east of the drainage line DL1.

A recent open hillslope landslide L14, labelled in the ENTLI database as Tag No. 11SWA0347E, is noted on the western flank adjacent to footpath FP3, which is located within the 7 June 2008 landslide secondary source area.

An area of abandoned structures and a trench is evident along the ridgeline, probably related to military construction during WWII.

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The upper portion of the natural hillside is generally covered with thin vegetation, while the middle and lower portions are covered with denser vegetation comprising shrubs and trees.

1967 Nine recent landslides (L7, L8, L10, L11, L13, L15, L16, L17 and MGS1) can be identified on the study area hillside. Landslide L15 (ENTLI Tag No. 11SWA0377E) is located further upslope of the 7 June 2008 landslide primary landslide source area. The debris trail appears to have stopped just a few metres downslope from footpath FP2. Landslide L11 is located below footpath FP2 along drainage line DL2. This channelized debris flow appears to have stopped about half-way between footpaths FP1 and FP2. The landslide source area at the head of drainage line DL1 is 'Y'-shaped in plan, with distinct eastern and western portions (Landslides L7 and L8 respectively). Landslides L7 and L8 (ENTLI Tag Nos. 11SWA0373E and 11SWA0374E) with highly reflective materials are visible along drainage line DL1 and the debris travel distance is estimated to be about 150 m (plan distance).

Retrogressive failure (L13) (ENTLI Tag No. 11SWA0346E) can be seen upslope of landslide GRS2. This is inferred as an area of instability and resulted in the eastern portion of slope No. 11SW-A/C593 having its crest line extended in the southeast direction to its present location. The debris entered an ephemeral drainage line and merged with the debris trail from landslides L7 and L8.

A cut slope failure (L17) is located next to landslide L13 on the western portion of slope No. 11SW-A/C593. Landslide MGSL1 is a small-scale failure that occurred next to the landslide L13 debris trail. Landslide L10 (ENTLI Tag No. 11SWA0376E) is located southeast of landslide L9, and debris of landslide L10 also merged with the debris trail from landslides L7 and L8.

Another cut slope failure (L16) is visible on slope No. 11SW-A/C608 along Pik Shan Path. Some of the debris appears to be deposited on the downslope hillside.

Vegetation disappeared from an extensive area on the natural hillside southeast of the study catchment, probably as a result of a hillfire.

1969 This single aerial photograph shows only the lower portion of the study area.

Some of the landslide scars are visible with highly reflective materials but most of the debris trails have been re-vegetated.

1973 Most of the landslide scars have been re-vegetated, except landslides L8, L13, L14, L15, L17 and MGS1.

An access road leading from Hatton Road to a transmission tower located to the south of the study area has been constructed.

1976 No observable changes.

1977 No observable changes.

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1978	Site formation works in the present-day location of Simon K.Y. Lee Hall and Hsu Long Sing Amenities Centre are underway. The formation of slope No. 11SW-A/C600 is in progress by cutting into the natural hillside.
1979	Site formation works near the toe of the study area are underway.
1980	Site formation works near the toe of the study area are underway.
1981	Anthropogenic disturbance along footpath FP3 is noted, probably upgrading the original stairway and laying the water mains along it. Site formation works near the toe of the study area are underway and slope No. 11SW-A/C600 has been formed.
1982	A low-rise rectangular building has been constructed at the present-day location of the CYC Building.
1984	Site formation works near the toe of the study area are underway. No significant changes on the natural hillside except an increase in vegetation cover on the study catchment.
1987	Simon K.Y. Lee Hall and Hsu Long Sing Amenities Centre have been constructed.
1988	No significant changes.
1990	No significant changes.
1991	The transmission tower has been demolished.
1992	No significant changes.
1993	The low-rise building at the present-day location of the CYC Building has recently been demolished.
1994	The construction of the CYC Building was in progress.
1995	The construction of the CYC Building has been completed.
1996	No significant changes.
1998	The WSD filter bed has been demolished and the construction of Elliot No. 2 Salt Water Service Reservoir at its present-day location was in progress.
1999	The photographs only cover the lower portion of the study catchment. The construction of Elliot No. 2 Salt Water Service Reservoir has been completed.
2000	No significant changes.
2001	No significant changes.

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2002	No significant changes.
2003	No significant changes.
2004	No significant changes.
2005	No significant changes.
2006	The study area is generally covered with dense vegetation.
2007	No significant changes.

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Table A1 - List of Aerial Photographs (Sheet 1 of 2)

Date Taken	Altitude (ft)	Photograph Number
1924	12500	Y00025
1924	12500	Y00036
11 November 1945	20000	Y0465-66
8 May 1949	8600	Y01519
27 December 1956	16700	Y03180
1 February 1963	2700	Y07601, 03
1963	2700	Y07681-82
2 February 1963	2700	Y07530
16 May 1967	6250	Y13299-300
1969	Unknown	Y14656
12 December 1973	3000	6986, 88
4 October 1976	4000	15507
6 May 1977	4000	18318
5 December 1978	4000	23931
28 September 1979	5500	27167-68
5 November 1980	4000	32244-45
26 October 1981	10000	39014
28 July 1982	3500	43071-72
29 July 1982	4000	43302
2 March 1984	4000	53625-26
9 September 1987	4000	A10279-80
27 September 1988	4000	A14382
3 February 1989	2000	A16430-31
20 March 1990	4000	A20836-37
14 November 1990	4000	A23752
2 October 1991	4000	A27664-65
12 May 1992	4000	A30890
5 December 1993	10000	CN5330-31
5 May 1994	4000	CN6841
17 November 1994	4000	CN7920

Note: All aerial photographs are in black and white except for those prefixed with CN, CW, CS or RW.

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Table A1 - List of Aerial Photographs (Sheet 2 of 2)

Date Taken	Altitude (ft)	Photograph Number
7 December 1995	3500	CN12597-98
7 June 1996	4000	CN14060
4 August 1998	2500	CN20933-34
31 October 1998	4000	CN22111-12
4 June 1999	2500	CN22920-21
19 April 2000	2500	CN26306
26 July 2000	2500	CN27543-44
24 September 2001	4000	CW33685-86
20 November 2001	8000	CW35972-74
3 January 2002	2500	CW38203
21 January 2002	16000	RW00904-05
17 April 2002	3500	CW39471
25 October 2002	4000	RW01401
25 September 2003	8000	CW50117-18
10 February 2004	8000	CW55236-37
8 March 2005	4000	CW63774-75
15 December 2005	8000	CW69803-04
21 December 2006	6000	CS02327-28
12 July 2007	3000	CW76943-44

Note: All aerial photographs are in black and white except for those prefixed with CN, CW, CS or RW.

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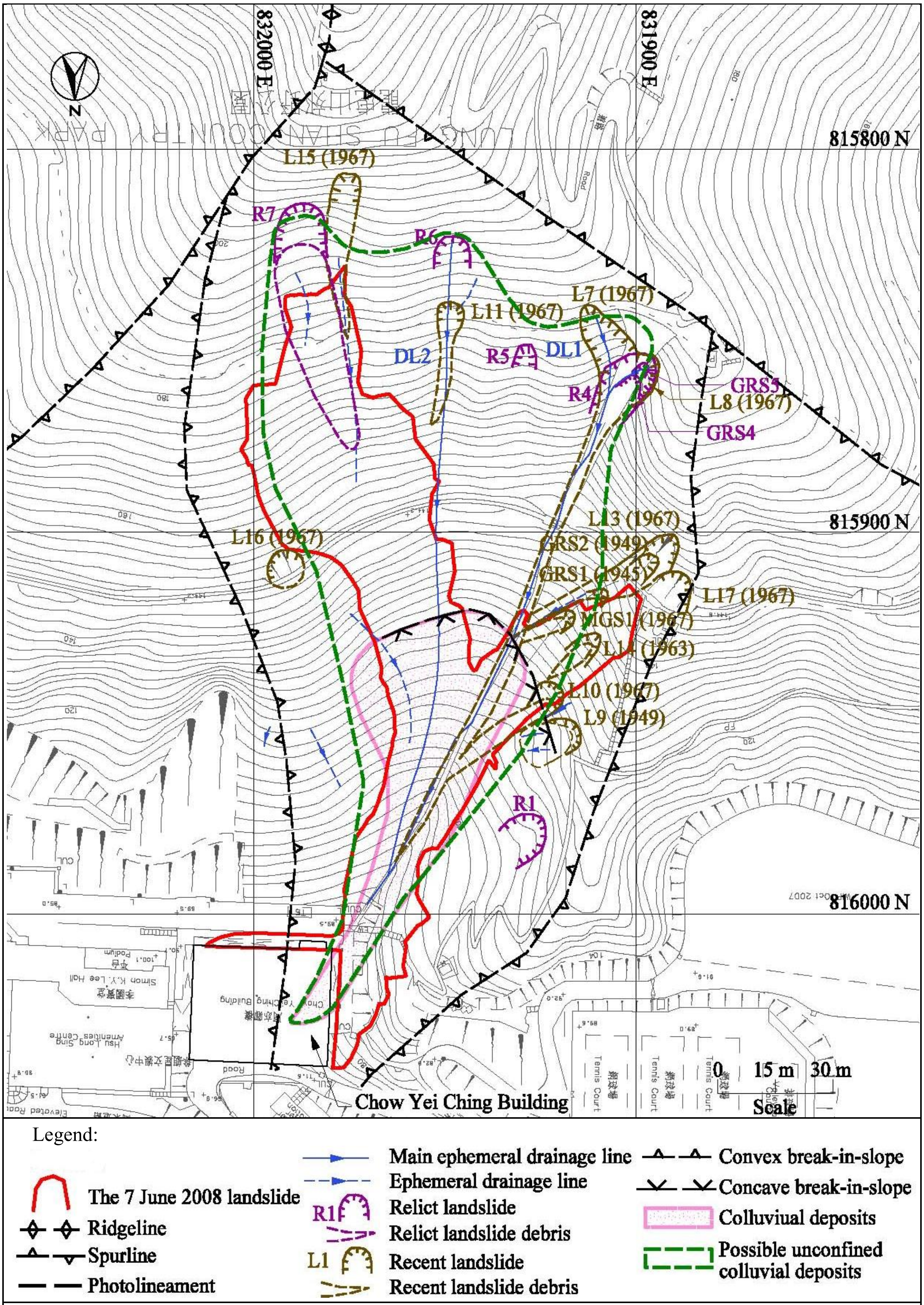

Note: Base plan is extracted from 1:1000 survey sheets No. 11SW-7C dated March 2008.

Figure A1 - Aerial Photograph Interpretation

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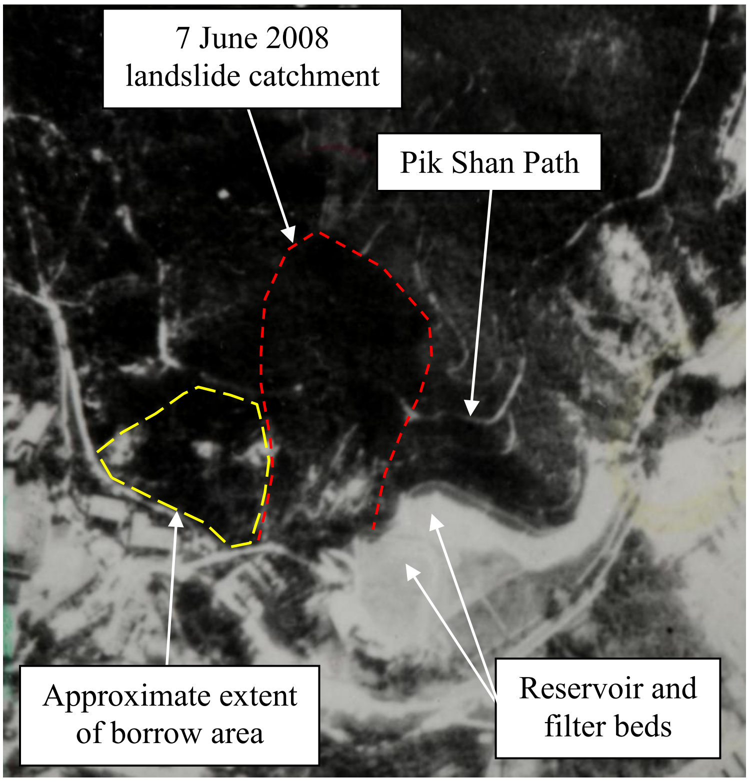

Plate A1 - Extract from 1924 Aerial Photograph (Y00025)

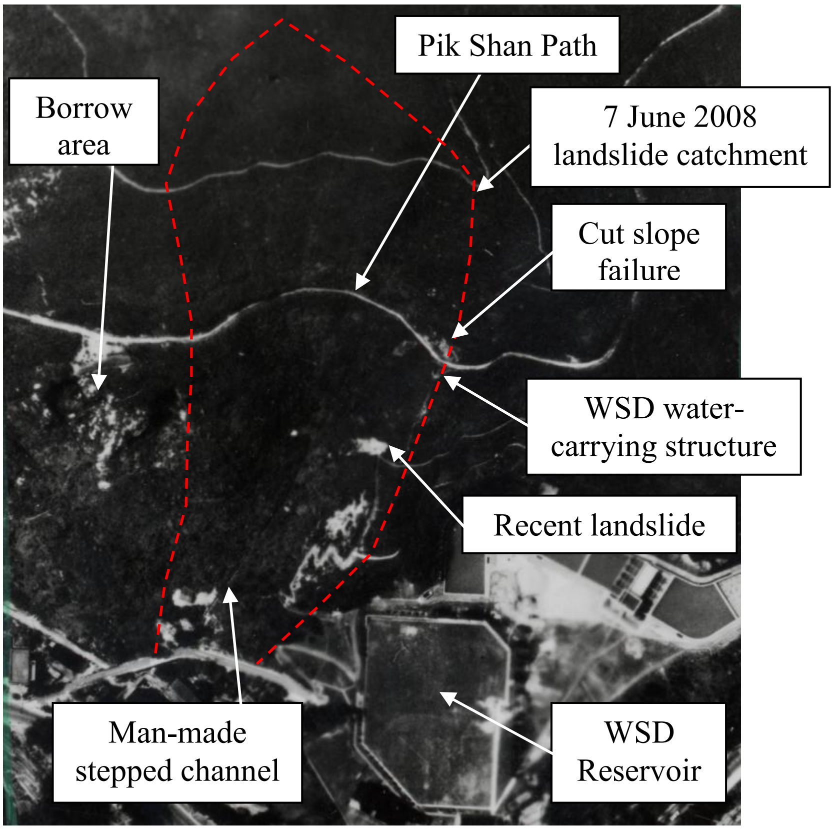

Plate A2 - Extract from 1949 Aerial Photograph (Y01519)

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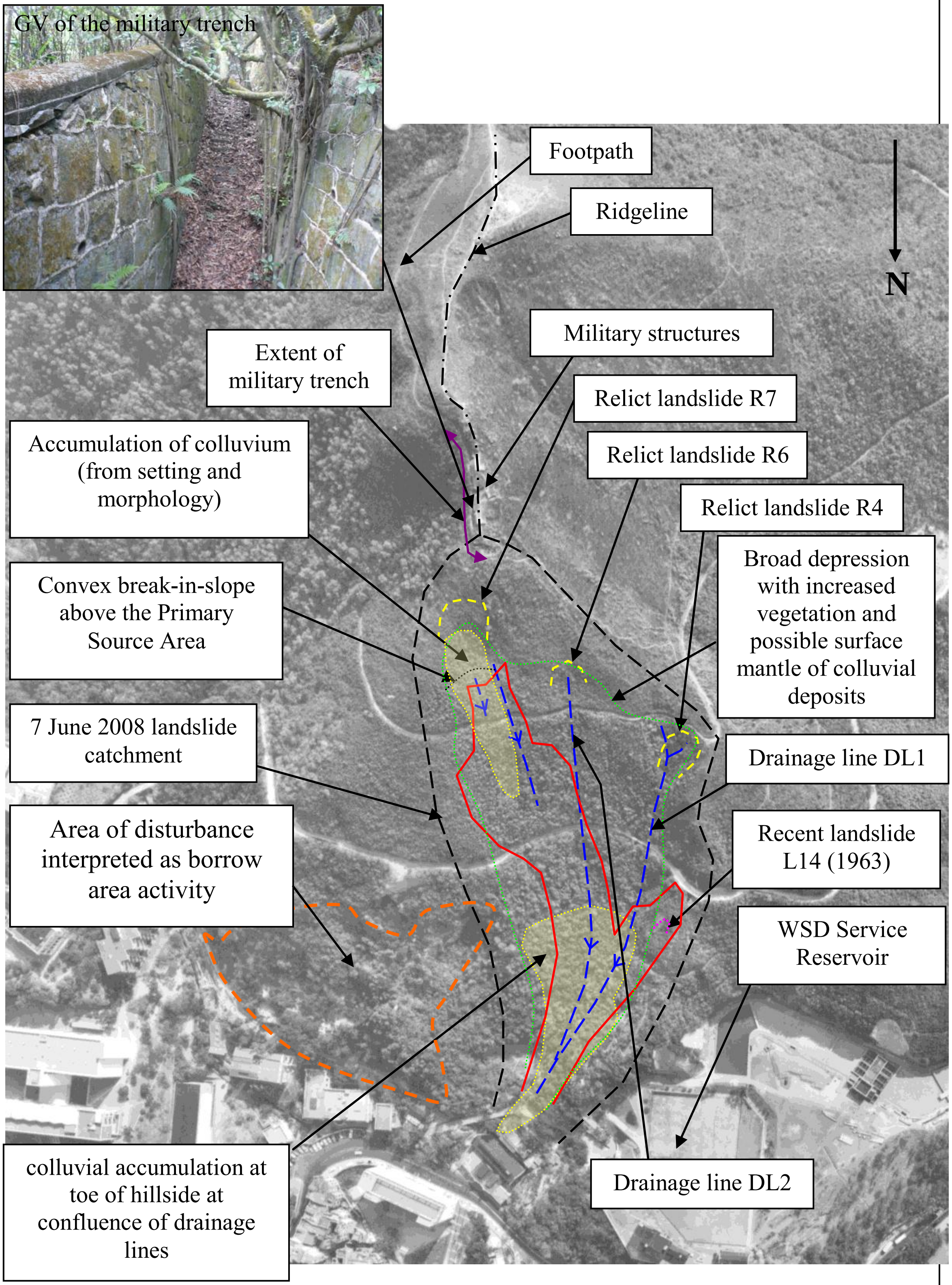

Plate A3 - Extract from 1963 Aerial Photograph (Y07601)

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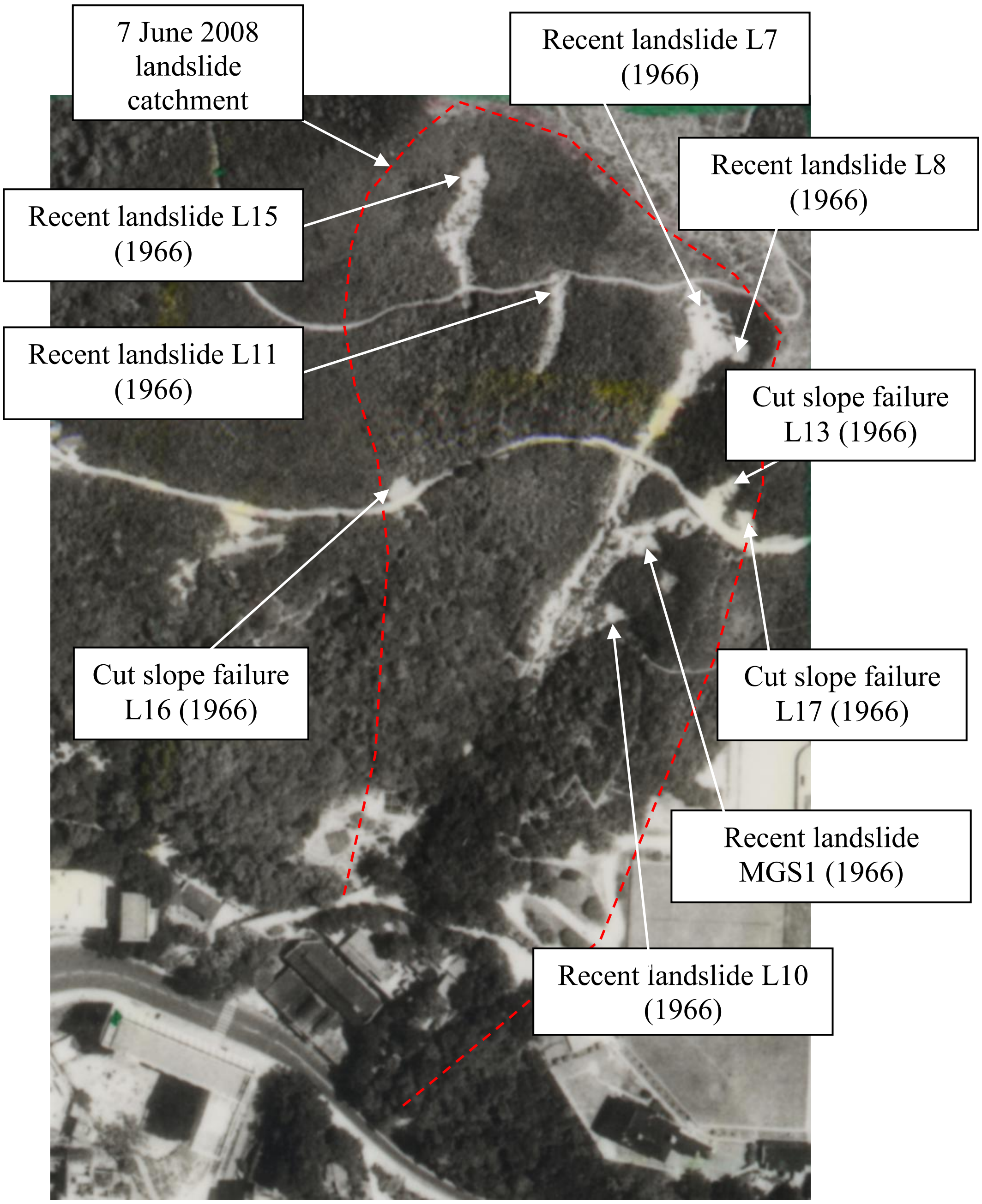

Plate A4 - Extract from 1967 Aerial Photograph (Y13299)

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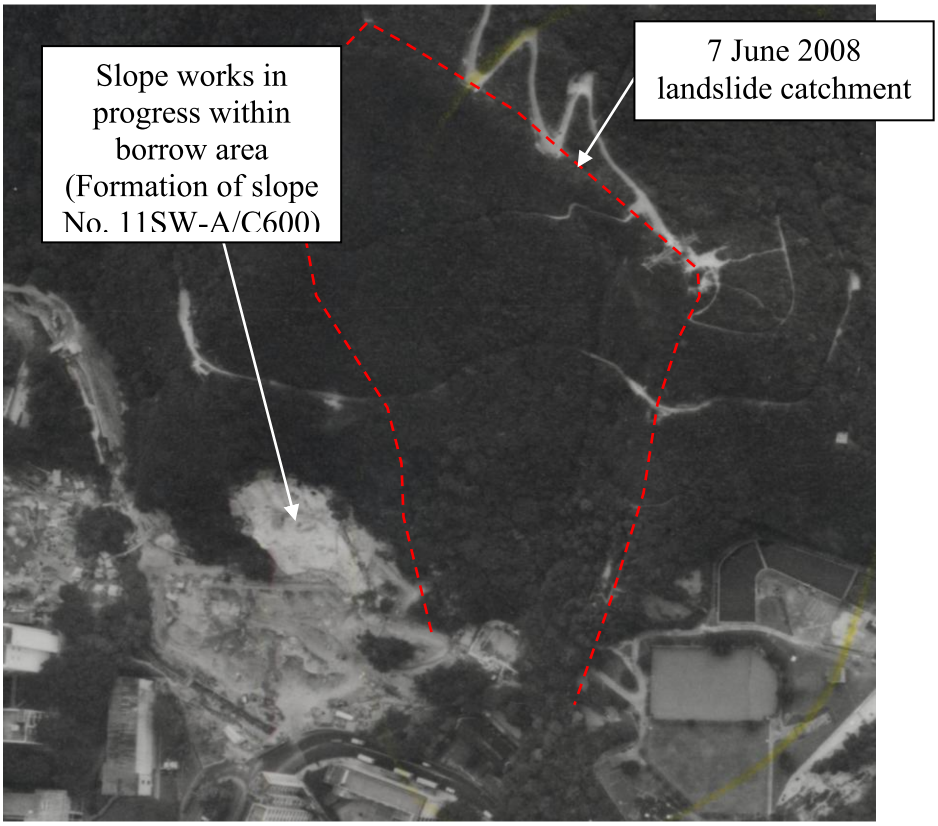

Plate A5 - Extract from 1978 Aerial Photograph (23931)

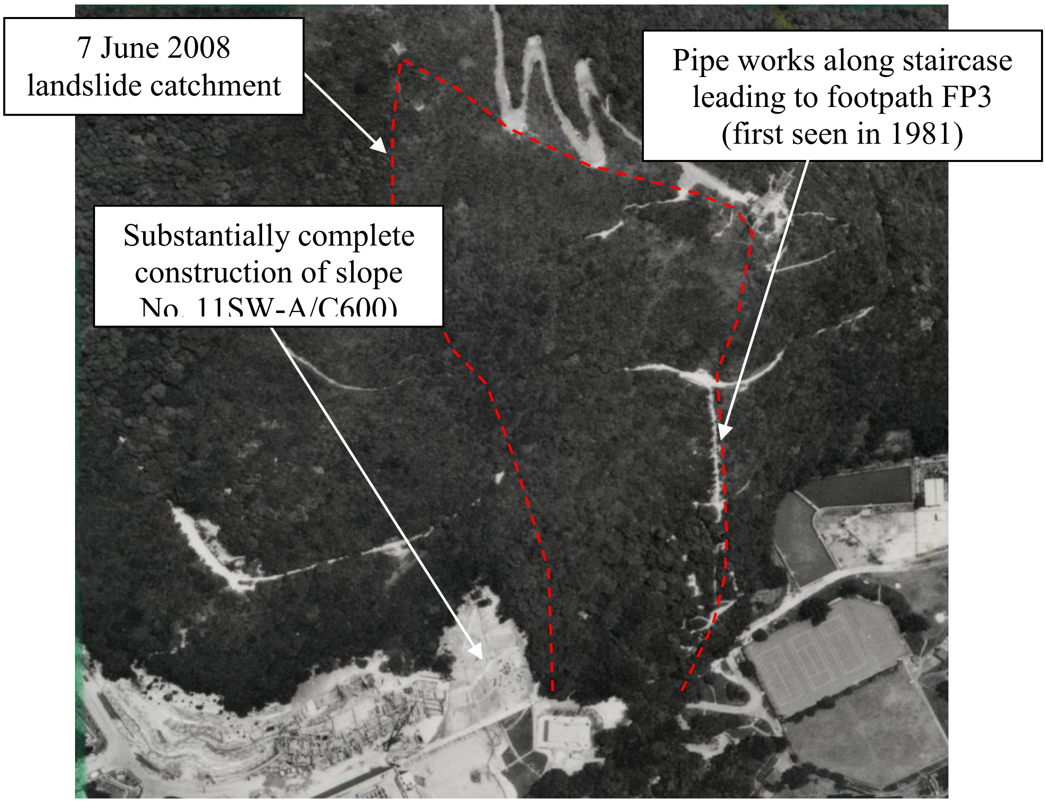

Plate A6 - Extract from 1982 Aerial Photograph (43072)

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APPENDIX B

GROUND INVESTIGATION INFORMATION

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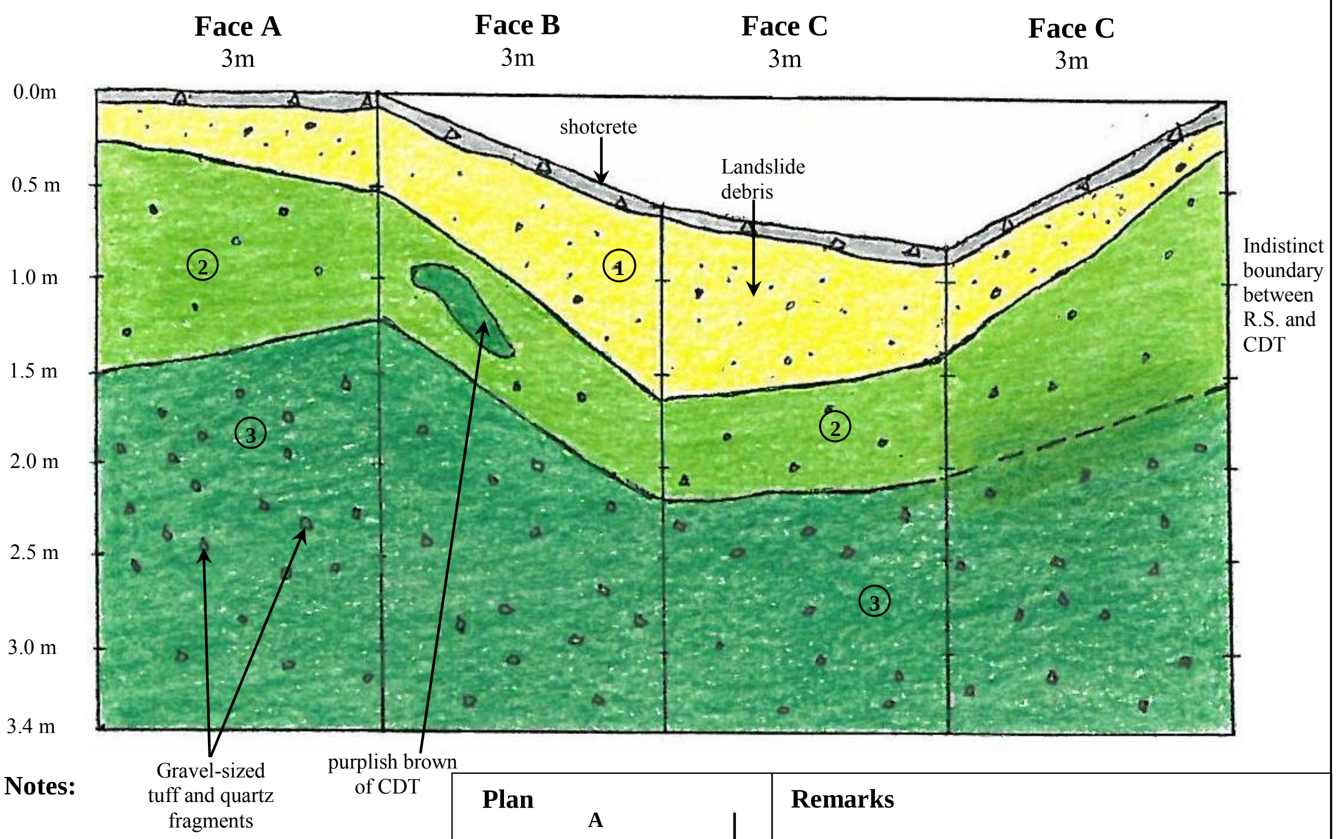
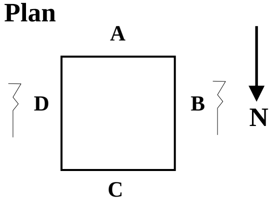
Trial Pit No. **TPH 1** Logged by: CI Date: 17 September 2008



Plan



Remarks

Max Depth: 3.40m
Shoring: Yes
Water Seepage: No

Average Depth: 3.0m
Stability: Stable

Description

① Very soft to soft, yellowish brown silty CLAY, with occasional sub-rounded gravel and cobble-sized rock fragments, roots and rootlets. (Landslide Debris)

② Soft to firm, reddish brown, sandy clayey SILT, with occasional gravel-sized tuff and quartz fragments. (Residual Soil)

③ Extremely weak, reddish and purplish brown, spotted white, completely decomposed coarse ash crystal TUFF (Firm very sandy clay/silt with much mica crystals and some fine to medium gravel-sized tuff and quartz fragments. (CDT)

Figure B1 - Trial Pit Record for TPH 1

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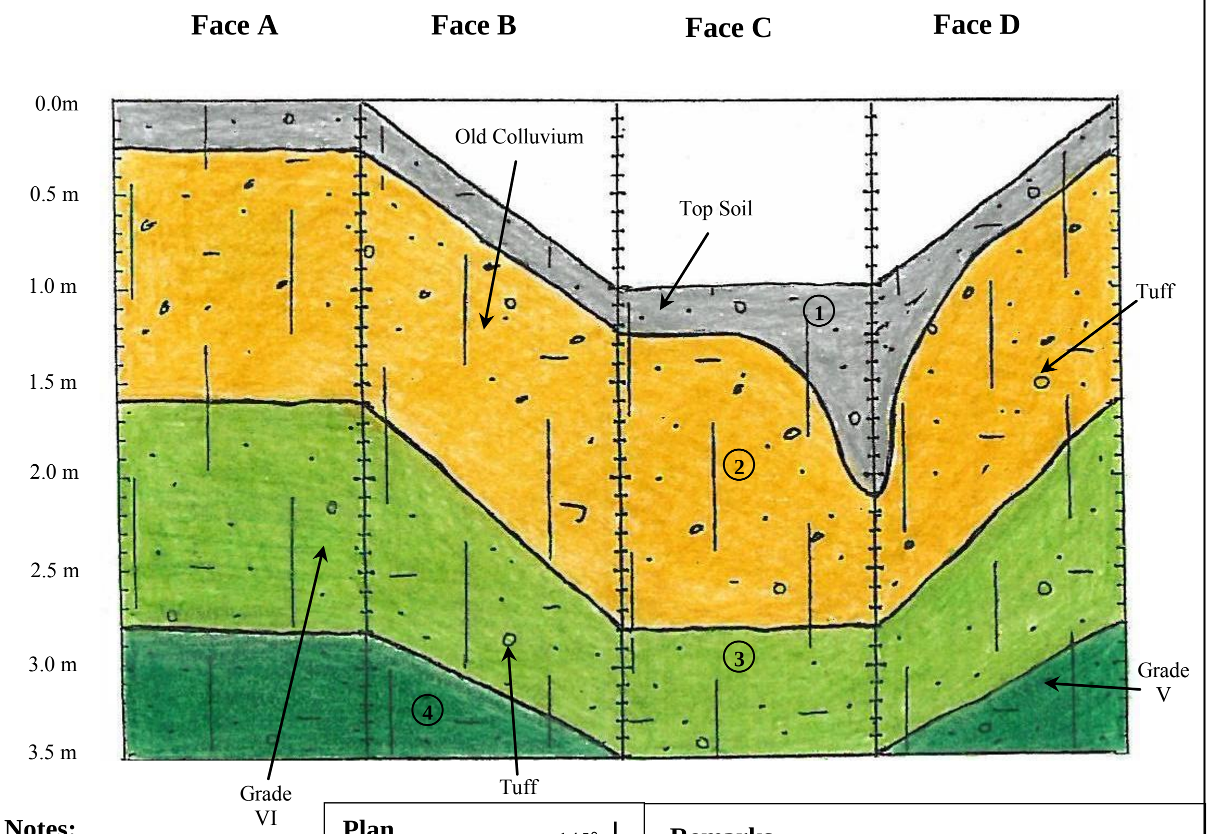
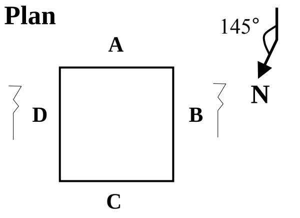
Trial Pit No. **TPH 2** Logged by: SJW Date: 17 September 2008



Notes:

Plan



Remarks

Max Depth: 3.5m
Shoring: Yes
Water Seepage: No
Average Depth: 3.0m
Stability: Stable

Description

① Hard, dry to moist, greyish brown, sandy clayey SILT with some sub-angular fine to medium gravel-sized rock fragments and rootlets.
(Top Soil)

② Firm, moist, yellowish brown to reddish brown, slightly sandy clayey SILT with some sub-angular fine to coarse gravel-sized, and occasional cobble-sized weak to moderately strong tuff fragments
(Colluvium -older)

③ Firm, moist, reddish brown, very sandy clayey SILT with occasional sub-rounded fine gravel-sized tuff and quartz fragments
(Residual Soil -RS)

④ Extremely weak, moist, light reddish brown, completely decomposed coarse ash crystal TUFF. (Firm, sandy clayey SILT with some fine gravel) No relict joints noted.
(Completely Decomposed Tuff - CDT)

Figure B2 - Trial Pit Record for TPH 2

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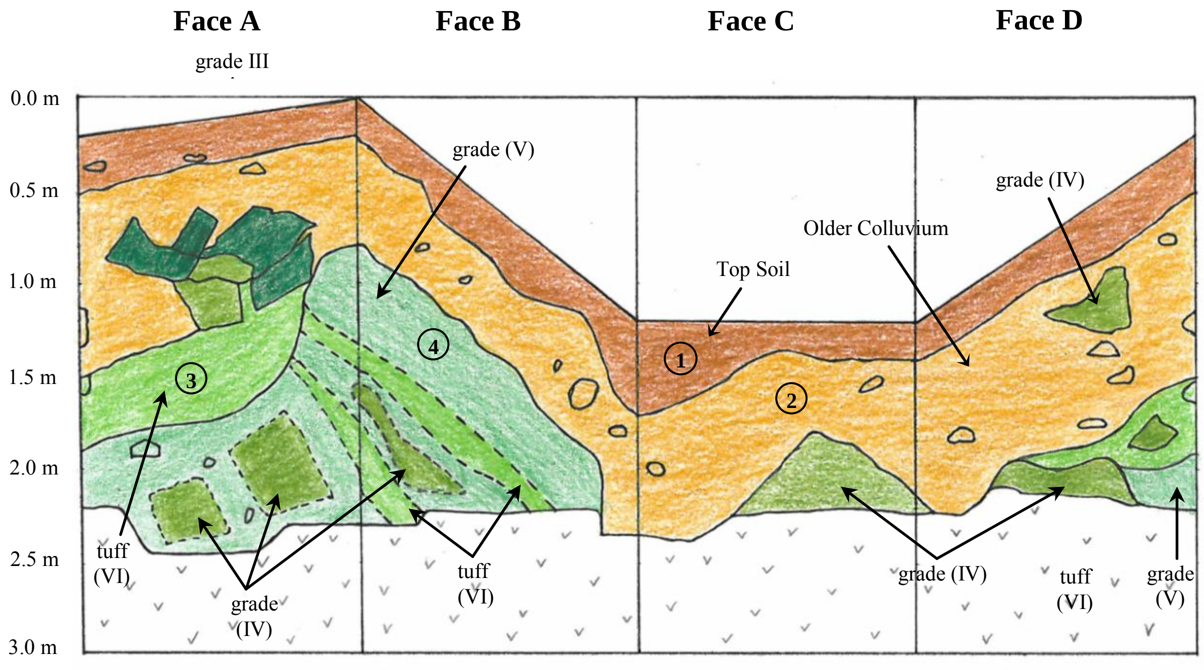
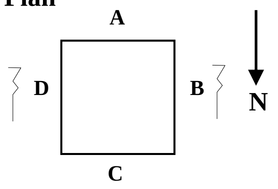
Trial Pit No. **TPH 3** Logged by: SJW Date: 8 October 2008



Notes:

Plan



Remarks

Max Depth: 2.3m
Shoring: Yes
Water Seepage: No

Average Depth: 1.7m
Stability: Stable

Description

① Firm, (dessicated) brownish grey, slightly clayey sandy SILT with some sub-angular fine to coarse gravel-sized, and occasional cobble-sized tuff fragments, and some rootlets. (Top Soil)

② Firm, moist, light yellowish brown to reddish brown, sandy clayey SILT with some sub-angular fine to coarse gravel-sized, and occasional cobble- and boulder-sized moderately decomposed altered tuff fragments. (Colluvium - older)

③ Firm, reddish brown, sandy clayey SILT with some sub-rounded fine gravel fragments. (Residual Soil)

④ Very weak to weak, very pale brown, mottled pale red and light greenish grey, completely to highly decomposed TUFF (sandy fine to coarse GRAVEL)

Figure B3 - Trial Pit Record for TPH 3

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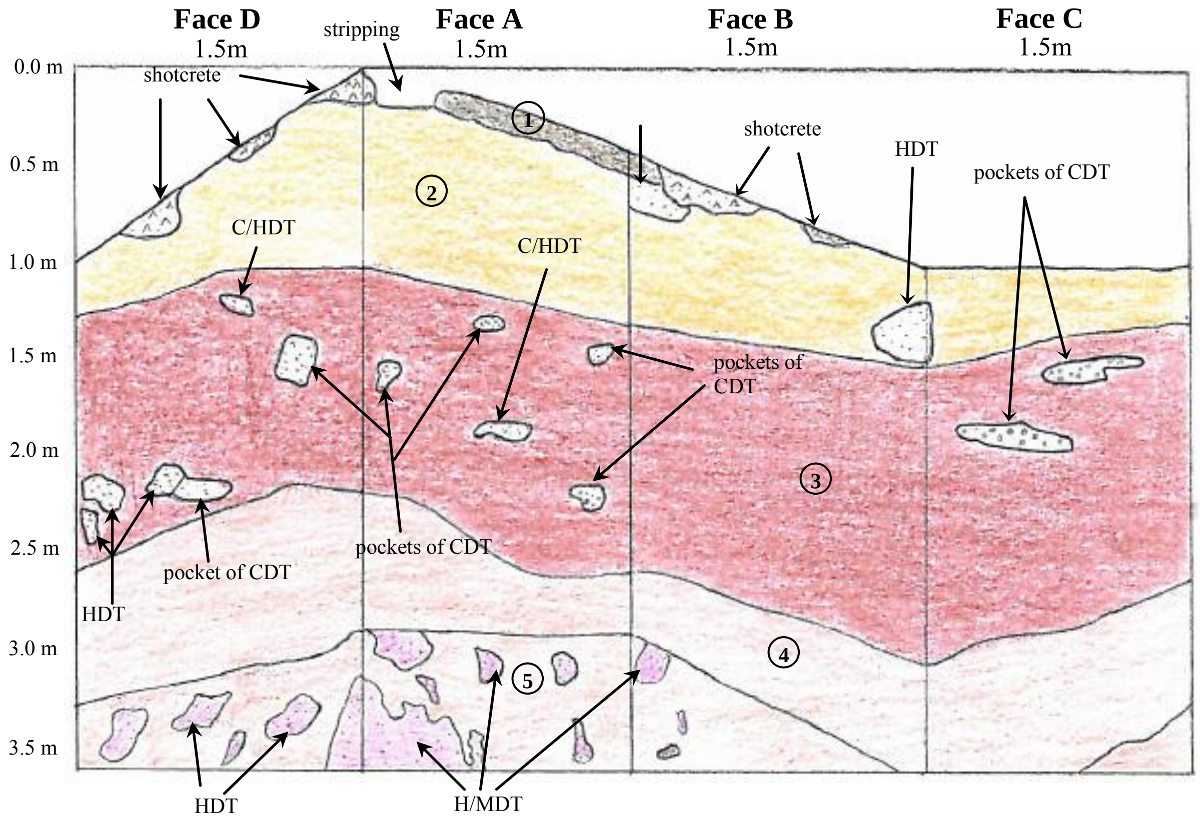
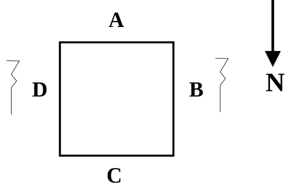
Trial Pit No. **TPH 4** Logged by: SJW Date: 3 November 2008



Notes:

Plan



Remarks

Max Depth: 3.50m
Shoring: Yes
Water Seepage: No

Average Depth: 3.0m
Stability: Stable

Description

① Loose to dense, greyish brown, very silty SAND, some fine to coarse gravel sized rock fragment, with roots and rootlets (Top soil)

② Soft to firm, yellowish brown sandy silty CLAY with some sub-angular to sub-rounded fine to coarse gravel-sized highly to moderately decomposed altered coarse ash tuff fragments, with occasional cobble-sized highly decomposed rock fragments and occasional rootlets (Colluvium - young)

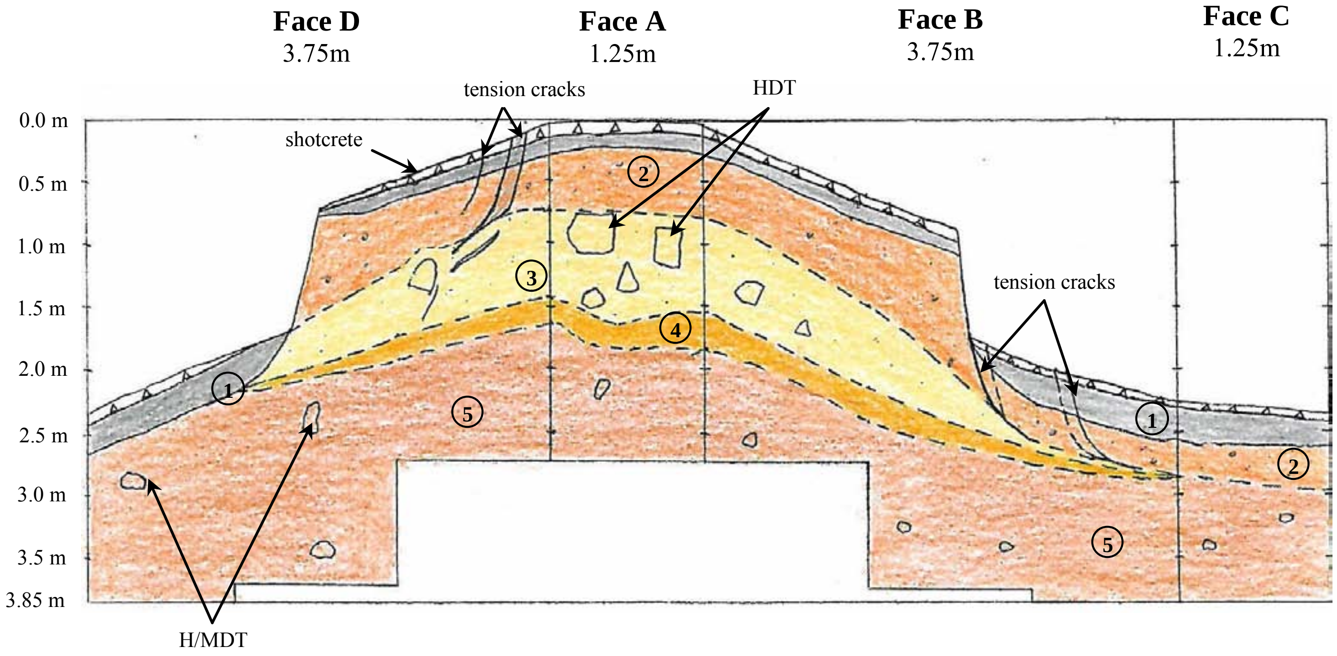
③ Firm to stiff, reddish brown, mottled grey and yellowish brown, sandy very silty CLAY or clayey SILT, with some fine to medium gravel and cobble-sized highly decomposed altered coarse ash tuff fragments (with much mica and some recrystallization effects), and occasional rootlets (Colluvium - old)

④ Firm to stiff, reddish brown, sandy silty CLAY, with occasional rounded to sub-rounded medium gravel sized highly decomposed coarse ash tuff fragments (Residual Soil)

⑤ Moderately strong to moderately weak, reddish purple, mottled grey, highly to moderately decomposed altered coarse ash TUFF with kaolin and silty partings along relict joints. Residual soil penetrating less weathered rock (Highly to Moderately Decomposed Tuff)

Figure B4 - Trial Pit Record for TPH 4

Trial Pit No. **TPH 5** Logged by: SJW Date: 3 December 2008



Description

① Firm, greyish brown, sandy SILT with many subangular gravel sized rock fragments with many roots/rootlets (Top Soil)

② Firm to stiff, orangish brown, sandy clayey SILT, with much medium gravel and cobble-sized rock fragments and occasional subangular moderately decomposed altered tuff boulders (Colluvium 1 - relatively young)

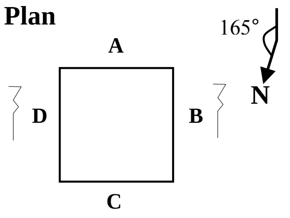
③ Soft to firm (at base), reddish brown, sandy silty CLAY with much sub-angular to angular, fine to medium gravel sized tuff fragments and with occasional cobble sized highly decomposed tuff fragments (Colluvium 2 - relatively young)

④ Soft to firm, moist, sandy silty CLAY (Possible disturbed zone)

⑤ Firm to stiff, reddish brown, mottled yellowish brown, sandy silty CLAY with much sub-rounded fine to medium gravel and some angular cobble sized highly to moderately decomposed tuff fragments (Colluvium - old)

Notes:

Plan



Remarks

Max Depth: 3.85m
Shoring: Yes
Water Seepage:

Average Depth:
Stability:

Figure B5 - Trial Pit Record for TPH 5

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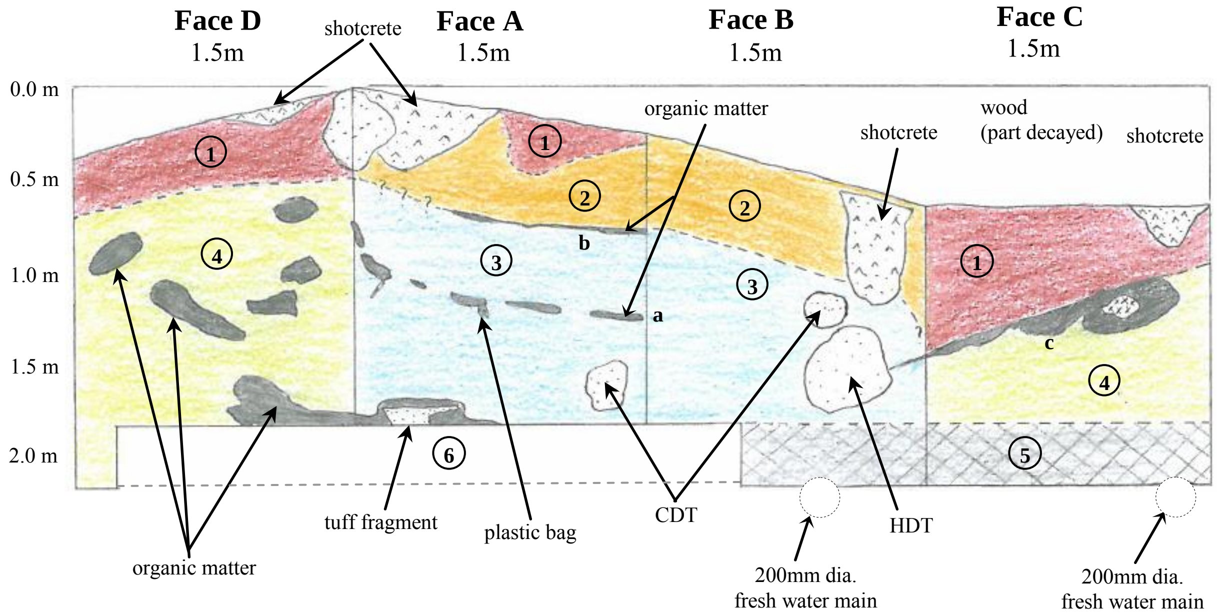
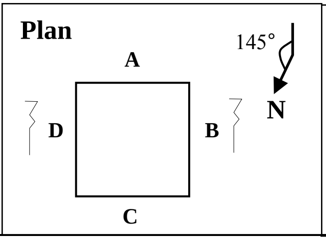
Trial Pit No. **TPH 6** Logged by: SJW Date: 6 November 2008



Notes:
a – Partly decayed leaf
b – Organic layer (possibly layer boundary within debris)
c – Organic layer (possibly layer boundary within debris)



Remarks

Max Depth: 3.5m
Shoring: Yes
Water Seepage: No

Average Depth: 3m
Stability: Stable

Description

① Soft to firm, moist, reddish brown, sandy SILT/CLAY with occasional gravel-sized tuff fragments and occasional dark grey odorous organic pockets (Landslide debris1)

② Very soft to soft, moist, yellowish brown, slightly sandy SILT/CLAY with some sub-rounded fine to medium gravel sized tuff fragment and with some dark grey organic pockets (odorous) and decayed roots/plants matter (Landslide debris 2)

③ Soft, moist, reddish brown, very sandy SILT/CLAY with much sub-rounded fine gravel sized rock fragment, and with occasional sub-rounded coarse gravel sized completely decomposed tuff fragments (Landslide debris 3)

④ Soft, yellowish brown, slightly sandy SILT/CLAY, with some sub-angular to sub-rounded gravel sized tuff and sandstone fragments, with many pockets of dark grey organic soft silt/clay (Landslide debris 4)

⑤ Medium to dense, dark yellowish brown, clayey sandy SILT, with much sub-angular fine to coarse gravel, with occasional plastic bag fragment and some rootlets (Fill)

⑥ Concrete plate (Pik Shan Path)

Figure B6 - Trial Pit Record for TPH 6

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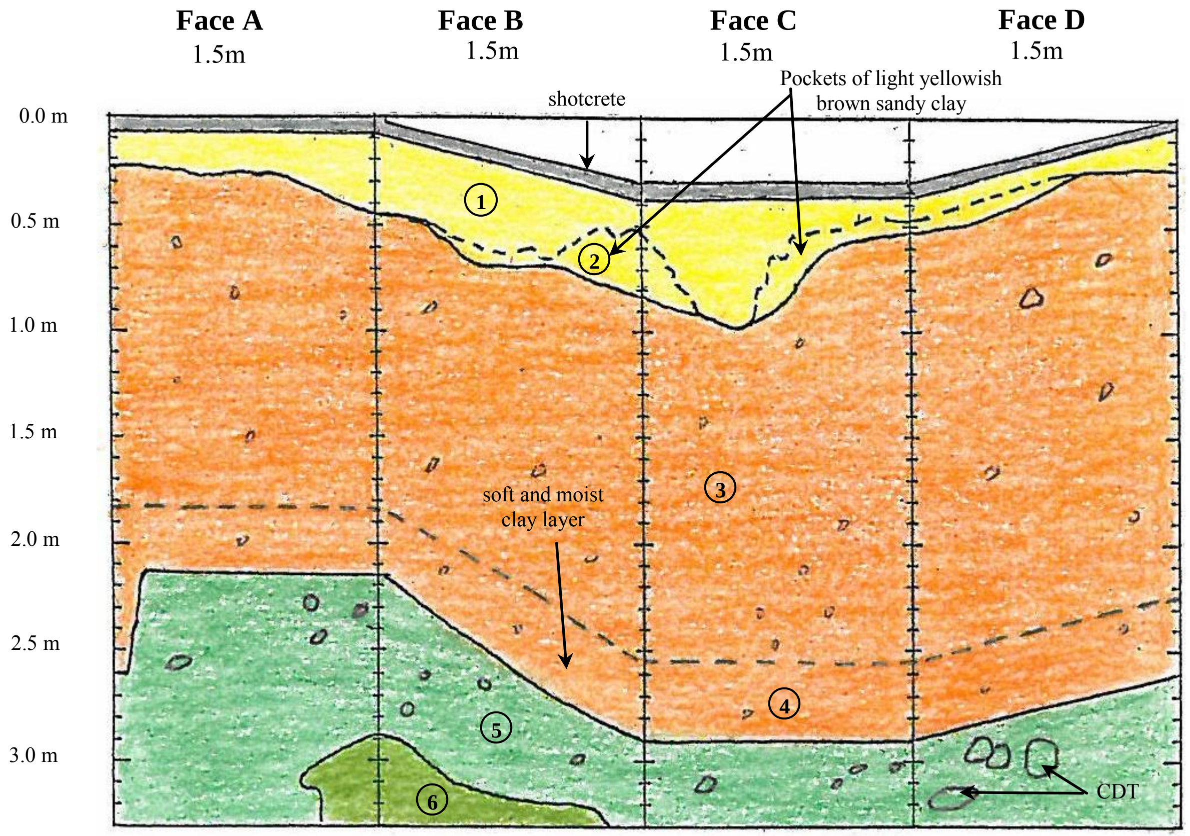
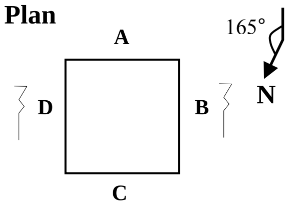
Trial Pit No. **TPH 7** Logged by: SJW Date: 21 November 2008



Notes:

Plan



Remarks

Max Depth: 3.3m
Average Depth: 3m
Shoring: Yes
Stability: Stable
Water Seepage: No

Description

① Firm, moist, grey, mottled pale brown, sandy clayey SILT with occasional subangular fine to coarse gravel sized rock fragments and decayed rootlets (Landslide debris)

② Pockets of light yellowish brown sandy CLAY

③ Firm, moist, orangish brown, slightly sandy CLAY/SILT with some subangular fine and occasional coarse gravel of quartz and rock fragments and cobble sized pocket of completely decomposed tuff (Colluvium-old)

④ Soft to firm, reddish brown, very sandy silty CLAY with much fine angular gravel sized tuff fragments (Disturbed/remoulded colluvium - old)

⑤ Extremely weak, light reddish brown, completely decomposed TUFF (Slightly sandy clayey SILT)
Transitional to residual soil

⑥ Moderately weak to weak, very pale brown, highly decomposed TUFF with relict joints infilled with sandy silt/clay (5 mm thick)

Figure B7 - Trial Pit Record for TPH 7

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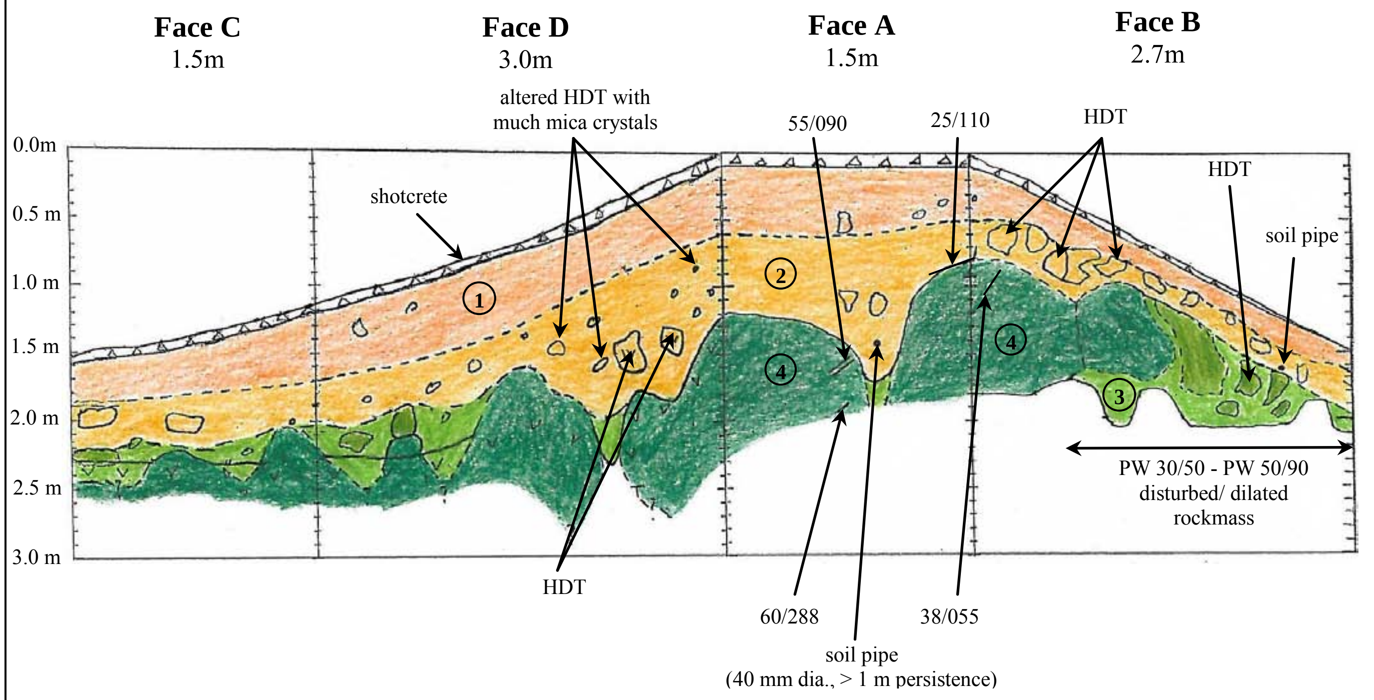
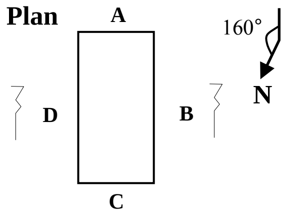
Trial Pit No. **TTH 1** Logged by: SJW Date: 15 October 2008



Notes:

Plan



Remarks

Max Depth: 2.5m
Shoring: Yes
Water Seepage: No

Average Depth: 1.2m
Stability: Stable

Description

① Firm, moist, orangish brown, slightly sandy CLAY/SILT with some subangular to subrounded, fine to coarse gravel sized tuff fragments (locally much angular to subangular cobbles sized tuff fragments) and with occasional rootlet (Colluvium -young)

② Soft to firm, moist, light yellowish brown to reddish brown, mottled light grey, sandy clayey SILT with some subangular fine to coarse gravels, cobbles, occasional boulders of weak to moderately strong highly decomposed tuff fragments (Colluvium-old)

③ Firm, moist, reddish brown, very sandy clayey SILT with occasional subangular fine gravel of quartz and with occasional subangular to subrounded cobble sized tuff fragments (Residual Soil)

④ Moderately strong, light grey, highly to moderately decomposed altered coarse ash TUFF with many fractures with reddish brown silt/clay infill

Figure B8 - Trial Pit Record for TTH 1

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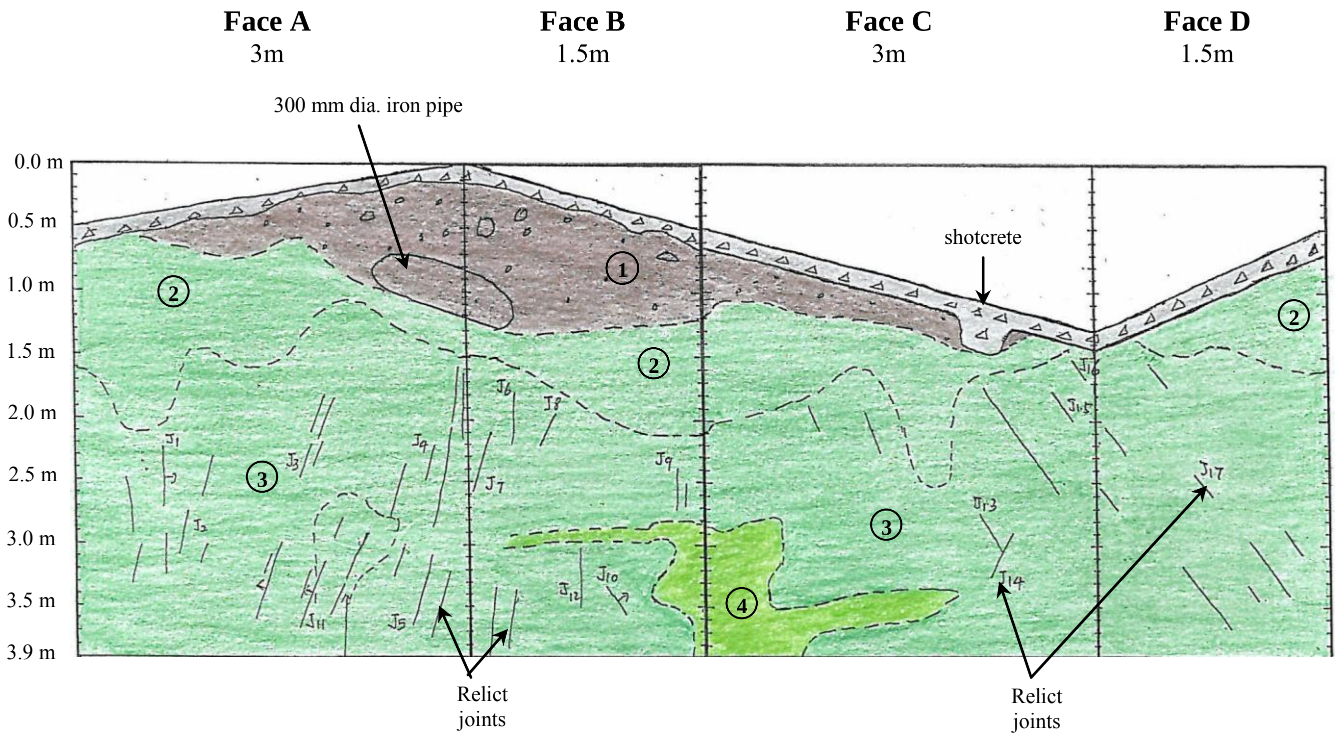
Trial Pit No. **TTH 2** Logged by: SJW Date: 8 October 2008



Description

① Dense, moist, light yellowish brown, mottled grey, silty fine to medium SAND with some sub-angular fine to coarse gravels, occasional cobbles of rock fragments and occasional concrete fragments. A 300 mm dia. iron pipe exposed at the comer of Faces A and B (Fill)

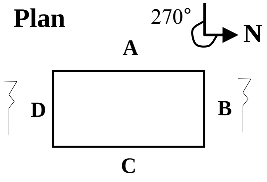
② Dense, moist, very pale brown, mottled pale brown, slightly sandy SILT with occasional sub-rounded fine to medium gravel sized quartz fragments and with pockets of completely decomposed tuff (Residual soil)

③ Extremely weak to very weak, moist, yellowish brown, completely decomposed coarse ash TUFF with closely to medium spaced, occasional very closely spaced, with iron oxide stained relict joints. (slightly altered) (Very silty fine to medium SAND with many fine to coarse gravel sized quartz and rock fragments)

④ Dense, moist, light yellowish brown, slightly sandy SILT with occasional sub-rounded fine gravel sized quartz fragments (Residual Soil)

Notes:		**J6**	210/82 Fe	**J12**	240/86 Fe
J1	320/82 Fe	**J7**	198/76 Fe	**J13**	195/74 Fe
J2	145/80 Fe	**J8**	214/65 Fe	**J14**	325/71 Fe
J3	185/66 Fe	**J9**	240/81 Fe	**J15**	150/60 Fe
J4	191/79 Fe	**J10**	095/76 Fe	**J16**	165/56 Fe
J5	180/77 Fe	**J11**	140/75 Fe	**J17**	220/47 Fe

Plan



Remarks

Max Depth: 3.90m
Shoring: Yes
Water Seepage: No

Average Depth: 3.0m
Stability: Stable

Figure B9 - Trial Pit Record for TTH 2

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APPENDIX C

THEORETICAL DEBRIS MOBILITY ANALYSIS

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C1. GENERAL

The runout of debris from the primary source area of the 7 June 2008 landslide, was back-analysed using the GEO's numerical simulation package, the 3-dimensional Debris Mobility Model (3dDMM). The program uses the numerical scheme called 'Particle-In-Cell' (PIC) (Harlow, 1963) and has been used to simulate a number of historic landslides in Hong Kong (Kwan & Sun, 2007). The PIC adopts particle representation of the deformable materials concerned and calculates the properties of the materials, such as strain and stress, based on the Eulerian technique. The terrain on which the landslide initiates and flows is divided into an array of cells and the landslide debris is represented by a number of non-interacting particles. Two rheologies, the frictional and Voellmy models, are available in the numerical simulation package.

C2. THE MODEL

The topography adopted for the modelling was based on the pre-failure LiDAR survey. The initial thickness of the displaced material within the primary source area was estimated based on the pre-failure LiDAR survey, the post-failure topographical survey and field measurements. According to the site observations, the primary source area involved a detachment of about 1,750 m^3 of which about 220 m^3 remained within the source area, i.e. only about 1,530 m^3 of materials was completely detached from the source area. The model considers only the volume of debris which has completely detached, i.e. 1,530 m^3. For simplicity, the model also assumes all the materials were detached in one go.

Lo (2000) suggests that the frictional and Voellmy flow models may be used to represent the open hillside failure and the channelised debris flow respectively. The 7 June 2008 landslide involved an open hillside failure and the debris did not channelised until it reached the drainage line, DL1 in the lower hillside area. It is therefore considered that the 7 June 2008 landslide involved primarily an open hillside failure and the frictional rheology has been adopted for the entire debris trail in the analyses.

C3. SUMMARY OF RESULTS

Several analyses were carried out for a range of internal friction angle and the base friction angle in order to provide a reasonable fit to the extent and shape of the debris trail, deposition of debris and mass balance. The results seem to suggest that the extent and shape of the debris trail were not particularly sensitive to the internal friction angle of the debris. On the other hand, the base friction angle has a marked effect on the mobility of the debris flow. For example, if a relatively low base friction angle was adopted for the hillside below the source area, higher mobility of the debris would be resulted where the debris would travel away from the actual debris trail and to the west of the drainage line DL1.

The results of these analyses show that a combination of base friction angles of 22° for the colluvium in the primary source area and 27° for the downslope area where insitu materials were incised by the debris, can provide a reasonable fit to the debris trail. An internal friction angle of 32° was adopted for the colluvium in the source area. The best-fit parameters determined are summarised in Table C1.

The average velocity profile generated by the 3dDMM (Figure C1) indicates that the debris flow could accelerate from the primary source area as it entered the steep hillside below, with a gradient of about 43°. The debris flow reached its peak average velocity of about 11 m/s after 7 seconds of initiation, when the debris front reached approximately Chainage CH 110 (Figure C2). At about 8 second, the debris front reached the drainage line DL1 of a gentler gradient of about 33° where the debris also became partially confined and channelized. The debris flow then started to reduce in speed. The average velocity reduced further to about 6 m/s when the debris front reached the temporary steel bridge adjacent to CYC Building after 13 second. The momentum and thickness of debris at that time were calculated to be 2.5 x 10^7 kg m/s and 1.5 m respectively. At about 18 second, the debris came to a halt between Chainages CH 130 and CH 200 near the western side of CYC Building where the slope gradient is gentle (15°). The calculated maximum thickness of the debris deposited there was about 3 m.

A constant entrainment coefficient of 0.0025 was adopted which gives a reasonable fit to the overall mass balance. In the model, the debris flow increased in volume as it entrained along the debris trail, from initially 1,530 m^3 at the source area to about 2,100 m^3 when it came to rest near the CYC Building at 18 second (Figure C1). No significant amount of debris was deposited along the debris trail beside the main deposition area near CYC Building.

A summary input for the 3dDMM control spreadsheet is attached which shows the controlling parameters in the best-fit analysis.

C4. REFERENCES

Harlow, F.H. (1963). The Particle-in-cell Computing Method for Fluid Dynamics. Math. Comput. Phys., Vol. 3, pp 319-343.

Kwan, J. & Sun, H.W. (2007). Benchmarking exercise on landslide mobility modelling - runout analyses using 3dDMM. Proceedings of the 2007 International Forum on Landslide Disaster Management, Vol. II, pp 945-966.

Lo, D.O.K. (2000). Review of Natural Terrain Landslide Debris-resisting Barrier Design. Geotechnical Engineering Office, Hong Kong, 91 p (GEO Report No. 104).

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Table C1 - Parameters Determined for Theoretical Debris Mobility Analysis

Chainage (m)	Model Type	Internal Friction Angle (deg)	Base Friction Angle (deg)
0-60	Friction	32	22
60-210	Friction	32	27

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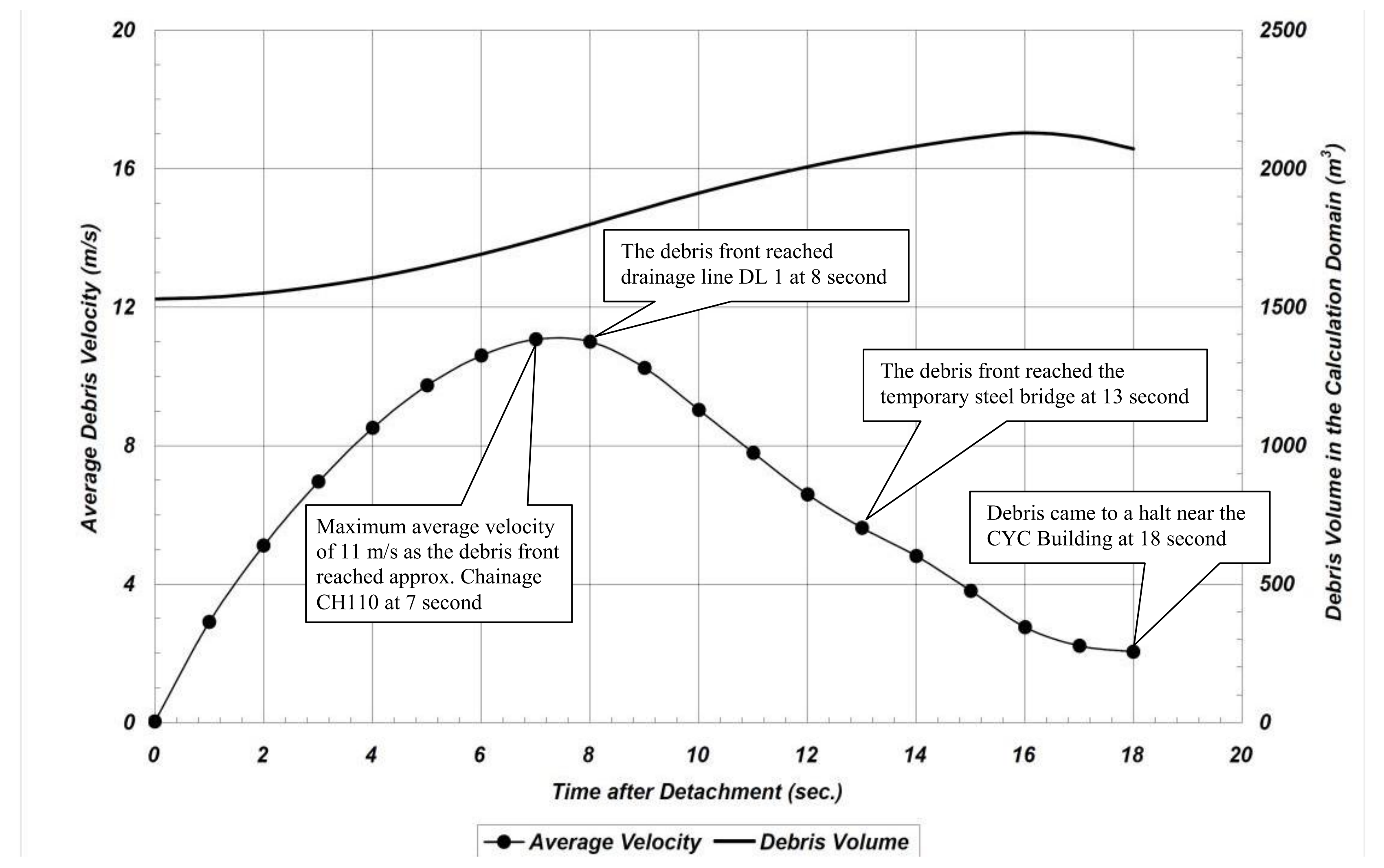

The debris front reached drainage line DL 1 at 8 second

The debris front reached the temporary steel bridge at 13 second

Maximum average velocity of 11 m/s as the debris front reached approx. Chainage CH110 at 7 second

Debris came to a halt near the CYC Building at 18 second

Note: Average velocity was calculated for the debris mass as a whole.

Figure C1 - Average Velocity and Volume of Debris versus Time

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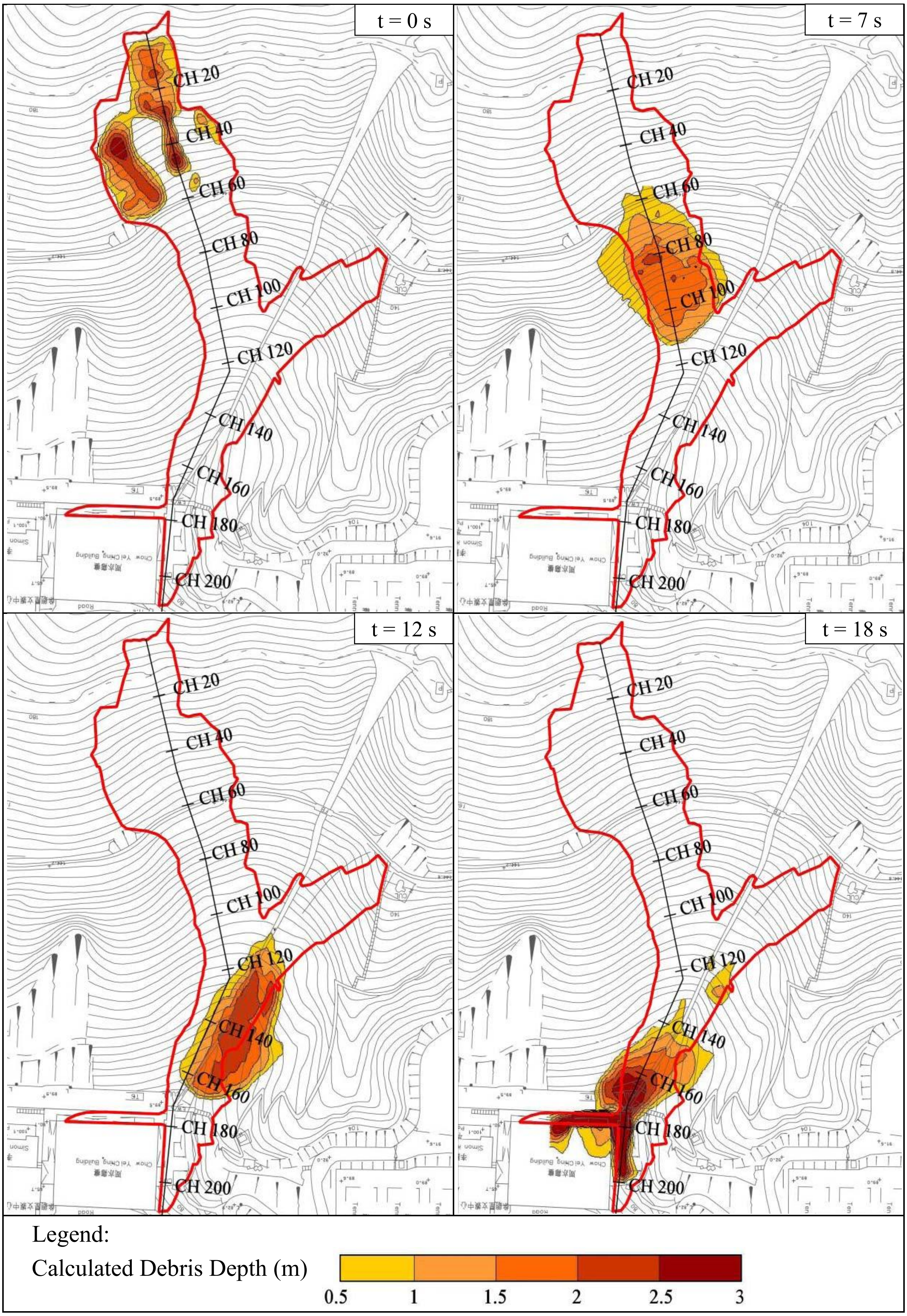

Figure C2 - Simulation Results of the 7 June 2008 Landslide

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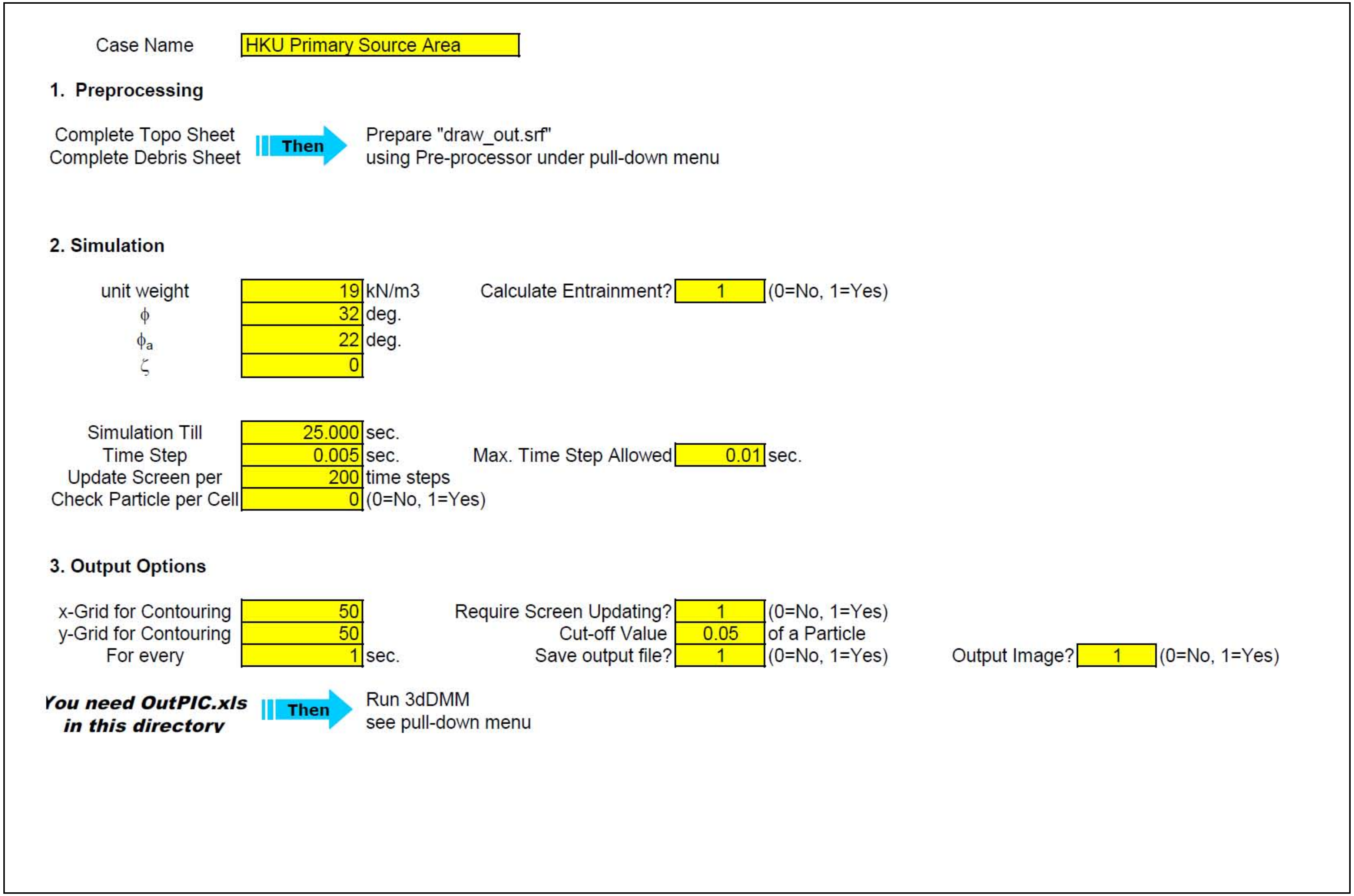
3dDMM INPUT



Case Name: HKU Primary Source Area

1. Preprocessing

Complete Topo Sheet
Complete Debris Sheet

Prepare "draw_out.srf"
using Pre-processor under pull-down menu

2. Simulation

unit weight: 19 kN/m3
ϕ: 32 deg.
ϕ_a: 22 deg.
ζ: 0

Calculate Entrainment?: 1 (0=No, 1=Yes)

Simulation Till: 25.000 sec.
Time Step: 0.005 sec.
Update Screen per: 200 time steps
Check Particle per Cell: 0 (0=No, 1=Yes)

Max. Time Step Allowed: 0.01 sec.

3. Output Options

x-Grid for Contouring: 50
y-Grid for Contouring: 50
For every: 1 sec.

Require Screen Updating?: 1 (0=No, 1=Yes)
Cut-off Value: 0.05 of a Particle
Save output file?: 1 (0=No, 1=Yes)
Output Image?: 1 (0=No, 1=Yes)

You need OutPIC.xls in this directory

Run 3dDMM
see pull-down menu

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GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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