REVIEW STUDY OF THE 7 JUNE 2008 LANDSLIDE ON SLOPE NO. 11NE-A/C351 AND THE NATURAL HILLSIDE ABOVE SHATIN PASS ROAD, TSZ WAN SHAN

GEO REPORT No. 302

AECOM Asia Company 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 4/2010 produced in August 2010

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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.

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H.N. Wong
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November 2014

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FOREWORD

This report presents the findings of a review study of a landslide incident (Incident No. 2008/06/0170) that occurred on slope No. 11NE-A/C351 and the uphill natural terrain, above Shatin Pass Road in Tsz Wan Shan. The landslide occurred sometime before noon on 7 June 2008, during which the Landslip Warning and Black Rainstorm Warning were in force. The landslide involved an open hillslope failure with a total displaced volume of about 3,500 m^3. Majority of the landslide debris was deposited on Shatin Pass Road and the hillside below. About 850 m^3 of the debris entered an ephemeral drainage line and developed into a channelised debris flow. The debris was not particularly mobile, and subsequently entered a relatively open and gently inclined primary drainage line with an overall runout distance of about 280 m. However subsequent outwash actions resulted in inundation and flooding of Tsz Ching Estate some 550 m downstream in three occasions after the landslide. The incident did not cause any casualties.

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes and process of the landslide. The scope of the study comprised desk study, site reconnaissance, ground investigation and engineering geological mapping. Recommendations for follow-up actions are presented separately.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2008 and 2009, for the Geotechnical Engineering Office, 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 AECOM Asia Company Limited.

Mr. Fred H. Y. Ng
Project Director
AECOM Asia Company 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

Shortly before noon of 7 June 2008, a landslide (Incident No. 2008/06/0170) occurred above Shatin Pass Road, which is a minor access road overlooking a public housing estate, Tsz Ching Estate in Tsz Wan Shan (Figure 1) some 550 m away at the toe of the hillside. The Landslip Warning was in force at that time, and the Black Rainstorm Warning was in effect from 6:40 am to 11:00 am.

The landslide involved the western portion of a registered cut slope No. 11NE-A/C351 and the natural hillside above, with a total displaced volume (terminology after Cruden & Varnes, 1996) of about 3,500 m³ (Plates 1 and 2). Majority of the debris was deposited on the hillside and some in the primary drainage line. Another minor landslide with a failure volume of about 6 m³ (Secondary landslide, Figure 1) occurred on the middle portion of slope No. 11NE-A/C351, which was also reported in the incident. This landslide investigation report focuses on the larger landslide.

Subsequent water flow in the primary drainage line washed a large amount of fines and cobbles downstream, inundating an access road and open area behind Ching Tai House, Tsz Ching Estate in three other occasions after the 7 June 2008 landslide (Figure 2). There was no reported casualty due to the June 2008 incident.

Following the June 2008 incident, AECOM Asia Company Limited (AECOM), the Landslide Investigation Consultants for Kowloon and the New Territories in 2008 and 2009, carried out a review 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 and process of the landslide. The scope of the study comprised desk study, site reconnaissance, ground investigation and engineering geological mapping. Recommendations for follow-up actions are presented separately.

2. DESCRIPTION OF THE SITE

The 7 June 2008 landslide involved part of slope No. 11NE-A/C351, above Shatin Pass Road and a large area of the hillside above (Plate 3). The cut slope is very steep with a slope angle of about 70°. At the location of the failure, the slope is up to 10 m high and covered with shotcrete.

The hillside above Shatin Pass Road is mostly vegetated with grass and shrubs, and inclined at about 40°, with a catchment area of about 4,500 m² above the 7 June 2008 landslide (Figure 2). The top of the catchment has an elevation of about 440 mPD.

A number of poorly-defined ephemeral drainage lines are present within the hillside above and below Shatin Pass Road, near the 7 June 2008 landslide source area. The primary drainage line of the catchment begins some 110 m to the east of the landslide, trending southwest along a fault line (Figure 3). Some ephemeral drainage lines typically trending south or southeast intercept the primary drainage line within the central and lower portions of the hillside (Figure 4). The lower section of the primary drainage line is lined with stone

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pitching, forming a trapezoidal channel. Another prominent drainage line intercepts the primary drainage line near its outlet, above cut slope No. 11NE-A/C300 (Figures 2 and 4). Both drainage lines then discharge to a 3 m wide cascade channel, which connects to a 3 m wide × 6 m long × 4 m (maximum) deep culvert behind Ching Tai House, Tsz Ching Estate (Figure 2). Surface runoff from slope No. 11NE-A/C300 is also collected by the cascade via the 300 mm wide U-channel along the crest and toe of the slope.

The hillside catchment related to the primary drainage line, covering the hillside above Shatin Pass Road and that below, measures about 350 m wide and 540 m long with a total plan area of about 130,000 m². The toe of the hillside encroaches on Tsz Ching Estate at an elevation of about 120 mPD.

3. THE 7 JUNE 2008 LANDSLIDE

The 7 June 2008 landslide was first observed by the security officer of Tsz Ching Estate at 12:05 pm. The landslide involved the western portion of cut slope No. 11NE-A/C351 and the natural terrain above. The failure volume was about 3,500 m³, of which about 1,500 m³ came to rest on Shatin Pass Road. The remaining (about 2,000 m³) continued downslope, with about 1,200 m³ travelled as debris avalanche and deposited over a large area of the hillside below Shatin Pass Road. The rest travelled along an ephemeral drainage line (labelled DF1, Figure 2) below the road (Plate 1).

Following the 7 June 2008 landslide, subsequent outwash actions carried a large volume of fines and cobbles downstream in the primary drainage line of the catchment. The outwash materials piled up behind the rock trap above the inlet to the cascade channel at slope No. 11NE-A/C300 (Plate 4). The blockage would have resulted in an overflow (Plate 5), bringing a large amount of debris over the rock trap into the cascade channel and subsequently blocking the culvert below (Plate 7). In addition, the blockage would have caused an overland flow, bringing materials and muddy water downslope toward Ching Tai House and inundating the access road and open area behind Ching Tai House (Plates 6 and 7). A similar problem was also reported following the rainstorms on 13-14 June and 12 July 2008 (Plates 8 to 12). According to information provided by Housing Department (HD), a total of some 800 m³ of outwash materials comprising mainly fines with some cobbles were deposited on the open area behind Ching Tai House between 7 June and July 2008 (Appendix C). HD is not aware of any serious flooding incidents in the area prior to the June 2008 event.

The emergency repair works for the landslide was carried out by Highways Department (HyD). The works comprised removing about 1,500 m³ of debris from Shatin Pass Road, and installing soil nails and raking drains at the landslide source area. The works were completed in August 2008 (Plate 13).

Improvement to the drainage channels within the public housing estate were carried out by HD. The works included clearing the blockage in the drainage channels within the housing estate. Additional fences were also erected on top of the rock trap (Plate 14) to minimise the risk of overtopping.

Drainage Services Department (DSD) also carried out remedial works to the lower portion of the primary drainage line. The works included removal of loose boulders and

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rock, provision of sedimentation steps (Plate 15), shotcreting and realigning the channel.

According to the information supplied by the Water Supplies Department (WSD), a 100 mm diameter fresh water main running along the outer edge of Shatin Pass Road was not damaged as a result of the incident. However, part of a slope toe 225 mm U-channel on Shatin Pass Road (Plate 16), a steel access ladder (Plate 17) and a lamp post (Plate 18) at the western boundary of the failed cut slope, were destroyed. In addition, a temple located near the outlet of the primary drainage line was temporarily evacuated (Figure 2, Plate 31).

4. MAINTENANCE RESPONSIBILITY AND LAND STATUS

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (LandsD), slope No. 11NE-A/C351 falls within Government land and the maintenance responsibility of the slope rests with the HyD. The hillside above is on unallocated Government land, under the management of LandsD (Figure 2).

5 SITE HISTORY AND PAST INSTABILITIES

5.1 General

The history of the study area has been determined from an interpretation of the available aerial photographs together with a review of relevant documentary information and site observations. Detailed observations from the aerial photograph interpretation (API) are presented in Appendix A, and the salient observations are given below.

5.2 Site History

Shatin Pass Road and the associated roadside cut slopes (including slope No. 11NE-D/C351) are visible in the earliest available aerial photograph (1945). It is suspected that the road was constructed by the British Army between 1939 and 1941 with minimal geotechnical engineering input, as part of the construction of the “Gin Drinker’s Line” (a military defensive line).

The 1945 photographs also show pockets of possibly fill materials on the downhill side of Shatin Pass Road (Figure A1 and Plate A2).

An unlined drainage channel or ditch, located about 5 to 10 m above the crest of the failed slope No. 11NE-D/C351, is visible in the 1963 aerial photographs (Figure A1 and Plate A4). Similar unlined drainage channels are also visible above many of the slopes along Shatin Pass Road. The alignment of the drainage ditches is broadly parallel to the crest of the cut slopes formed along Shatin Pass Road. Two recent landslides that occurred right below the drainage ditch (labelled 59A and 93A in Figure 4) on the failed slope are identified (see Section 5.3).

By 1963, site formation works had commenced for Tsz Ching Estate; by 1967 construction of the estate appears to be complete.

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In the 1983 aerial photographs, upgrading works on the man-made slopes above Tsz Ching Estate was being undertaken. Improvement works on the lower part of the primary drainage line were also observed.

Sometime between 1996 and 1998 the western end of slope No. 11NE-A/C351 was shotcreted (Plates 20 and A8), together with many other slopes along Shatin Pass Road (Figure A1). The shotcrete extended above the slope boundary and possibly reached the unlined drainage ditch described above (Plate A8). The lateral extent of the shotcreted area on the eastern side matches closely with that of the 7 June 2008 landslide.

Between 1996 and 1999, the original Tsz Ching Estate was demolished and a new estate was constructed. The redevelopment of the estate involved significant alteration to the cut slopes located at the toe of the catchment. At the same time the streamcourses located above these slopes (i.e. the lower portion of the primary drainage line) were lined with granite blocks and the cascade in-between the cut slopes as well as the culvert at the bottom were constructed.

The temple located adjacent to the primary drainage line in the lower part of the landslide catchment was first observed in 2005. However, the area is densely vegetated and the temple could have been constructed earlier.

The landslide catchment was affected by a series of hillfires, one of which (in 2005) encroached onto the crown of the 7 June 2008 landslide. The approximate extents of these hillfires are shown on Figure A1.

5.3 Past Instability

The GEO's landslide database has recorded one incident in the vicinity of the 7 June 2008 landslide. Other possible instabilities have been identified based on the interpretation of the geomorphology and aerial photographs, as shown in Figure 4. The Enhanced Natural Terrain Landslide Inventory (ENTLI) and GEO's Large Landslide Database (Scott Wilson, 1999) do not record any landslides at the location of the 7 June 2008 landslide. The past instabilities relevant to the 7 June 2008 landslide are discussed in detail below.

The 1945 aerial photograph shows one relict[1] landslide on the hillside at a location directly above the western scarp of the 7 June 2008 landslide (Figure 4). In addition, many relict landslides in the form of poorly defined depressions can be identified below convex breaks-in-slopes and at the heads of some ephemeral drainage lines in the nearby area (Figure A3).

The 1959 aerial photographs show two landslides (labelled 59A and 59B on Figure 4) at the western end of slope No. 11NE-A/C351. Landslide No. 59A is located within the 7 June 2008 landslide. The main scarp of the failure extends above the cut slope to the unlined drainage ditch above (Plate A4). Another failure is also visible some 30 m southeast of the 7 June 2008 landslide, and is located on the hillside below Shatin Pass Road (labelled 59C on Figure 4).

[1] Relict landslides are those that occurred earlier than the time-scale of the available aerial photographs (i.e. pre-1945).

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In the 1964 aerial photograph a minor failure is visible within the pocket of possibly fill materials below the 7 June 2008 landslide (labelled 64A on Figure 4). The debris entered the ephemeral drainage line DF1, with a runout distance of about 10 m. The debris flow resulting from the 7 June 2008 landslide occurred along this ephemeral drainage line, which is referred to as "CDF1" in Figure 5.

Landslide Incident No. K89/5/109 (Plate A7) was observed on the 1989 aerial photographs and labelled as 89B on Figure 4. This incident occurred adjacent to the 7 June 2008 landslide (Plates 19 and 20). The failure volume was about 15 m^3 based on the incident record.

Another minor failure was observed within the source area of the 7 June 2008 landslide on the 1993 aerial photograph and is labelled 93A on Figure 4. The scarp of the failure appeared to have terminated along the unlined drainage ditch above the cut slope.

In summary, relict landslides are not uncommon on the catchment above the Shatin Pass Road. The construction of the road and the associated cut slopes prior to 1945 appeared to have worsened the hillside stability, as evidenced by the numerous recent[2] landslides occurring within the roadside cut slopes afterward (Figure 4).

6. PREVIOUS SLOPE INSPECTIONS

Slope No. 11NE-A/C351 is classified as "C1" feature (i.e. formed or substantially modified before 30 June 1978) under the GEO's Systematic Inspection of Features in the Territory (SIFT) exercise.

The slope was inspected in October 1996 by the consultants under GEO's Systematic Identification and Registration of Slopes in the Territory (SIRST) project. Heavy seepages were observed from several rock joints at about mid-height of the slope. Sign of distress such as "surface loosening" was also noted.

The slope has been subjected to routine maintenance inspections (RMI) and Engineer Inspections (EI) since 2001 (Plates 16 and 17). Potential unstable boulders and localized fractured zone were observed in several occasions. However, no seepage was noted, probably due to the presence of the newly applied shotcrete (Section 5.2). Available records show that routine maintenance works as well as preventive maintenance works including provision of wire mesh on the rock slope portion, shotcreting, and installation of pattern rock dowels were carried out after the inspections.

No inspection has been carried out for the natural hillside above the slope prior to the 7 June 2008 landslide.

[2] Recent landslides are those that can be identified distinctly on aerial photographs and the time period in which the landslides occurred can also be confirmed by available aerial photographs (i.e. post-1945).

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7. POST-LANDSLIDE FIELD OBSERVATIONS

7.1 General

The landslide was inspected by AECOM on 10, 13 and 16 June 2008. Detailed field mapping was carried out in end-July 2009. The findings are shown in the plans and section in Figures 5 to 7. The field mapping report is kept in GEO file ref. No. GCLI/2/A2/54-14. Salient observations are discussed below.

7.2 Source Area

The crown of the 7 June 2008 landslide is located at about 25 m above the western end of slope No. 11NE-A/C351 (or about 35 m above Shatin Pass Road, Figures 8 and 9). The landslide involved an open hillslope failure. The failure scar measures about 30 m wide and 35 m long, with an average depth of about 5 m. The total detached volume is about 3,500 m^3. The inspection on 10 June 2008 at Shatin Pass Road observed that the debris appeared relatively dry, containing a 2 to 3 m thick layer of mainly cobbles and boulders (Plates 21 and 22) overlying another layer of fine debris.

On the western half of the scar, an adversely orientated relict sheeting joint (40° - 50° / 200), at about 5 to 8 m below ground, was observed on the middle and lower part of the rupture surface (Figure 8, Plate 21). A persistent quartz vein was visible along the lower section of the sheeting joint (Plate 25). An elongated depression was present at the centre of the landslide scar, exposing another sheeting joint (Plate 24). A further sheeting joint, probably a continuation of that observed on the western and middle parts, was exposed at the lower eastern side of the rupture surface (Plate 22). The main failure on 7 June 2008, likely occurred along this laterally persistent, adversely orientated relict sheeting joint.

Three possible soil pipes were observed in the upper part of the scar in the highly to completely decomposed granite (Plate 26), which may indicate the possibility of preferential sub-surface flow toward the landslide site. Dense reeds (hydrophilic vegetation), which requires good supply of water from the ground, are present on the area immediately above the northeast corner of the 7 June 2008 landslide (Plates 23 and 27).

7.3 Debris Flow

Of the 3,500 m^3 landslide debris, about 850 m^3 might have entered an ephemeral drainage line DF1 below Shatin Pass Road, and developed into a channelised debris flow (Figure 7, Plates 28 and 29). The upper part of the drainage line is sloping at about 30° but is not particularly incised (Figures 5 and 10, Plate 28), with a channelisation ratio[3] (CR) of about 5. Not much depletion into the colluvium substrate was observed along the channel streambed or side slope.

Further downstream at around CH60 to CH80, the channel becomes boarder and gentler with the gradient locally reduced to about 20°. About 350 m^3 debris was deposited

[3] Channelisation ratio is defined as the width to depth ratio of the cross section area in a channel occupied by a pulse of landslide debris (Ng *et al*., 2002).

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along this part of the drainage line (Plate 30). Some debris deposited on the eastern spur of the channel was washed down along a poorly defined channel (or topographical depression, i.e. DT2) near CH80 (Figure 5). Minimal debris deposition was observed further along the drainage line between CH80 to CH110 where the channel bed is on rock outcrop (Plate 31) with a gradient of about 45°.

From CH110 to CH170, another 150 m^3 of debris was deposited mainly on the eastern flank of the ephemeral drainage line (Figure 10, Plates 32 and 33) as the channel gradient reduces to about 25°.

At about CH170, the drainage line reached the edge of a series of rock steps from a pegmatite intrusion (Plate 34). At this point, the drainage line turns abruptly from southwest to southeast (Plate 35). The active volume was about 350 m^3. Deposits of material oversplashed from the passage of the debris flow were noted at this location. However, no super-elevated deposits were observed (Plate 36). Beyond this point, the debris dropped abruptly over the rocky outcrop before entering the primary drainage line at about CH230, with an angle of entry of about 70° (Plate 29). Debris deposition between CH180 and CH230 was generally minimal.

The debris entered the primary drainage line at CH230, where the channel is open and about 7 to 10 m wide, with a CR ratio over 7. It was estimated that about 200 m^3 of the debris was deposited at CH230. The remaining 150 m^3 would have travelled further downstream before terminating at about CH280, where the channel gradient is reduced to about 18°. The location of the distal end is consistent with field observations as stated below. The surrounding vegetation below CH280 was not damaged. Also, an existing steel water pipe that ran along the primary drainage line was only damaged by the landslide at locations upstream of CH280 (Plate 37), whereas no damage was observed on the pipe downstream of CH280 (Plate 38).

The debris at the distal end comprised a 4 m section of the steel access ladder which came from slope No. 11NE-A/C351 (Plate 39). According to HyD, the steel access ladder that was destroyed during the 7 June 2008 landslide was constructed along the western end of slope No. 11NE-A/C351 (Plate 17) sometimes before 2006.

7.4 Debris Deposited in the Primary Drainage Line

About 550 m^3 of debris from the 7 June 2008 landslide may have been deposited along the primary drainage line. Of the 550 m^3 debris, about 350 m^3 could have reached the primary drainage line as a result of the debris flow through the ephemeral drainage line DF1 and the rest via poorly-defined ephemeral drainage lines (i.e. debris trails Nos. DT3 and DT4, Figure 5 and Plate 40) on the hillside below Shatin Pass Road. Based on post-failure observation, the main pulse of the debris flow did not travel far. It terminated at CH280 and did not reach the outlet of the primary drainage line. Similarly, the debris that entered the primary drainage line viz. debris trails Nos. DT3 and DT4 did not appear to have gone much further. Two pockets of debris deposition, each of about 100 m^3, were observed at about CH150 and CH170 of the primary drainage line (Figure 5).

Following the 7 June 2008 rainstorm and three other rainstorms in mid- and late June

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and mid-July, water flow in the primary drainage line had outwashed a total of about 800 m³ of fines and cobbles downstream, inundating an access road and open area behind Ching Tai House, Tsz Ching Estate. Some of the materials may have come from the debris of the 7 June 2008 landslide, and other from existing loose materials that may be present in the drainage line prior to the June 2008 event.

8. POST-LANDSLIDE GROUND EXPLORATION

8.1 Photogrammetric Survey

The failure volume of the 7 June 2008 landslide was found to be about 3,500 m³, based on the difference in ground profiles before and after the failure. The pre-failure ground profile is estimated by photogrammetric analysis of 2007 aerial photographs. The post-failure ground profile is determined by conventional topographic survey. Further details are given in Appendix B.

8.2 Ground Investigation

No previous ground investigation (GI) information at the landslide site is available. Therefore, a post-landslide GI was undertaken to assess the ground conditions (Figure 11 and Plate 41). The GI comprised three trial pits (Nos. TP1 to TP3), two slope strips (Nos. SS1 and SS2) and a small area of vegetation clearance. The works were carried out by Driltech Ground Engineering Ltd. between November 2009 and January 2010. The locations of the GI stations are shown in Figure 11 and the available logs are presented in Appendix D.

Trial pits Nos. TP1 to TP3 were excavated on the hillside to the immediate west of the landslide scar. Trial pits Nos. TP1 and TP2 encountered up to 0.75 m thick colluvium overlying moderately decomposed granite (MDG). Trial pit No. TP3 encountered 0.5 m of completely to highly decomposed granite (C/HDG) overlying MDG. No relict joints with similar dipping angle and direction as the sheeting joint revealed at the base of the landslide scar were observed in the trial pits.

The two slope strips (Nos. SS1 and SS2) revealed C/HDG with occasional corestones. Accumulation of colluvium with angular cobbles and boulders is evident in the upper 7 m and 3 m in strips Nos. SS1 and SS2 respectively. No discrete shear surfaces or relict joints were observed in the strips. This may have been due to the disturbance to the landslide site as a result of carrying out the emergency repair works including soil nailing and shotcreting works.

Vegetation clearance carried out along the crest of slope No. 11NE-A/C351, to the immediate east of the landslide area, revealed a 0.7 m to 1 m sub-vertical to vertical drop in topography (Plate 42). This feature was filled with slope washed deposits comprising soft to very soft fine material mixed with grass and shrubs. The alignment of this feature matches with that of the unlined drainage ditch identified in the API (Section 5.2).

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9. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. K07, which is located about 681 m to the southwest of the 7 June 2008 landslide location (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 by raingauge No. K07 over the month preceding the 7 June 2008 rainstorm, together with the hourly rainfall readings for the period between 5 and 7 June, 2008, are presented in Figure 12.

Within the above-mentioned period, approximately 13.3% of the rainfall readings (about 1383 nos.) in raingauge No. K07 are missing. The missing records occurred during periods of rainfall. To facilitate the analysis, the missing information has been deduced from the rainfall data recorded by nearby raingauges Nos. N42, K09 and K02 (Figure 1).

The 7 June 2008 landslide was first observed by the security officer of Tsz Ching Estate at 12:05 p.m. on 7 June 2008. Hence, for the purpose of rainfall analysis, the landslide was assumed to have occurred at noon on 7 June 2008. An analysis of the return periods for various durations of rolling rainfall recorded by raingauge No. K07, 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 4 hours was the most severe at raingauge No. K07, with a corresponding return period of about 20 years (Table 1).

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 No. K07 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 38 years for a rainfall duration of 2 hours at raingauge No. K07.

The maximum rolling rainfall for the 7 June 2008 rainstorms has been compared with the previous major rainstorms recorded by raingauge No. K07, which came into operation in March 1983 (Figure 13). The 7 June 2008 rainstorm is more severe than the previous major rainstorms for rainfall durations between 2 hours and 7 hours.

10. GEOLOGY AND GEOMORPHOLOGICAL SETTING

10.1 Geology

According to the Hong Kong Geological Survey 1:20 000 scale map series HGM 20 (GCO, 1986a & 1986b), the solid geology of the site comprises medium-grained granite intruded by a northwest-striking rhyolite dyke forming part of the western flank of the landslide (Figure 3). However, based on post-landslide observations and GI, no feldsparphyric rhyolite was observed on or near the 7 June 2008 landslide. The site is underlain by medium-grained granite, with some showing highly porphyritic texture containing phenocrysts of feldspar up to 20 mm across.

Several faults are present within the catchment (Figure 3). The nearest one is east-trending across the lower portion of the 7 June 2008 landslide. Another one runs parallel to the primary drainage line of the catchment, suggesting the alignment of the

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primary drainage line may be fault related.

In the Geotechnical Area Studies Programme (GASP) Report No. 1, Hong Kong and Kowloon (GCO, 1987) carried out by the Geotechnical Control Office (GCO, renamed GEO in 1991), the hillside where the 7 June 2008 landslide occurred was classified as a zone of general instability associated with predominantly insitu terrain.

A diagrammatic section through the 7 June 2008 landslide is given in Figure 15, which indicates that the site is mainly underlain by highly to completely decomposed granite with corestones, overlying moderately decomposed granite. The 7 June 2008 landslide appeared to have taken place within the highly to completely decomposed granite.

10.2 Geomorphological Setting

To the west of the source area, there was a prominent erosion front in the hillside (Figure A3 and Plate A4), which has retrogressively incised into the mostly saprolite covered hillside. Relict landslides, in the form of a serious of poorly defined depressions, tend to occur directly below the erosion front, probably as a result of retrogressive action in steeply-inclining terrain (Section 5.3).

To the northeast of the source area a prominent band of exposed rock, bounded by a concave break-in-slope in the southwest and a convex break-in-slope in the northeast, traverse the hillside following a northwest-southeast trend (Figure A3 and Plate 27). To both the southwest and northeast of this rock exposure numerous boulders or exhumed corestones are visible along a 10 m to 20 m wide zone either side of the outcrop. This area is interpreted as a zone of intermittent rock exposure or possibly *in situ* weathered rock with corestones (Figure A3). The presence of this band of competent rock has likely controlled the northeastern extent of the 7 June 2008 landslide.

11. DISCUSSION

11.1 Landslide Events

The 7 June 2008 landslide involved an open hillside failure. It occurred at a roadside cut slope No. 11NE-A/C351 and the uphill natural terrain, above Shatin Pass Road. About 3,500 m^3 of materials were detached. The debris would have surcharged the road and resulted in the failure of a pocket of fill materials on the downslope side of the road (Figures 14 and 15c). This subsequent failure involved about 50 m^3 of fill materials (Plate 43).

Most of the debris from the source area was deposited on Shatin Pass Road. A total of about 850 m^3 might have entered an ephemeral drainage line DF1 below the road and developed into a channelized debris flow. There was little entrainment along DF1 and the process of debris flow involved mainly deposition of materials. About 350 m^3 of debris could have reached the primary drainage line at CH230. The debris flow travelled further downstream for a short distance before terminating at CH280 (see Section 7.3 for details of the postulated debris flow process).

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Apart from the above, another 200 m^3 of debris could have reached the primary drainage line via the other poorly defined ephemeral lines (debris trails DT3 and DT4, see Figure 5). The total amount of debris reaching the primary drainage line was thus about 550 m^3.

Loosened boulders above the oversteepened area at the crest of the landslide scar might have subsequently detached and deposited on the surface of the landslide debris (Figures 14 and 15d). This may have explained the observed boulderly material (with an estimated volume of about 100 m^3) overlying the main body of fine debris deposits at Shatin Pass Road.

Between 13 and 14 June 2008, a further minor failure occurred at the northeast corner of the landslide scar (Plates 22 and 23), where the ground profile may have been oversteepened following the 7 June 2008 landslide event (Figures 14 and 15d). This minor failure involved a volume of about 20 m^3. The heavy rainstorm on 13 and 14 June 2008 might also have contributed to this subsequent failure.

11.2 Possible Causes of Failure

The 7 June 2008 landslide was rain-induced, as it occurred following a heavy rainstorm which is more severe than previous major rainstorms. Slope saturation and build-up of transient water pressures as a result of infiltration, water ingress from the unlined drainage ditch (Section 8.2) and possible sub-surface seepage flows (Section 10.2) may have triggered the failure during heavy rainfall. The presence of soil pipes at the landslide scar would have promoted sub-surface water flow to the landslide site (Section 7.2). The presence of hydrophilic vegetation at and above the landslide scar is probably an indication of water concentration. Seepages observed in previous inspection (Section 6) at the roadside cut slope (No. 11NE-A/C351) is also evident of sub-surface seepage flows. Covering the slope surface by a hard surface in late 1990s might have impeded sub-surface seepage flows (Section 6) and locally increased the groundwater pressure in the groundmass.

The steep hillside is subject to degradation, which is evidenced by the presence of many relict and recent landslides (Section 5.3). The presence of the laterally persistent, adversely orientated relict sheeting joint within the highly to completely decomposed granite, would have contributed to the hillside instability, including the 7 June 2008 failure (Section 7.2). The relict sheeting joint probably controlled part of the failure depth, above which perched water pressure might have been developed locally in areas confined by the persistence quartz vein. The formation of a large, steep unsupported cut into the hillside for the construction of Shatin Pass Road before 1945 would have further destabilised the hillside.

The effect of the 2005 hillfire (Section 5.2) on the 7 June 2008 landslide has also been considered. Aerial photographs in 2007 show that the area affected by the 2005 hillfire have been covered by dense vegetation. Hence there is no strong evidence indicating that the hillfire had a bearing on the 7 June 2008 failure.

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11.3 Scale of Failure

The 7 June 2008 landslide involved a large-scale failure with a failure volume of about 3,500 m^3. The landslide scar measured about 30 m wide, 35 m long and up to 8.5 m deep. The failure was not particularly spatially extensive but was relatively deep, compared with that of a typical natural terrain failure that usually occurs within 2 to 3 m of the surface mantle. The depth of failure was probably dictated by the location of the laterally persistent, adversely orientated relict sheeting joint, within the completely to highly decomposed granite (Figure 15).

11.4 Debris Mobility

The runout distance of the debris flow is up to 280 m, with a travel angle[4] of about 35°. Based on the classification system of Wong (2006), the debris mobility is classified as "Zone 2", and is relatively low (Figure 16). The debris flow had a maximum active volume of about 850 m^3, and was not mobile compared with events of similar scale in Hong Kong (Figure 17).

Post-landslide field observations indicated that the debris was relatively dry (Section 7.2), which is consistent with the limited catchment area above the landslide source area. The debris probably travelled at a relatively low velocity as evidenced by the lack of super-elevated deposits along the main debris trail at CH230 (Section 7.3). The 6 m wide Shatin Pass Road immediately below the landslide scar would have also aided to reduce the debris mobility.

Although some 850 m^3 debris entered the ephemeral drainage line DF1 below the landslide source area and developed into a debris flow, the drainage line is not well-defined with a zig-zag path that may have limited the debris mobility. Some of the debris subsequently entered the primary drainage line at a large angle (about 70°) and the morphology of the channel is relatively open and gently inclined, thus limiting the reach of the debris.

11.5 Outwash and Impact on Downstream Drainage Provision

Although the debris flow did not travel far along the primary drainage line, the substantial amount of surface runoff from the large catchment area after a heavy rainfall would have consequently washed out a relatively large amount of bouldery materials. Based on the catchment area and estimated depth of flow in the primary drainage line, the velocity of the flow in the primary drainage line could be up to 2 m/s at about CH500.

The outwash materials would have blocked the downstream drainage system, resulting in flooding of the area behind Ching Tai House, Tsz Ching Estate. Such a process was reactivated in subsequent rainstorms between 13 and 14 June and on 12 July 2008, again causing flooding of the area.

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[4] Travel angle is the angle of a line connecting the head of the landslide source to the distal end of the displaced mass (Cruden & Varnes, 1996).

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The theoretical capacity of the downstream drainage system at Ching Tai House is adequate to cater for the surface runoff from the 7 June 2008 rainstorm. However, the downstream provision to prevent debris from entering the drainage system appears not adequate, resulting in blockage and subsequent overflows. This incident also illustrates the potential impact of outwash debris on the existing downstream drainage system, especially for large catchments.

12. CONCLUSION

The 7 June 2008 landslide involved a large-scale failure (about 3,500 m^3). It occurred on the western side of a roadside cut slope No. 11NE-A/C351 and the uphill natural terrain, above Shatin Pass Road. The failure was probably rain-induced. Both the slope and hillside above are relatively steep and have a history of relict and recent failures. This indicates that the hillside is subject to degradation, and the formation of the unsupported cut would have further destabilised the hillside. The 7 June 2008 failure was relatively deep, probably dictated by the location of a laterally persistent, adversely orientated relict sheeting joint within the highly to completely decomposed granite.

Some of the debris entered the relatively open and gently inclined primary drainage line and developed into a CDF, with a runout distance of about 280 m before terminating within the drainage line. Continuous flow in the primary drainage line due to the large catchment area and presence of tributaries subsequently washed out a significant volume of materials downstream. The outwash materials blocked the downstream drainage system, resulting in inundation and severe flooding in Tsz Ching Estate. This incident highlighted the vulnerability of the downstream drainage provision to blockage by landslide debris and the severe subsequent impact, especially for large catchments.

This incident is an example of hillside degradation. It also illustrates: (i) the de-stabilisation effect of unsupported cut to vulnerable hillside; (ii) the ability of stream flow in large catchment in transporting materials from debris flow deposits for a considerable distance even if the debris flow is not particularly mobile; and (iii) the vulnerability of the downstream drainage provision to blockage by landslide debris and the severe subsequent impact, especially for large catchments.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. K07 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 K07 [(3)] from Evans & Yu (2001)
5 Minutes	11.0	5:55 a.m. on 7 June 2008	< 2	< 2
15 Minutes	31.0	8:45 a.m. on 7 June 2008	3	3
1 Hour	84.0	10:20 a.m. on 7 June 2008	4	8
2 Hours	165.5	10:15 a.m. on 7 June 2008	19	38
4 Hours	221.0	10:10 a.m. on 7 June 2008	20	28
12 Hours	303.5	10:50 a.m. on 7 June 2008	13	12
24 Hours	421.0	10:45 a.m. on 7 June 2008	18	23
48 Hours	443.0	10:55 a.m. on 7 June 2008	11	7
4 Days	505.0	10:55 a.m. on 7 June 2008	9	4
7 Days	566.0	10:55 a.m. on 7 June 2008	9	5
15 Days	688.5	10:55 a.m. on 7 June 2008	7	3
31 Days	769.0	10:55 a.m. on 7 June 2008	3	2

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. K07 extracted from Appendix B of Evans & Yu (2001) to assess the spatial variability of rainfall.
(4) According to the eyewitness, the landslide was first observed at about 12:05 p.m. on 7 June 2008.
(5) The nearest GEO automatic raingauge to the landslide site is raingauge No. K07 located about 681m to the southwest of the landslide site.

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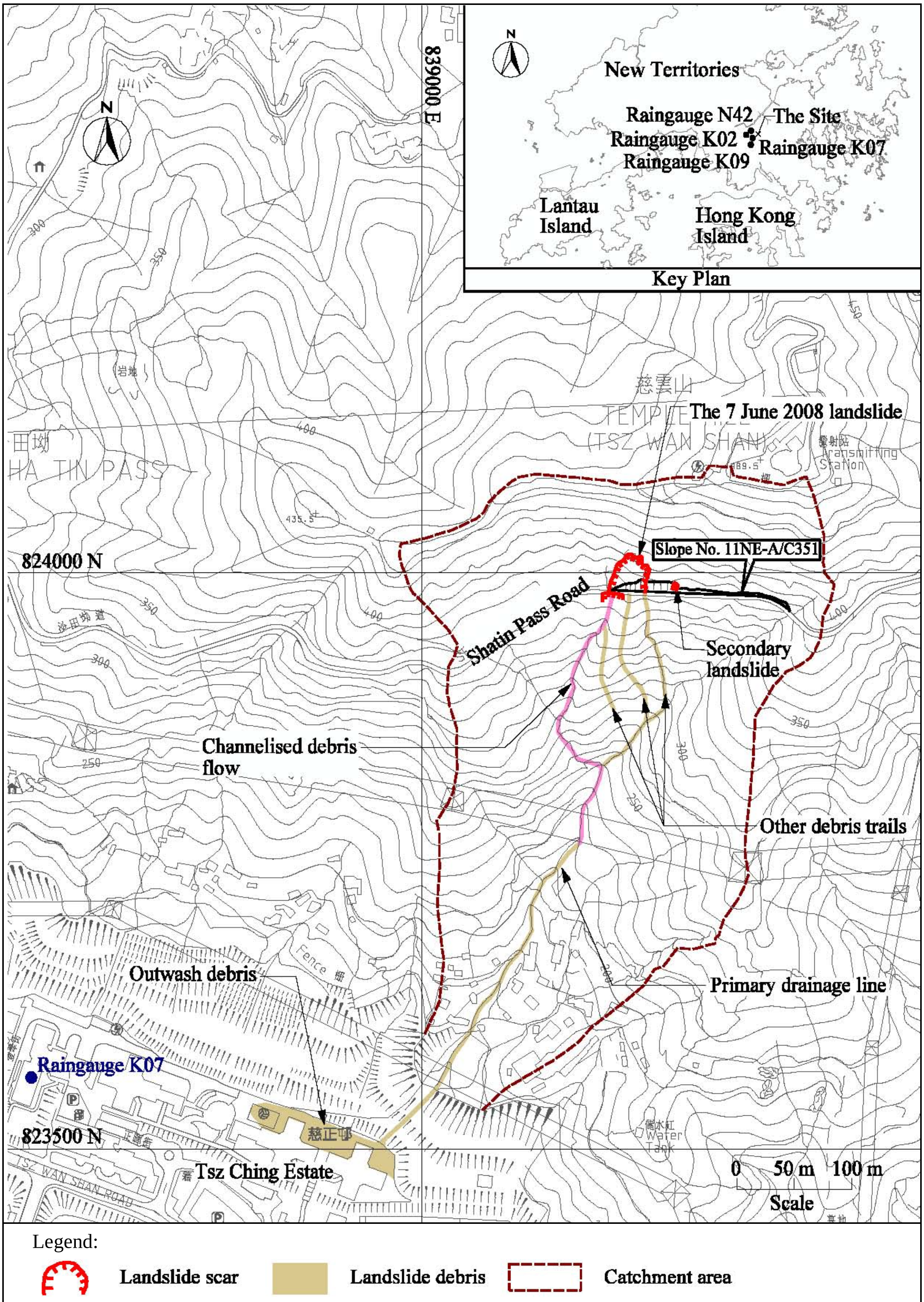

Note: Base plan is extracted from 1:5000 survey sheets Nos. 7SE-C and 11NE-A dated March 2008.

Figure 1 - Location Plan

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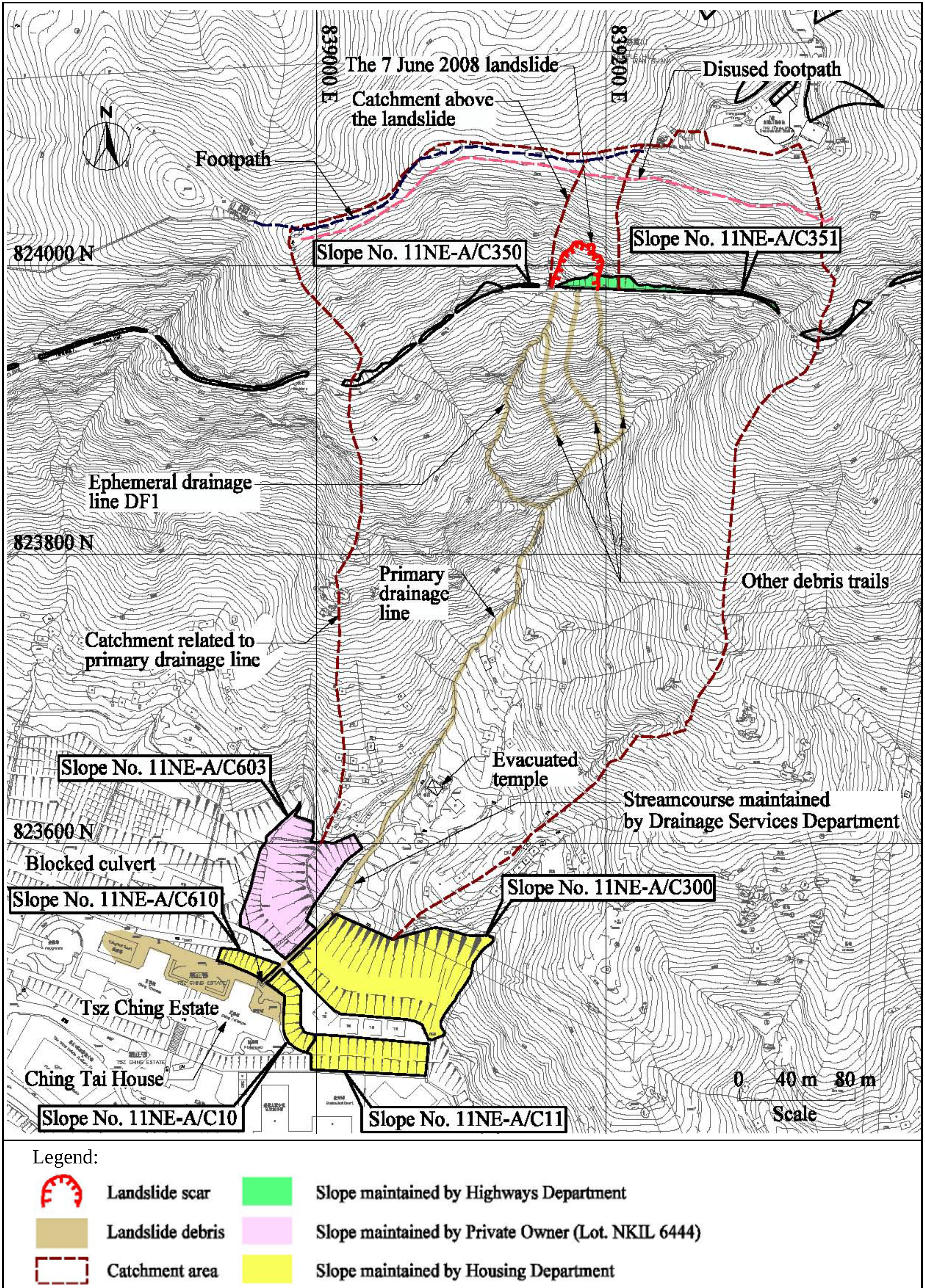

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-1B, 11NE-2A, 7SE-21D and 7SE-22C dated March 2008.

Figure 2 - Site Layout Plan

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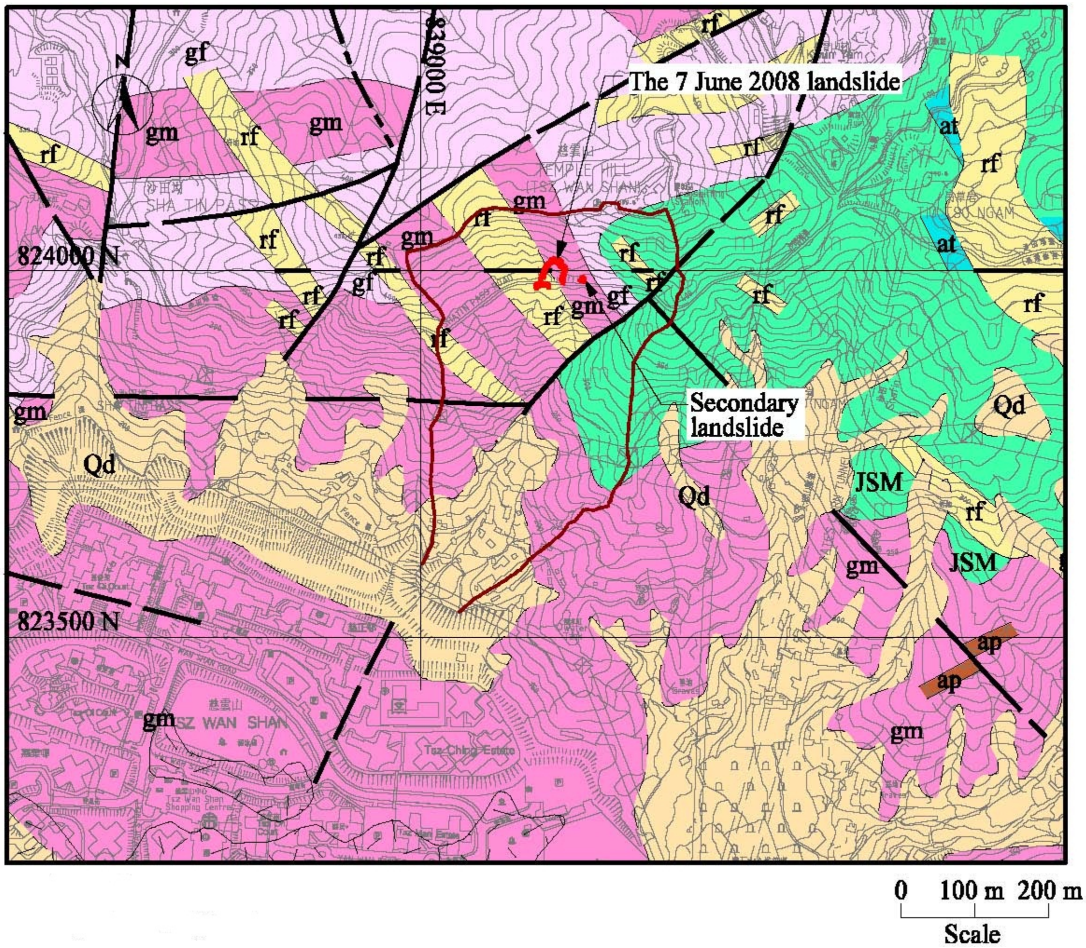

Legend:

Superficial deposits

Qd — Debris flow deposits — Unsorted sand, gravel, cobbles and boulders; clay/silt matrix

Solid geology

gf — Fine-grained granite

gm — Medium-grained granite, 2 - 6mm

rf — Feldsparphyric rhyolite

JSM — Shing Mun Formation

Fill

m m m — Hornfels

Geological lines

Photogeological lineament

Fault

Geological boundary, superficial deposits

Note: Extracted from Hong Kong Geolgical Survey, Map Series HGM 20, Sheet 7 and 11. 1:20 000 scale (GCO, 1986).

Figure 3 - Regional Geology

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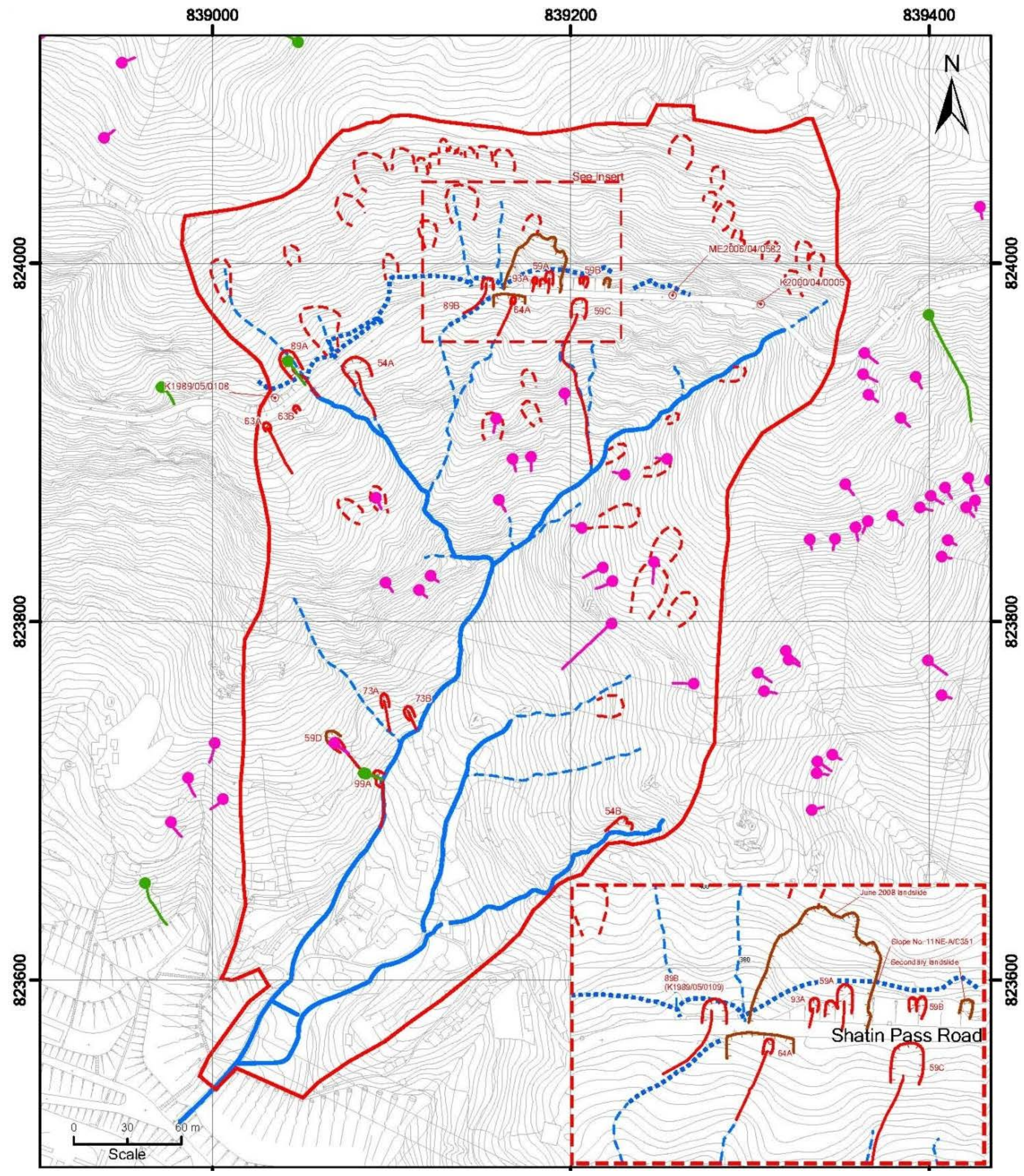

Legend:

7 June 2008 landslide scar
Recent landslide with date first observed and extent of debris trail where visible
Relict landslide scar
Landslide Incident
ENTLI recent features
ENTLI relict features

Drainage line

Drainage line
Ephemeral drainage line
Unlined drainage ditch

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE-21D, 7SE-22C, 11NE-1B and 11NE-2A dated August 2009.

Figure 4 - Drainage Lines and Past Instabilities

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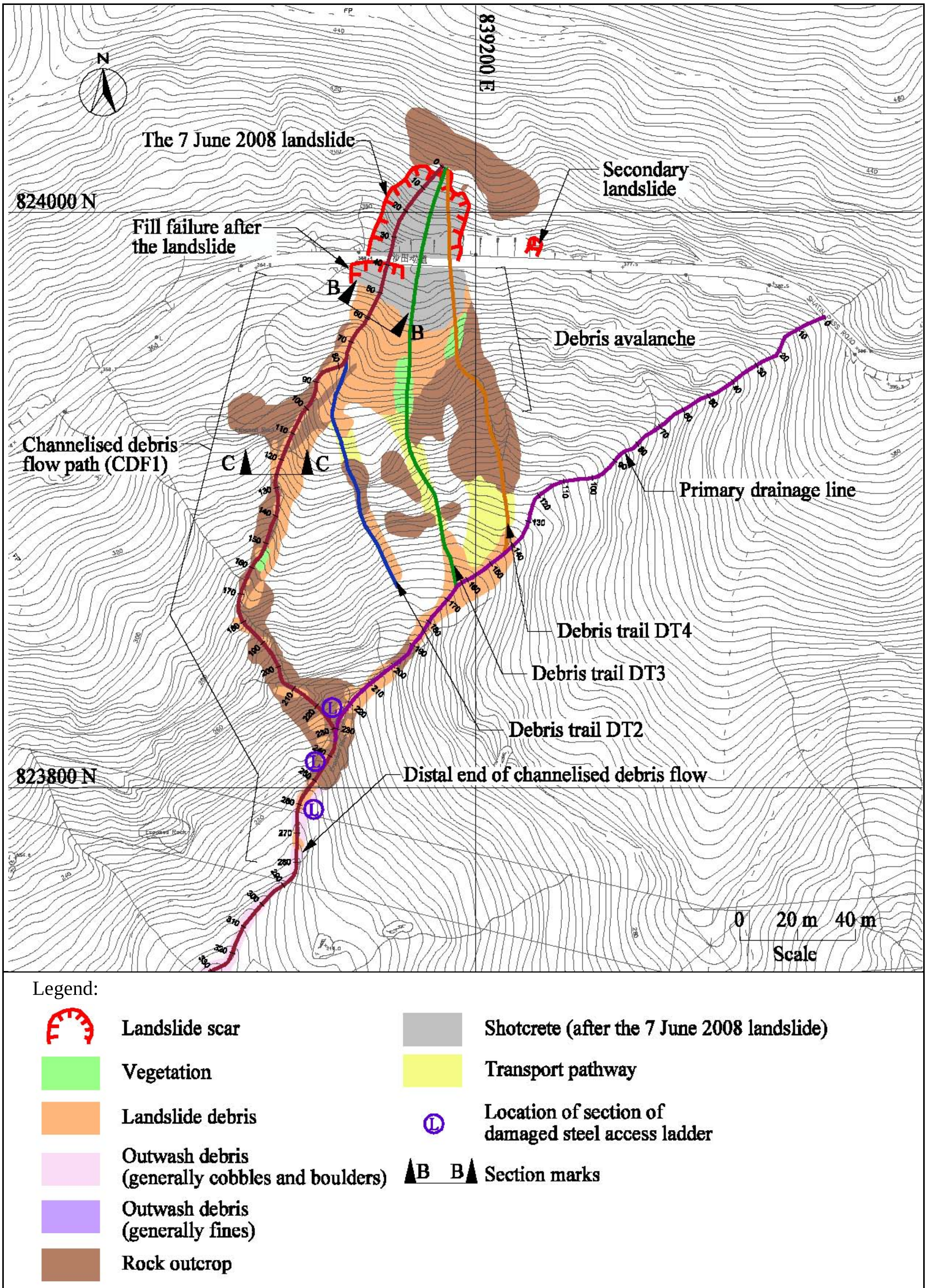

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-1B, 11NE-2A, 7SE-21D and 7SE-22C dated March 2008.

Figure 5 - Plan of Upper Debris Trail

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Legend:

- Outwash debris (generally cobbles and boulders)
- Rock outcrop
- Outwash debris (generally fines)

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-1B, 11NE-2A, 7SE-21D and 7SE-22C dated March 2008.

Figure 6 - Plan of Lower Debris Trail

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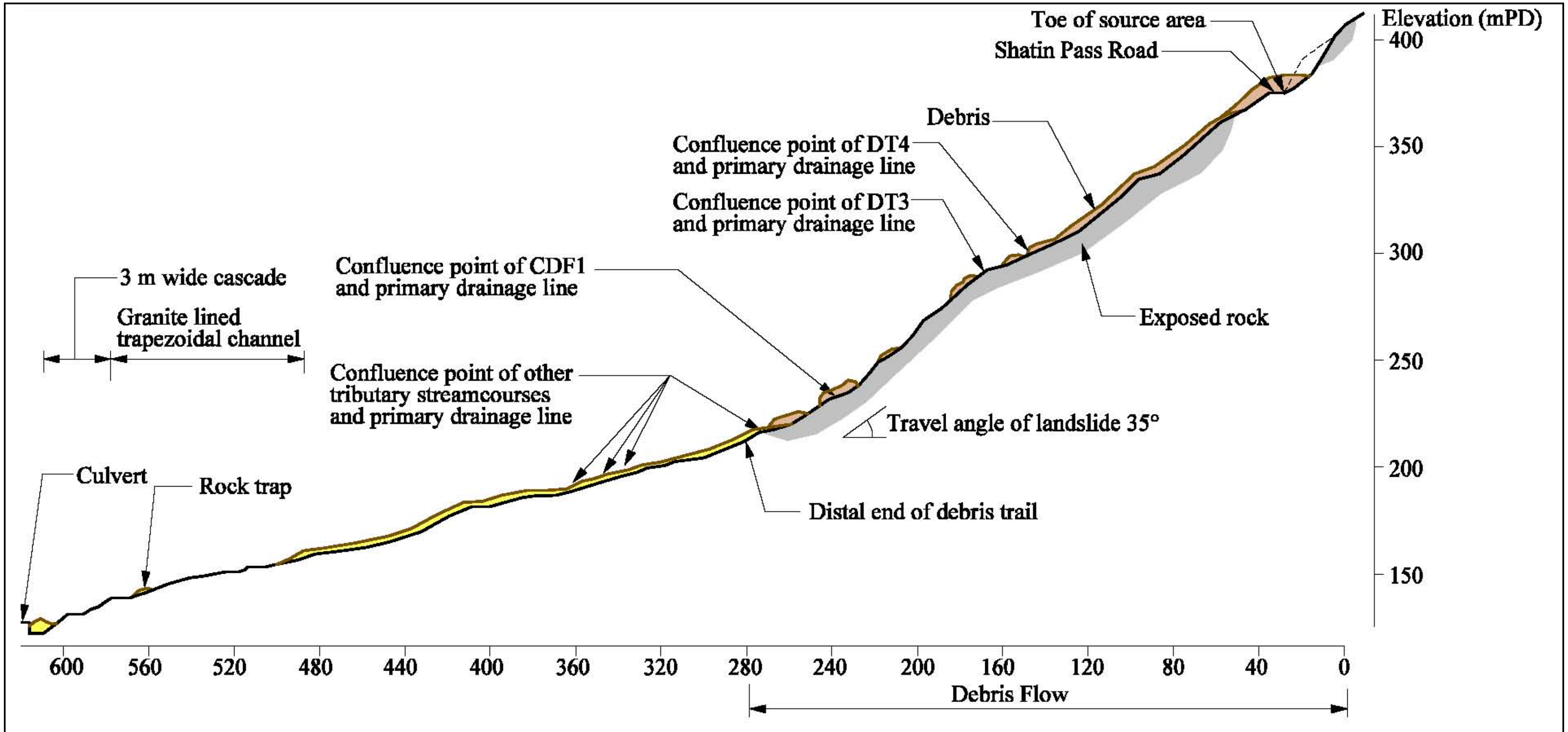

800 (bulked vlume)	50	Reworked debris/debris deposited along the lower section of primary drainage line△	150	200	150	350◇		Deposition (m^3)	CDF1
			0	150	350	500	850+	Mass Balance (m^3)*	

Legend:

- * Due to the slow velocity of the debris and the rocky streambed along most of the section of the ephemeral drainage line, entrainment due to erosion from side slopes and depletion of (colluvium substrate) pre-existing along the streambed is considered negligible along CDF1.
- \+ Include about 50 m³ fill body failure below the head of the ephemeral drainage line at Shatin Pass Road.
- ◇ Include about 50 m³ washout onto the debris trail No. DT2 at about CH 80.
- △ Pockets of debris were observed depositing near the confluence points of debris trails Nos. DT3 & DT4. It is estimated that total amount of debris reaching the primary drainage line to be 500 - 600 m³.

Figure 7- Longitudinal Section

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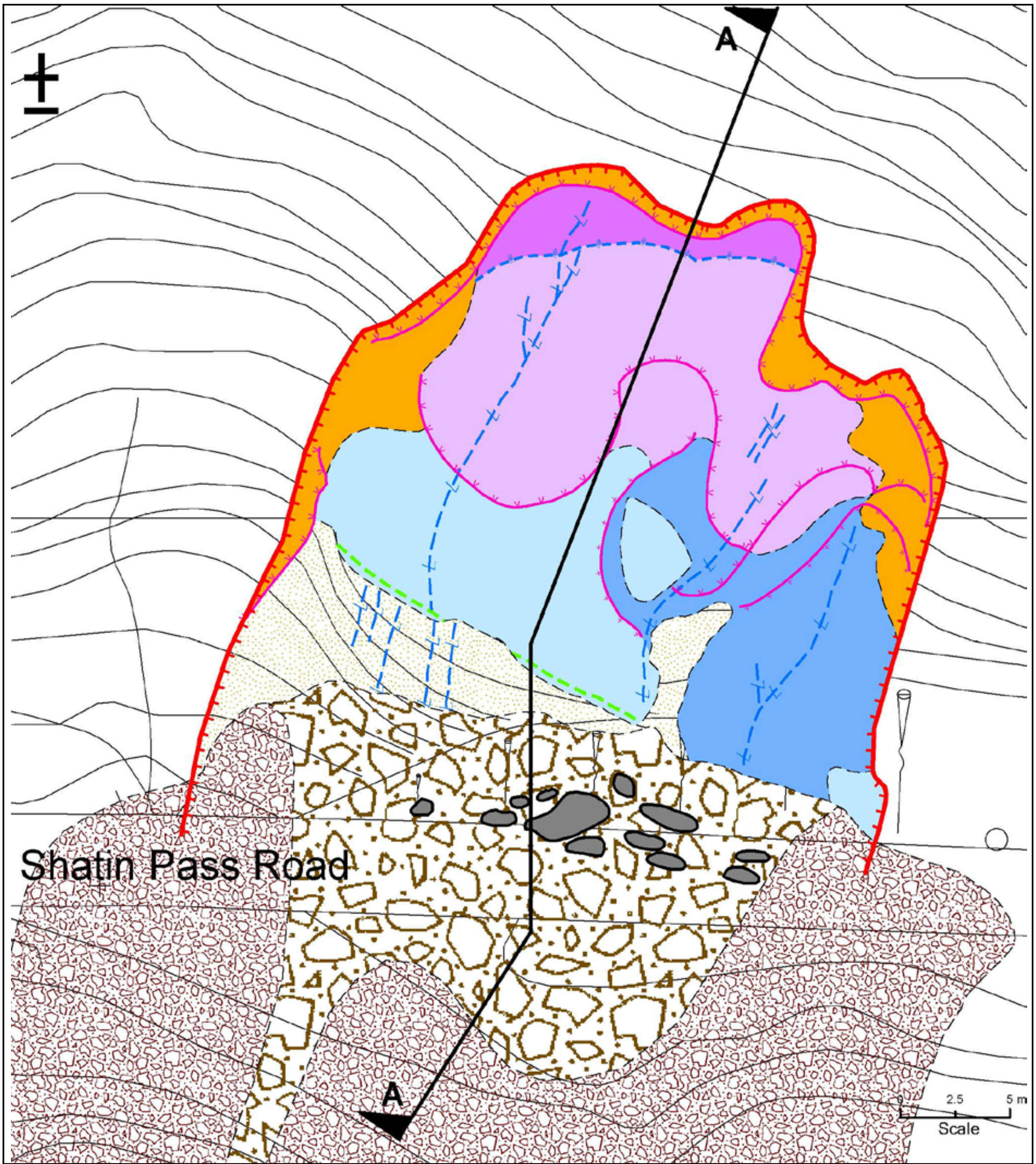

Legend:

- Main scarp
- Convex break-in-slope
- Concave break-in-slope
- Quartz vein
- Shallow erosion gullies (developed after the 13-14 June 2008 rainstorm)
- Highly and completely decomposed granite
- Joint surface with highly and completely decomposed granite
- Slightly to moderately decomposed granite corestones within highly to completely decomposed granite (PW 30/50)
- Slightly to moderately decomposed granite
- Colluvium
- Landslide debris (fine thin veneer)
- Landslide debris (many boulders)
- Landslide debris (generally fine)

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE-22C and 11NE-2A dated August 2009.

Figure 8 - Plan of Source Area

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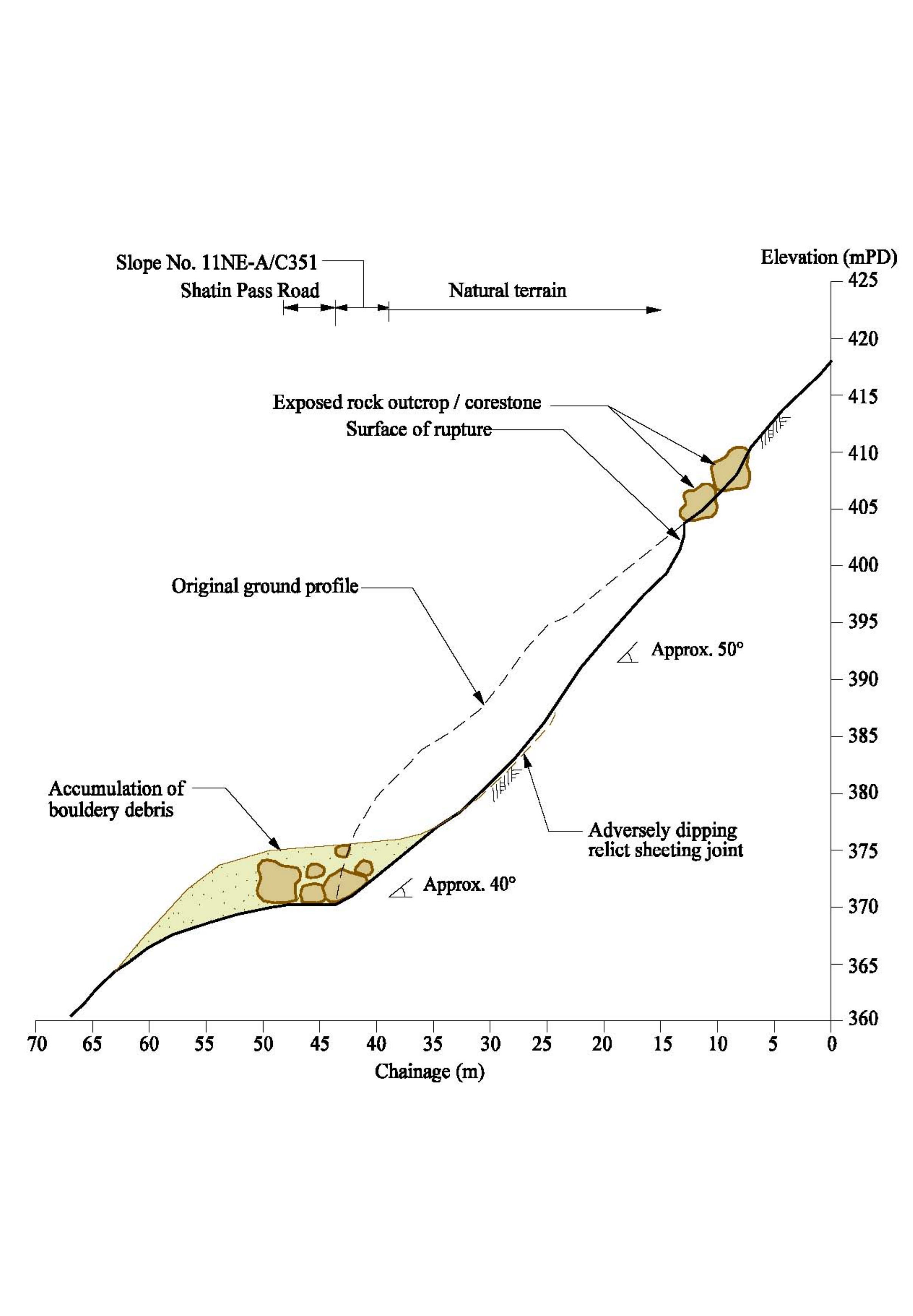

Figure 9 - Cross Section A-A through Source Area

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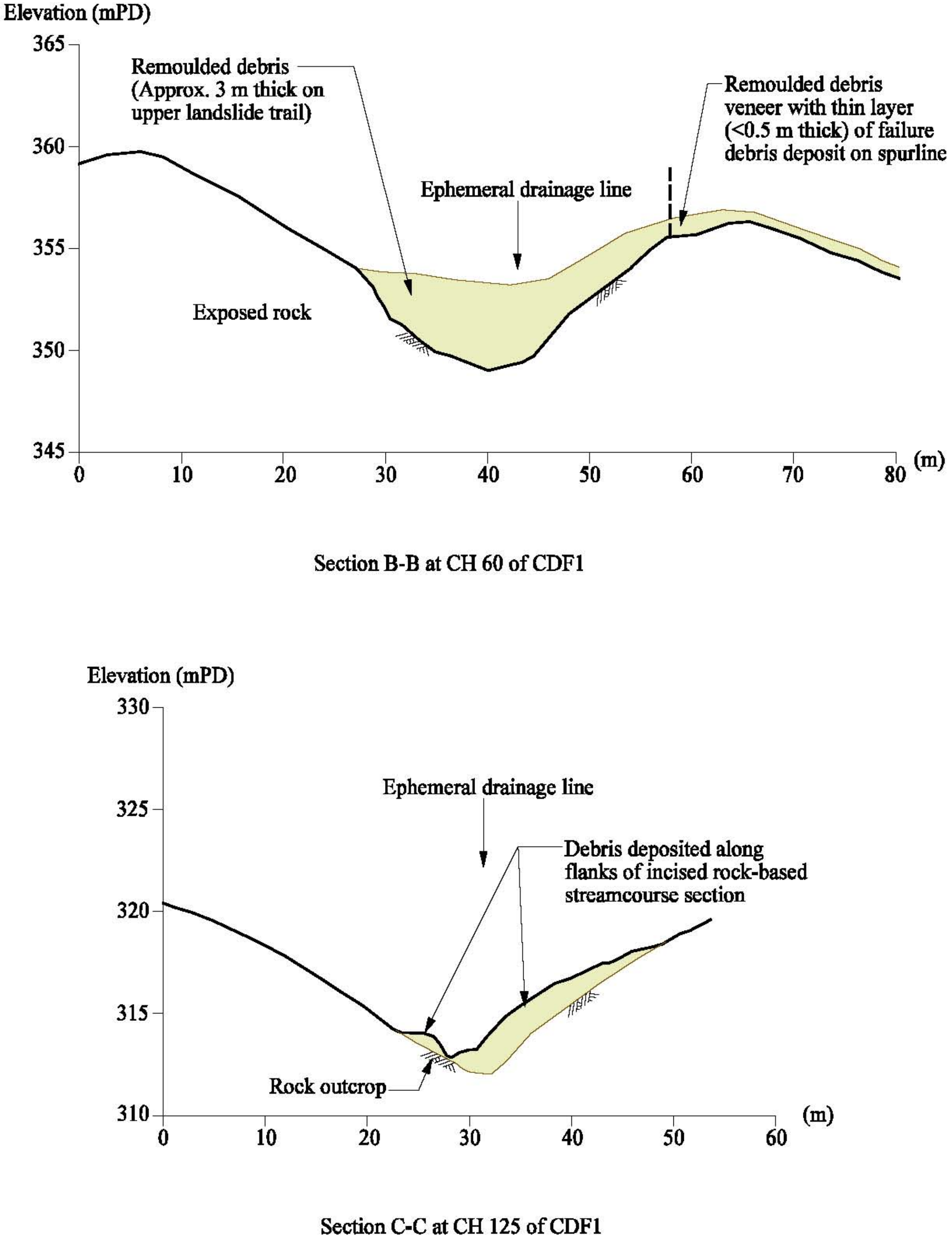

Note: See Figure 5 for location of sections.

Figure 10 - Cross Sections B-B and C-C

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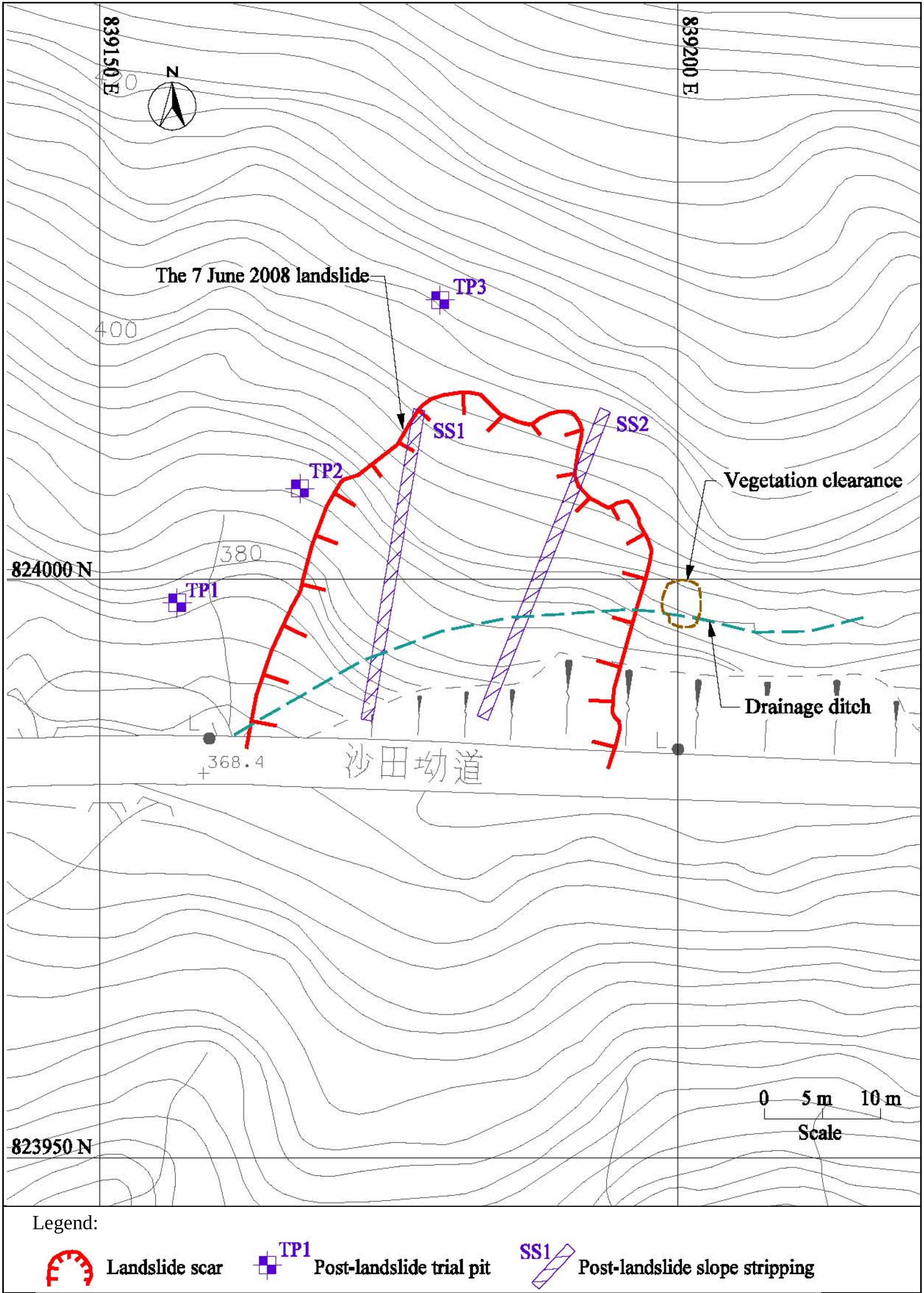

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-1B, 11NE-2A, 7SE-21D and 7SE-22C dated March 2008.

Figure 11 - Ground Investigation Plan

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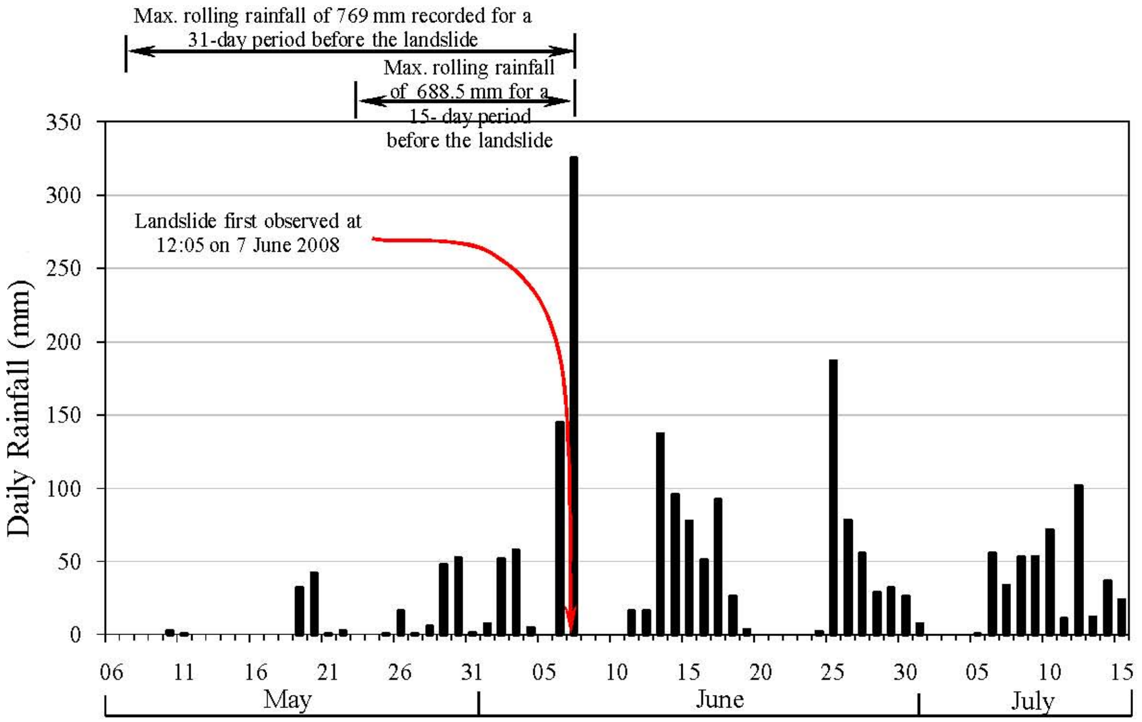
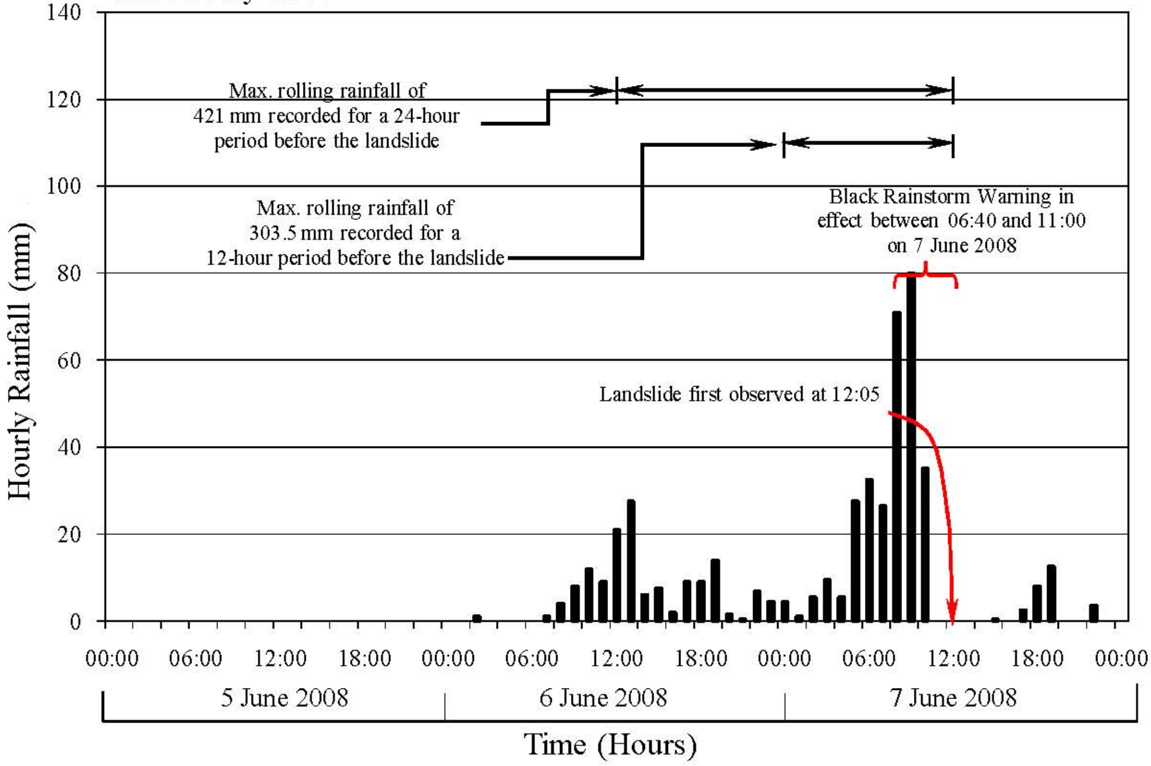


(a) Daily Rainfall Recorded at GEO Raingauge No. K07 between 6 May 2008 and 31 July 2008



(b) Hourly Rainfall Recorded at GEO Raingauge No. K07 between 5 June 2008 and 7 June 2008

Figure 12 - Daily and Hourly Rainfall Records at GEO Raingauge No. K07

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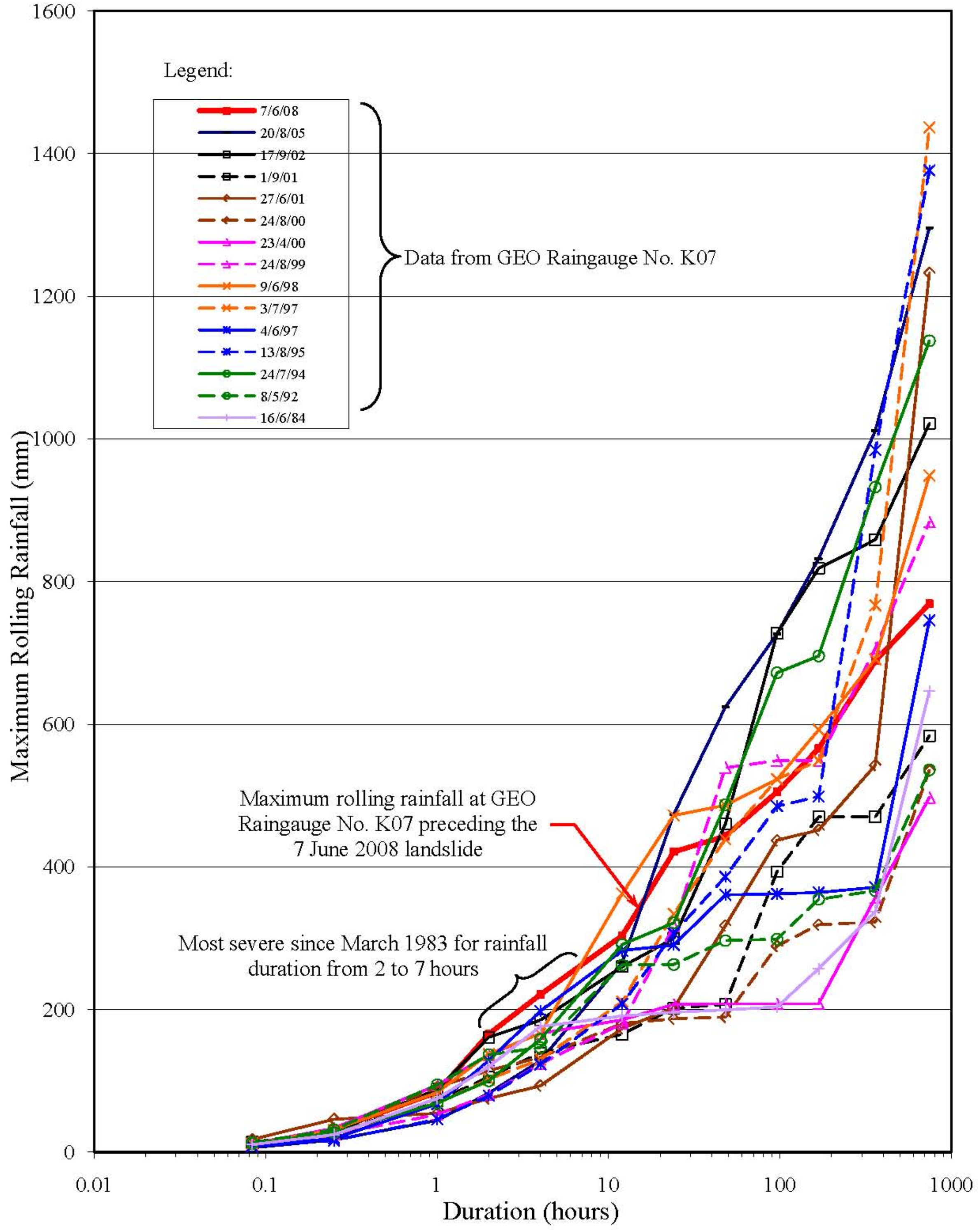

Notes: (1) Maximum rolling rainfall are evaluated from 5-minute readings from GEO Raingauge No. K07, about 681 m to the southwest of the site.

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. K07 since March 1983 when the raingauges became operational.

Figure 13 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. K07

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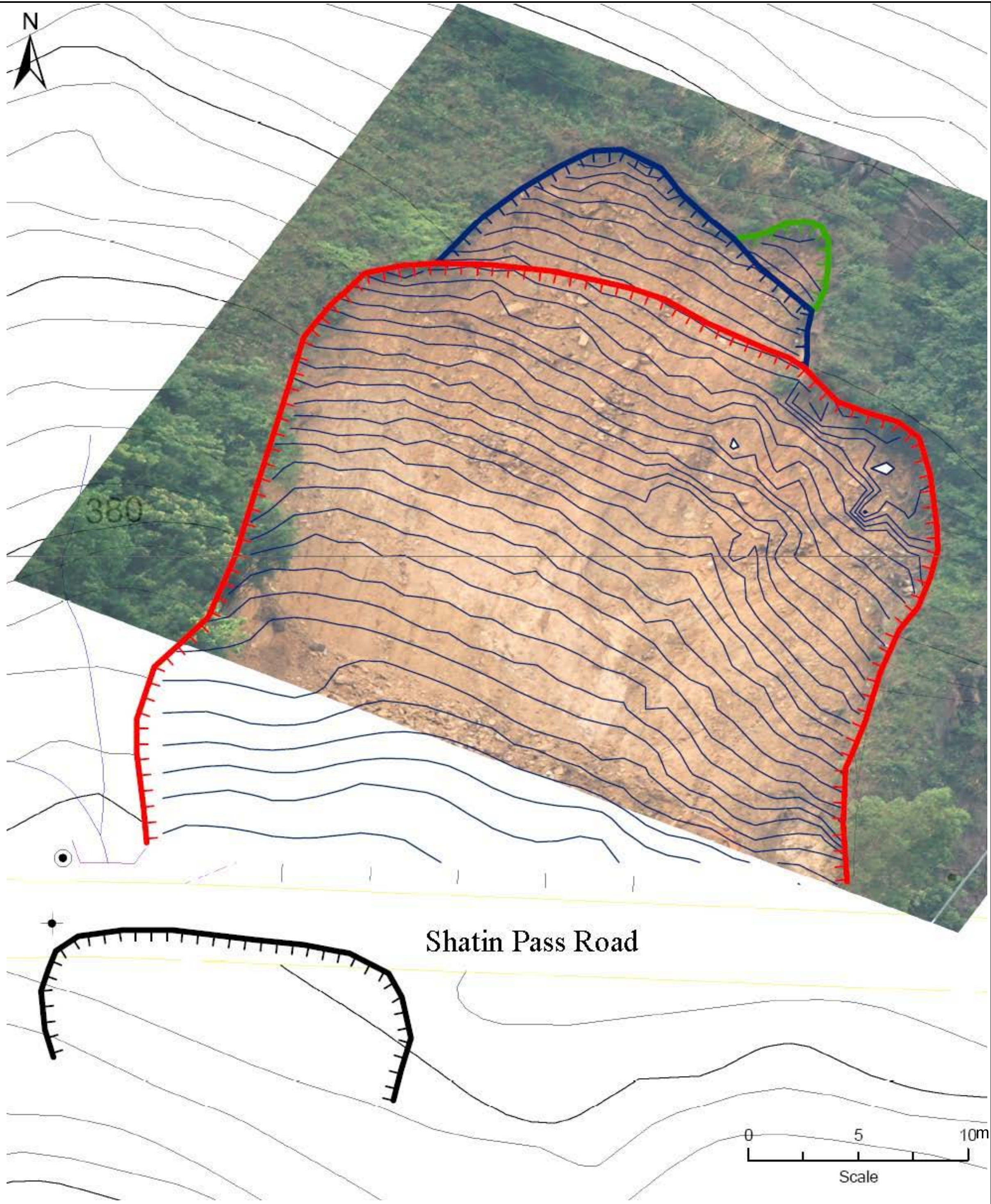

Legend:

Main Phase (7 June 2008)
Fill Failure below Shatin Pass Road (7 June 2008)
Subsequent Widening (before 9 June 2008)
Retrogressive Enlargement (observed on 16 June 2008)

Notes:
(1) Base plan is extracted from 1:1000 survey sheets Nos. 7SE-22C and 11NE-2A dated August 2009.
(2) Contours within source taken from laser scan carried out by HyD in June 2008.
(3) Photograph is a rectified oblique aerial photograph taken on 16 June 2008.

Figure 14 - Probable Sequence of Failure

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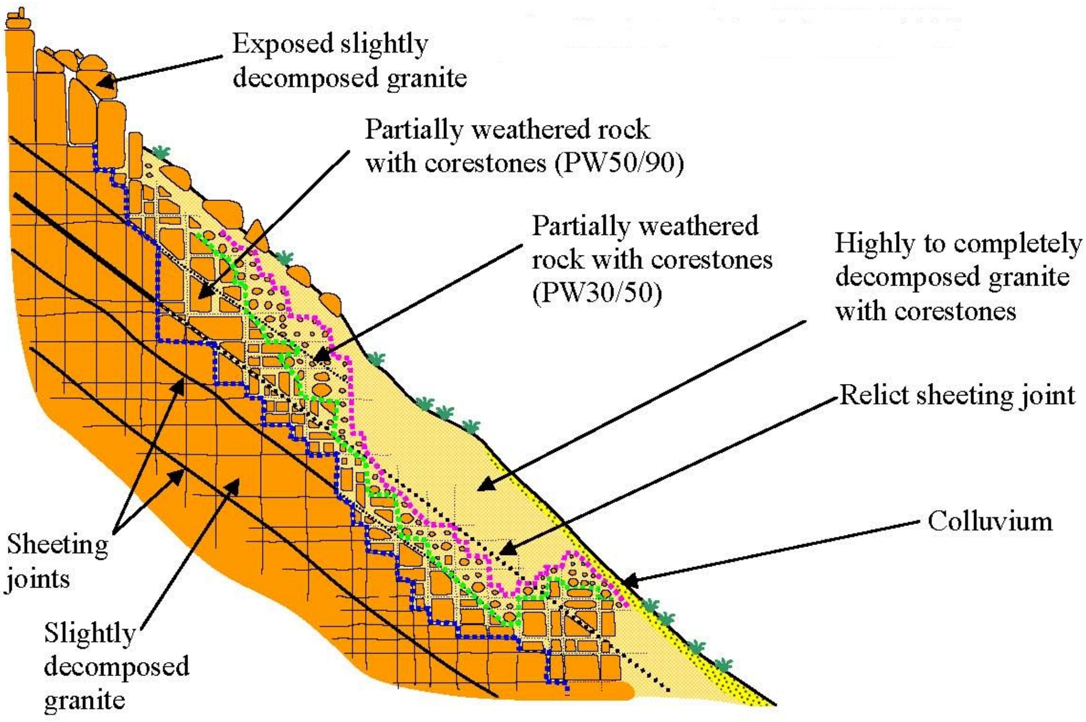
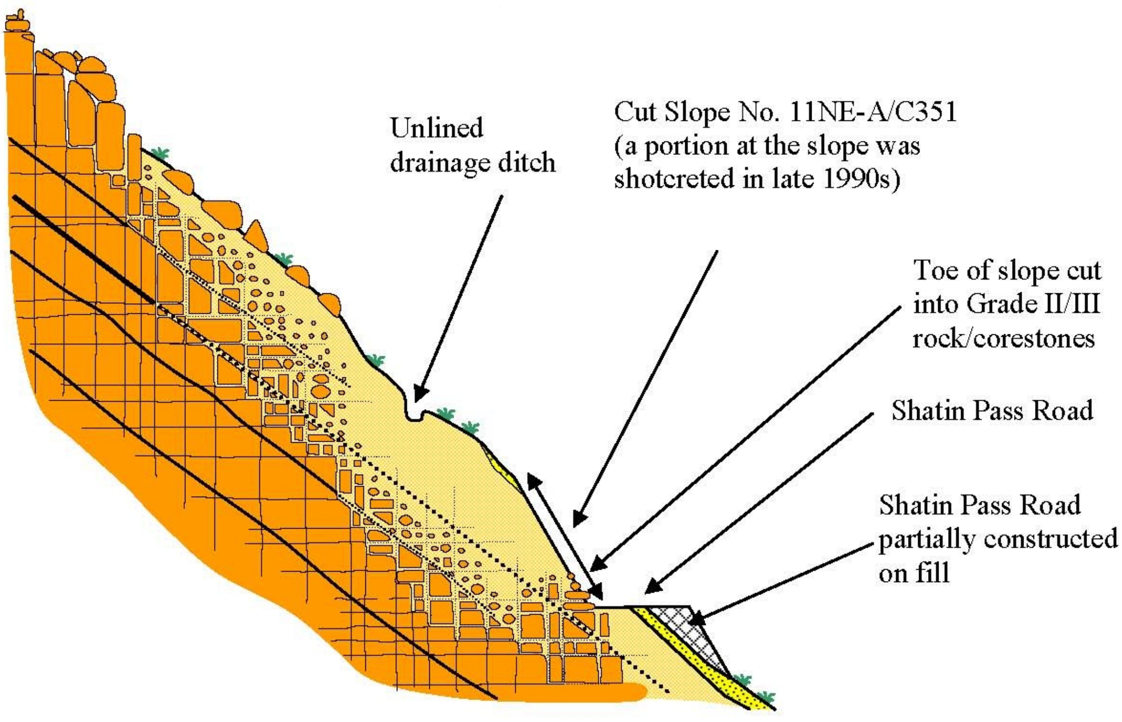


(a) Site in natural state before construction of Shatin Pass Road (before 1940)



(b) Construction of Shatin Pass Road and formation of Slope No. 11NE-A/C351 (1939-1941)

Figure 15 - Diagrammatic Sections (Sheet 1 of 2)

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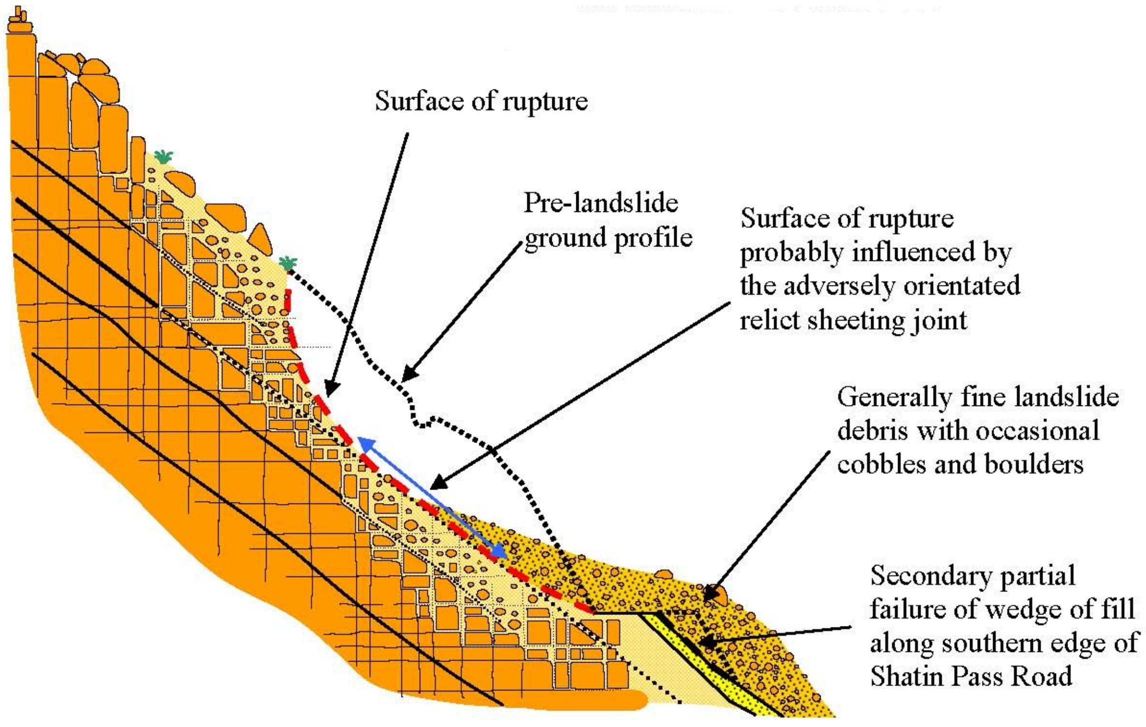
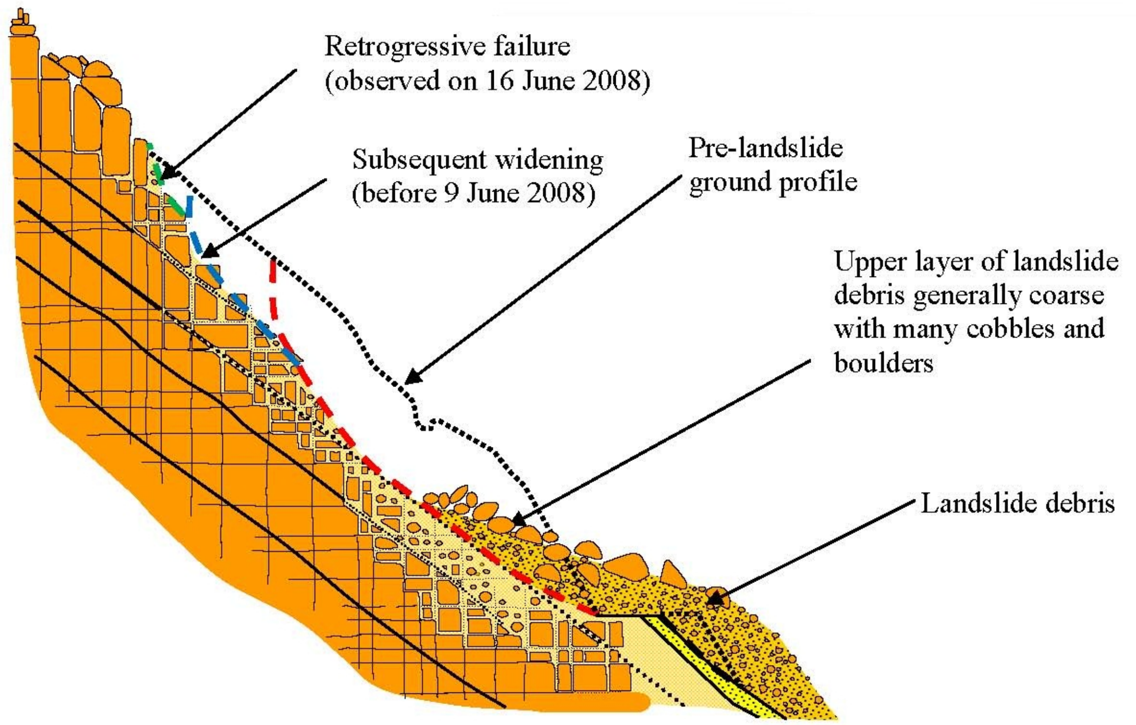


(c) The landslide on 7 June 2008



(d) The landslide after 14 June 2008

Figure 15 - Diagrammatic Sections (Sheet 2 of 2)

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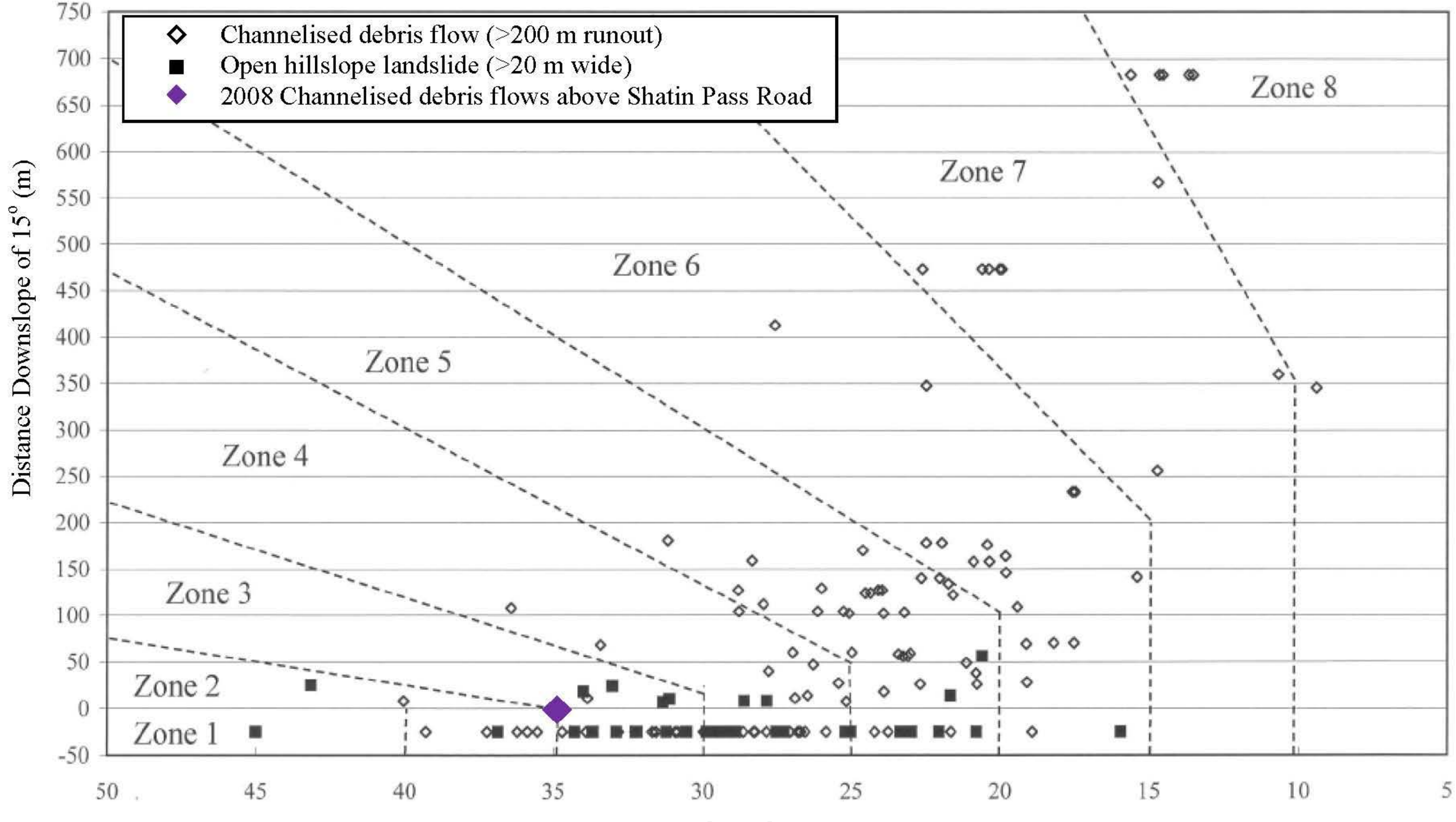
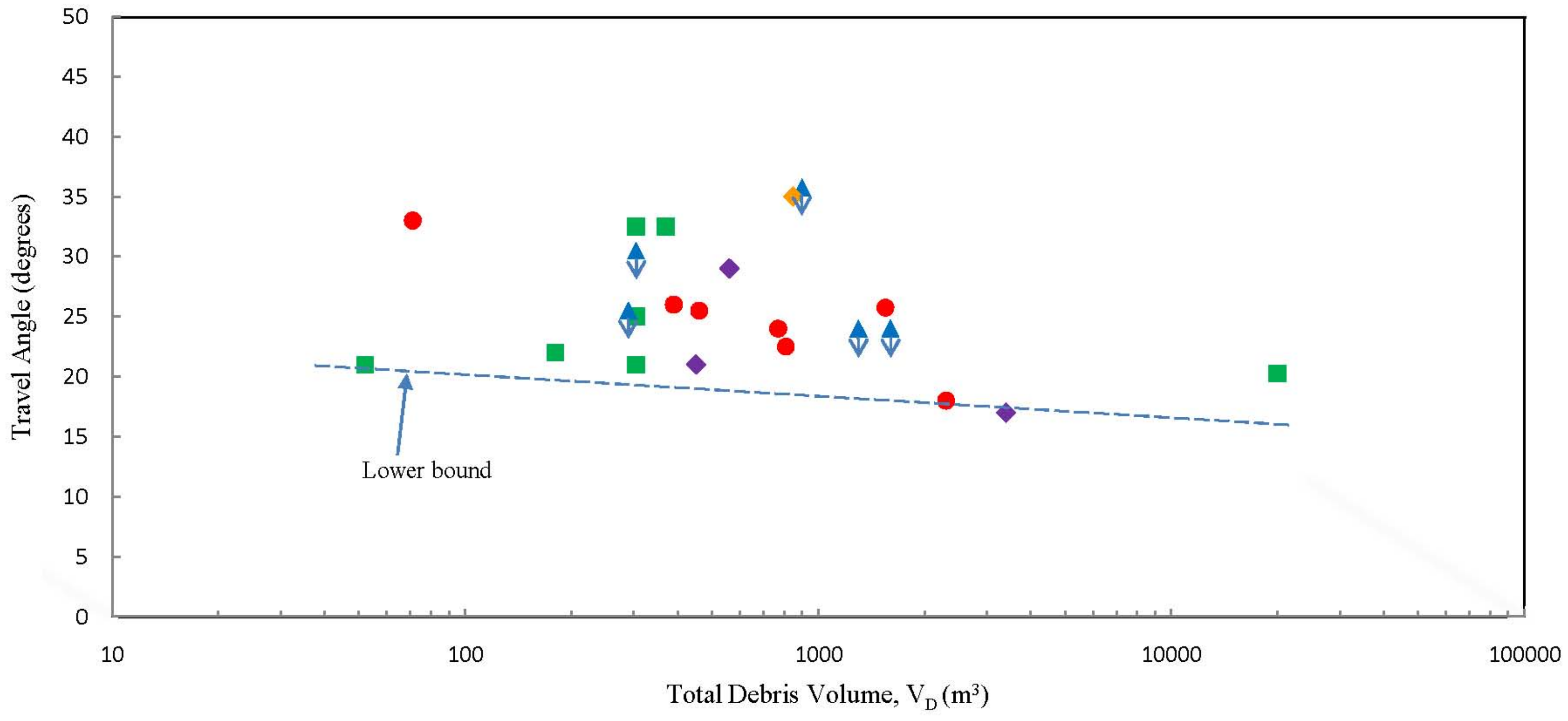


Note: Original Chart extracted from Wong et al (2006).

Figure 16 - Proximity Zones and Debris Runout Data from the 2008 Landslides



Legend:

Channelised debris flows:

Natural terrain landslides on Lantau Island in November 1993 by Wong *et al*., (1998) (upper bound)

Natural terrain landslides in the vicinity of Tung Chung New Town, Lantau Island by Franks (1998)

Values reported by Hungr (1998) and Ayotte & Hungr (1998)

June 2008 channelised debris flows above Yu Tung Road (AECOM, 2010)

June 2008 landslide on slope No. 11NE-A/C351 and the natural hillside above Shatin Pass Road

Figure 17 - Data on Debris Mobility for Channelised Debris Flows of Different Scale in Hong Kong

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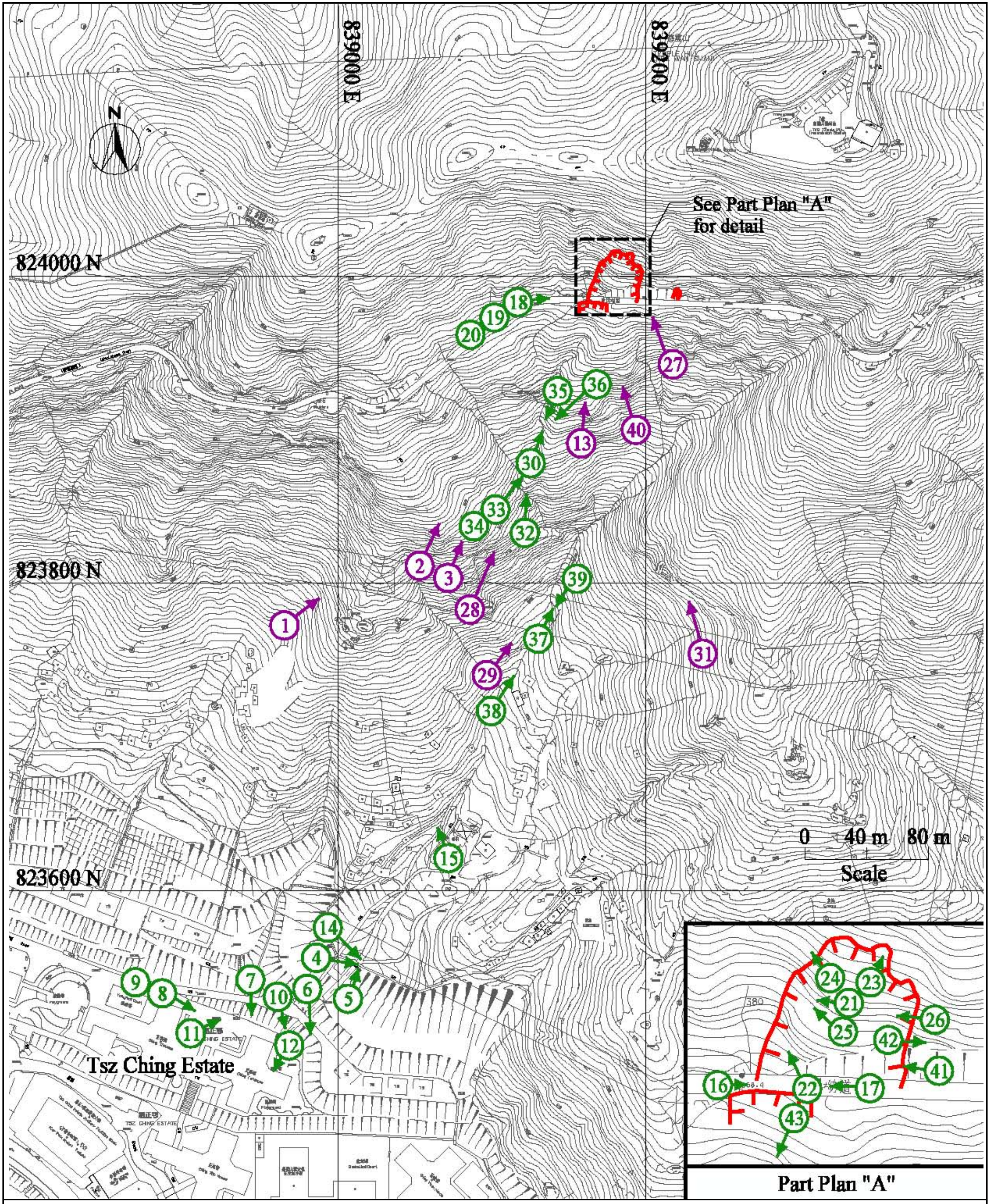

Legend:

Landslide scar

Location and direction of photograph taken

Aerial view

Note: Base plan is extracted from 1:1000 survey sheets No. 11NE-1B, 11NE-2A, 7SE-21D and 7SE-22C dated March 2008.

Figure 18 - Locations and Directions of Photographs

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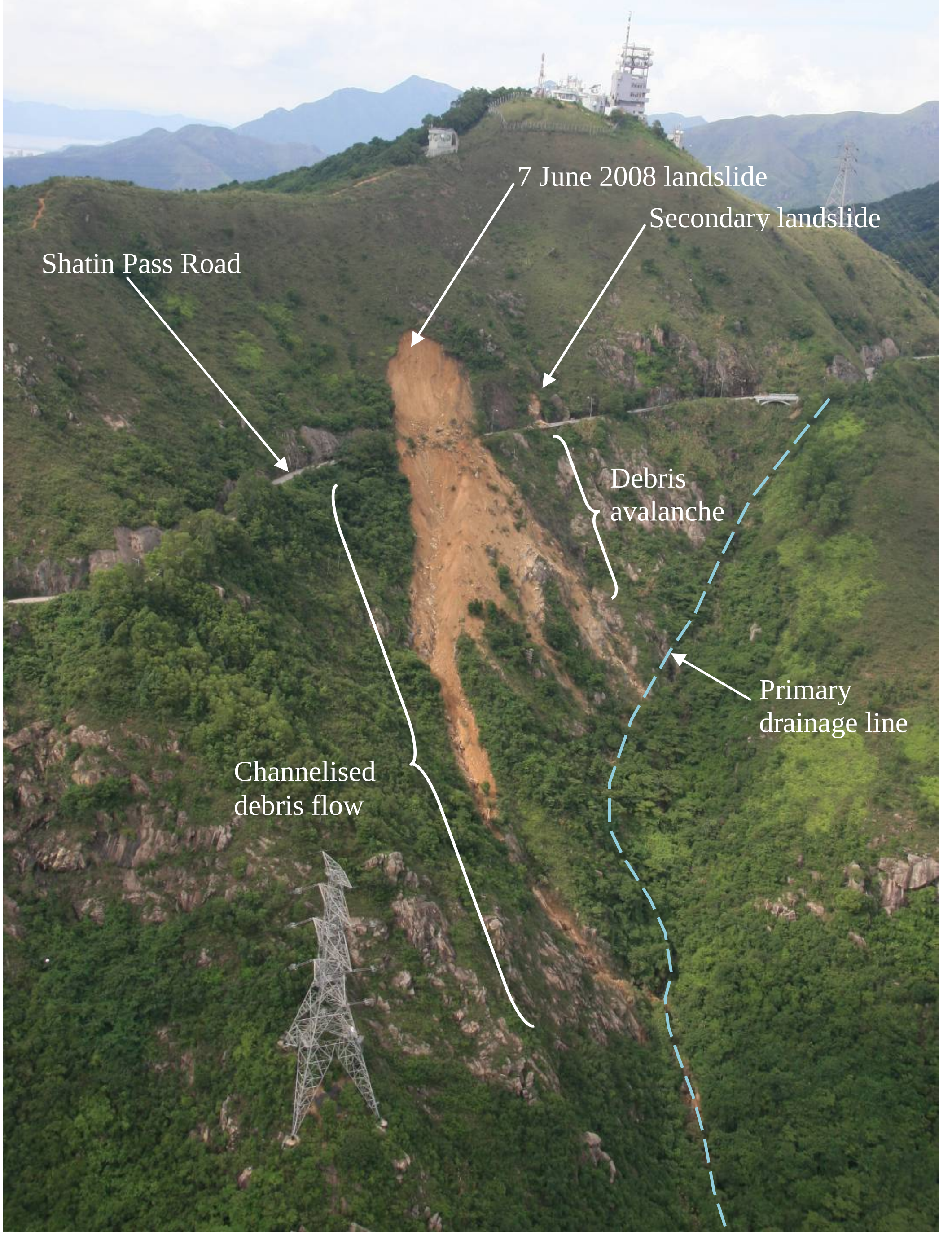

Plate 1 - Oblique Aerial View of the Landslide Site
(Photograph taken on 9 June 2008)

Note: See Figure 18 for locations and directions of photographs.

Plate 2 - Earliest Photograph of the Source Area of the 7 June 2008 Landslide Taken from the Roof of Ching Tai House (Photograph taken on 7 June 2008)

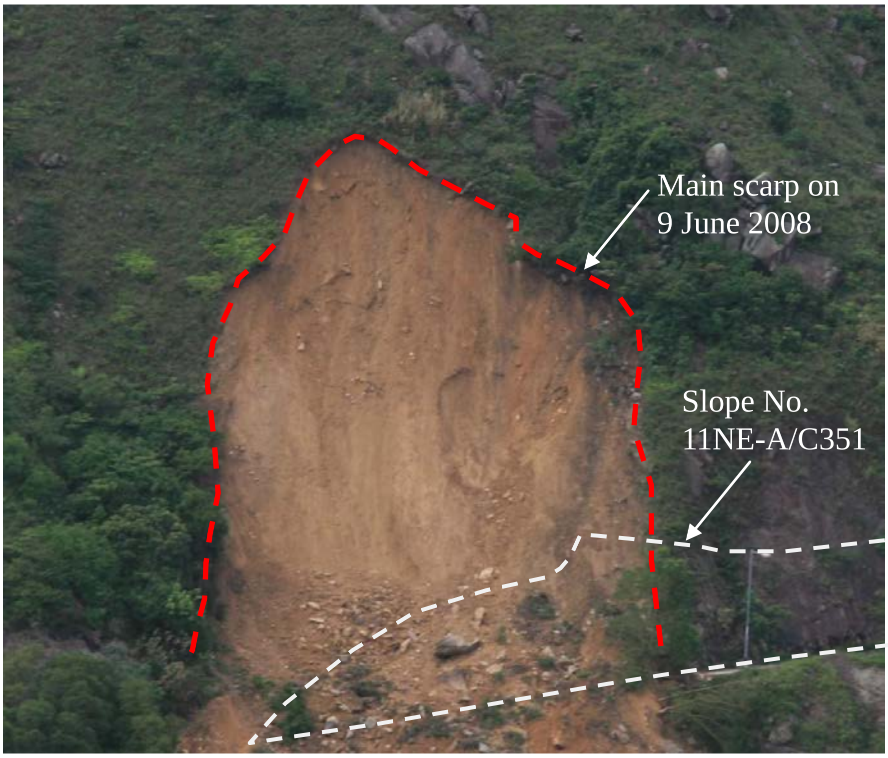

Plate 3 - Oblique Aerial View of the Landslide Source Area (Photograph taken on 9 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 4 - Record Photograph from DSD Showing Blockage at the Rock Trap above Slope No. 11NE-A/C300 at Tsz Ching Estate (Photograph taken on 13 June 2008)

Plate 5 - Record Photograph from DSD Showing Overflow of the Rock Trap above Slope No. 11NE-A/C300 at Tsz Ching Estate (Photograph taken on 13 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 6 - General View of Outwash Debris within Tsz Ching Estate
(Photograph taken on 9 June 2008)

Plate 7 - Debris Outwash Accumulated behind Fence above Tsz Ching Estate
(Photograph taken on 10 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 8 - Some of the Outwash Debris within Tsz Ching Estate was Partially Removed (Photograph taken on 12 June 2008)

Plate 9 - Debris Outwash within Tsz Ching Estate after the 13 and 14 June 2008 Rainstorm (Photograph taken on 15 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 10 - Debris Outwash Accumulated behind Fence above Tsz Ching Estate after the 13 and 14 June 2008 Rainstorm (Photograph taken on 16 June 2008)

Plate 11 - Debris Outwash within Tsz Ching Estate after the 12 July 2008 Rainstorm (Photograph taken on 12 July 2008)

Note: See Figure 18 for locations and directions of photographs.

Plate 12 - Debris Outwash Accumulated behind Fence above Tsz Ching Estate after the 12 July 2008 Rainstorm
(Photograph taken on 12 July 2008)

Plate 13 - Ongoing Remediation Work of the Source Area
(Photograph taken on 22 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 14 - View of the Repaired Rock Trap above Slope No. 11NE-A/C300 at Tsz Ching Estate (Photograph taken on 6 January 2010)

Plate 15 - View of Sedimentation Steps Constructed after 7 June 2008 Landslide Incident (Photograph taken on 6 January 2010)

Note: See Figure 18 for locations and directions of photographs.

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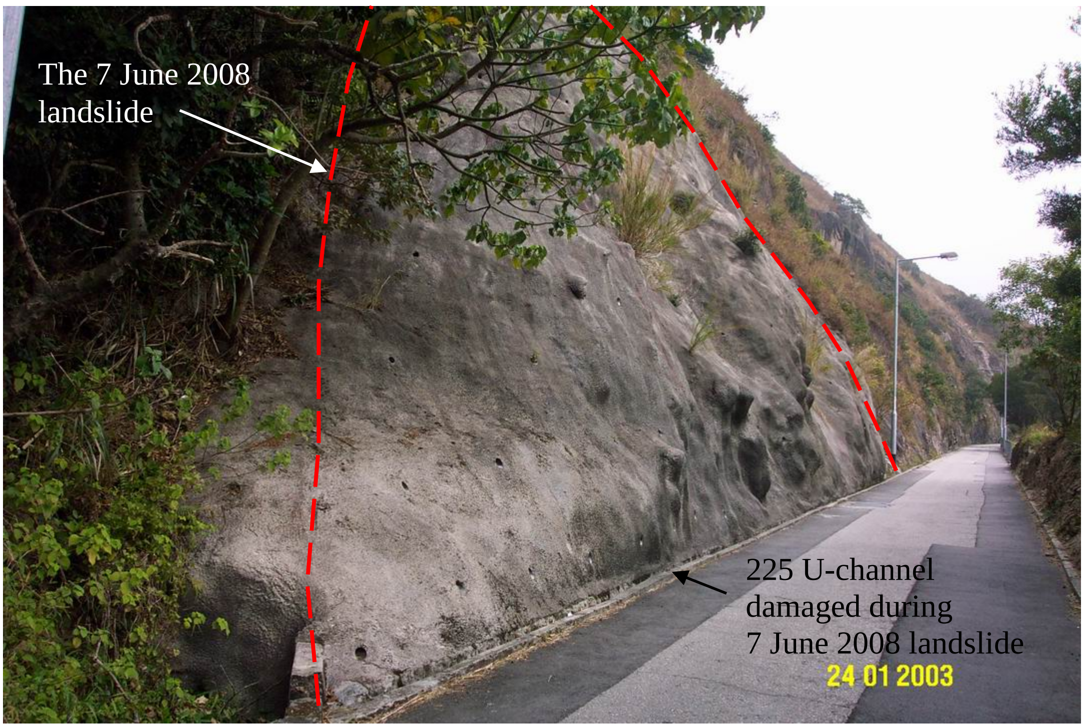

Plate 16 - Record Photograph from 2003 RMI Showing the 7 June 2008 Landslide Looking East (Photograph taken on 24 January 2003)

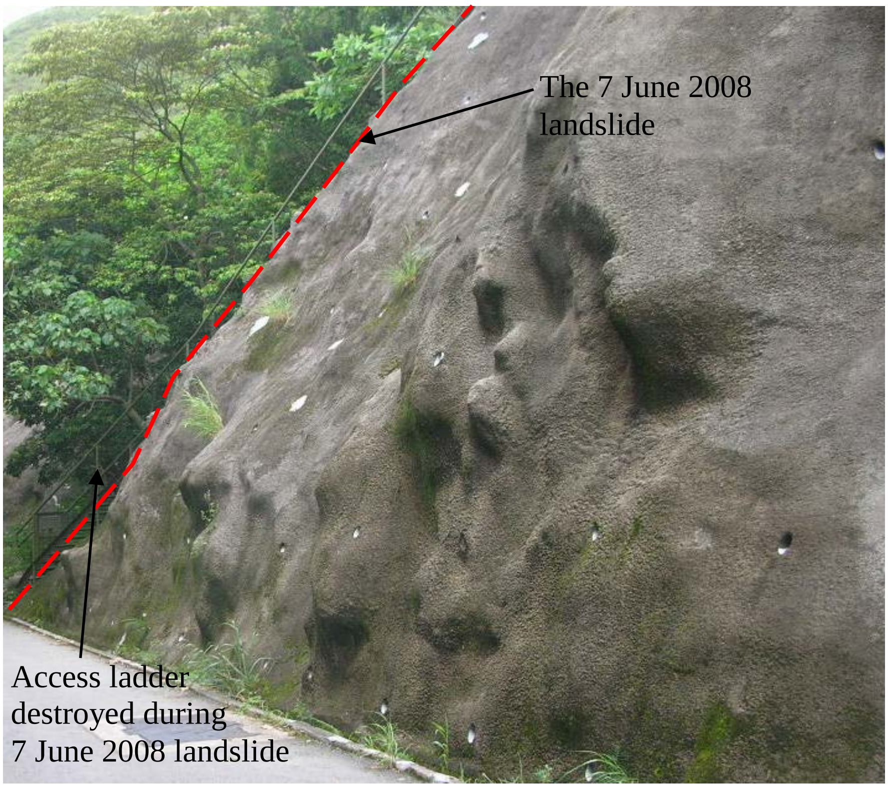

Plate 17 - Record Photograph from 2007 RMI for Slope No. 11NE-A/C351 Showing Vegetation Removal (Photograph taken on 16 June 2007)

Note: See Figure 18 for locations and directions of photographs.

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Plate 18 - View of Landslide Debris and Damaged Lamp Post at Shatin Pass Road (Photograph taken on 9 June 2008)

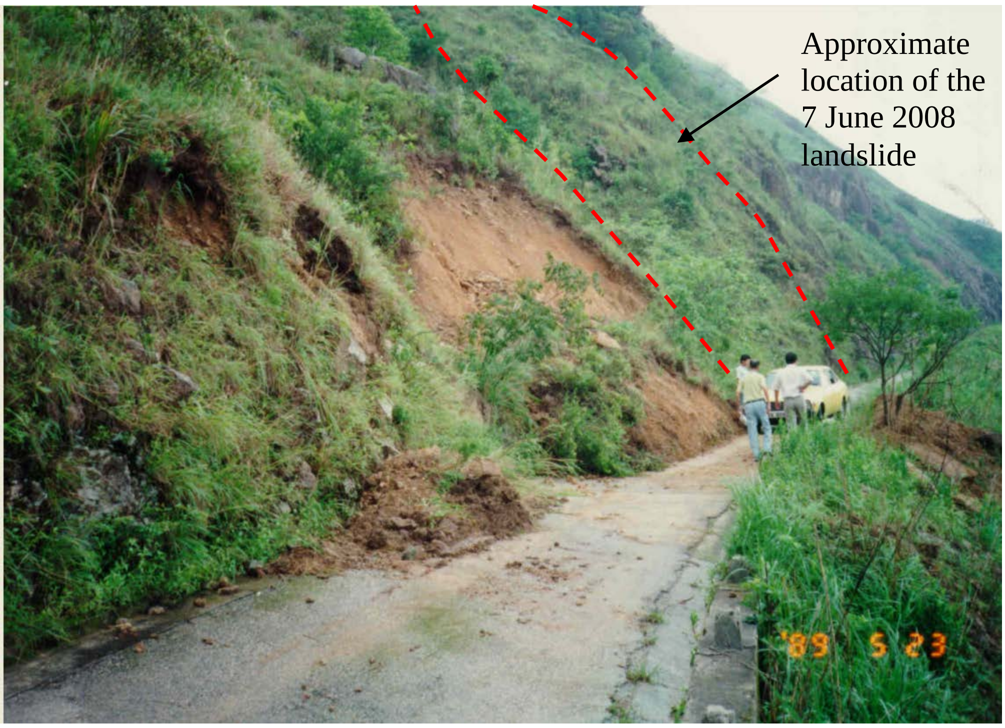

Plate 19 - Record Photograph of Landslide Incident No. K89/5/109 (Photograph taken on 23 May 1989)

Note: See Figure 18 for locations and directions of photographs.

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Plate 20 - Recent Photograph Showing the Shotcrete Covered Scar from Landslide Incident No. K89/5/109 (Photograph taken on 24 August 2009)

Note: See Figure 18 for locations and directions of photographs.

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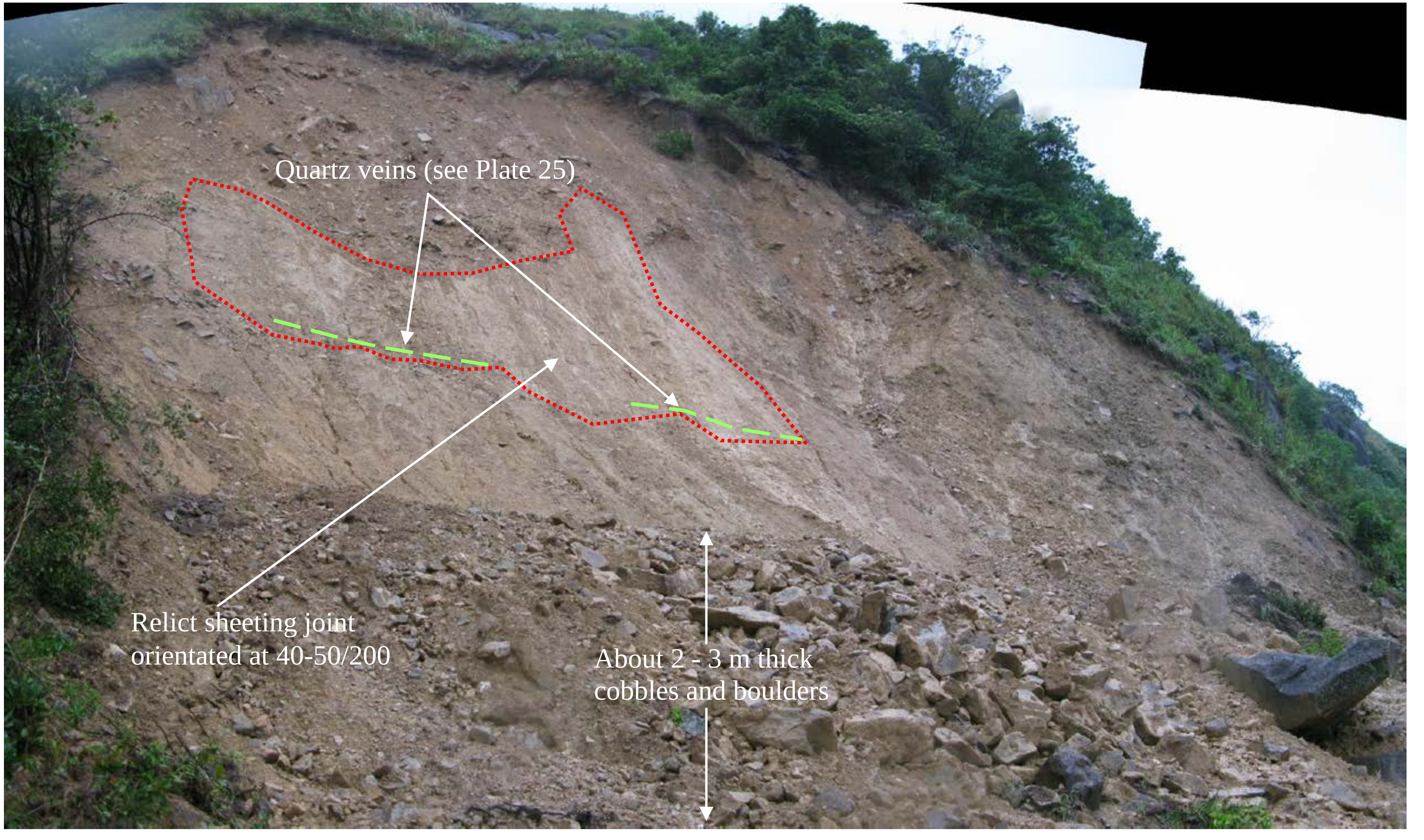

Plate 21 - Panoramic View of the Source Area from the West Flank (Photograph taken on 13 June 2008)

Note: See Figure 18 for locations and directions of photographs.

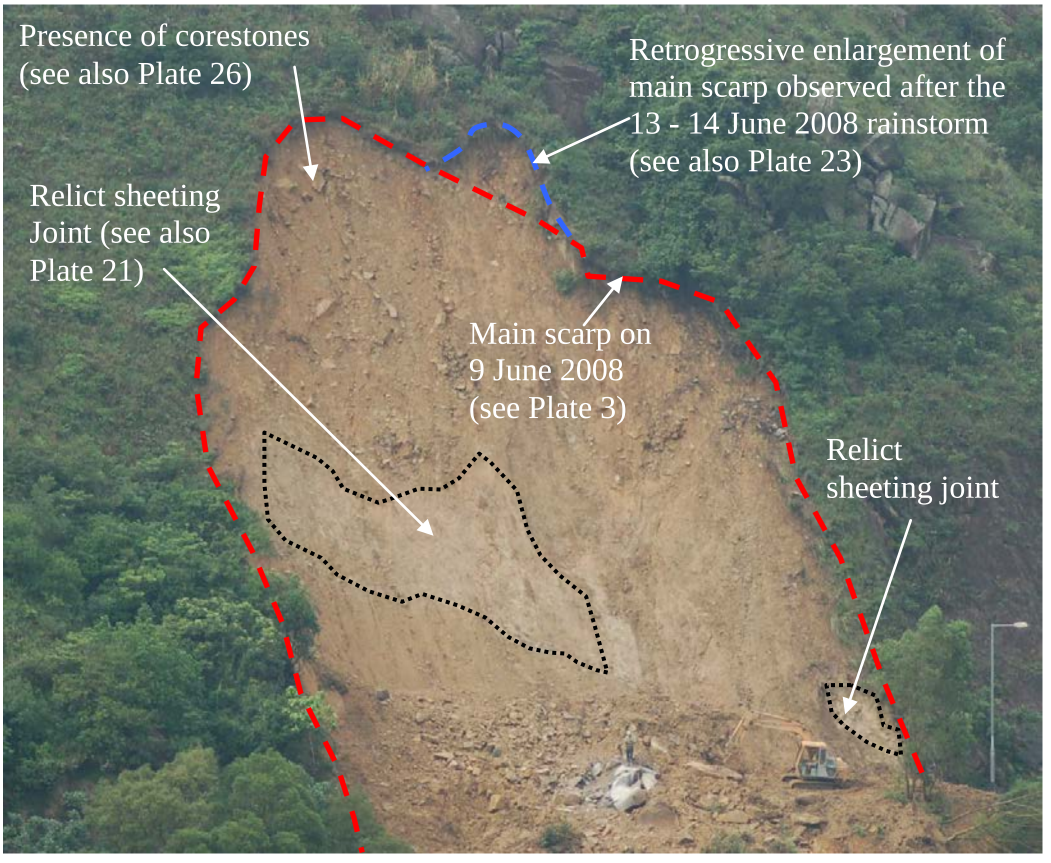

Plate 22 - Oblique Aerial View of the Landslide Site Showing Secondary Enlargement of Main Scarp after the 14 June 2008 Rainstorm (Photograph taken on 16 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 23 - Detailed Panoramic View along the Crown of the 7 June 2008 Landslide (Photograph taken on 13 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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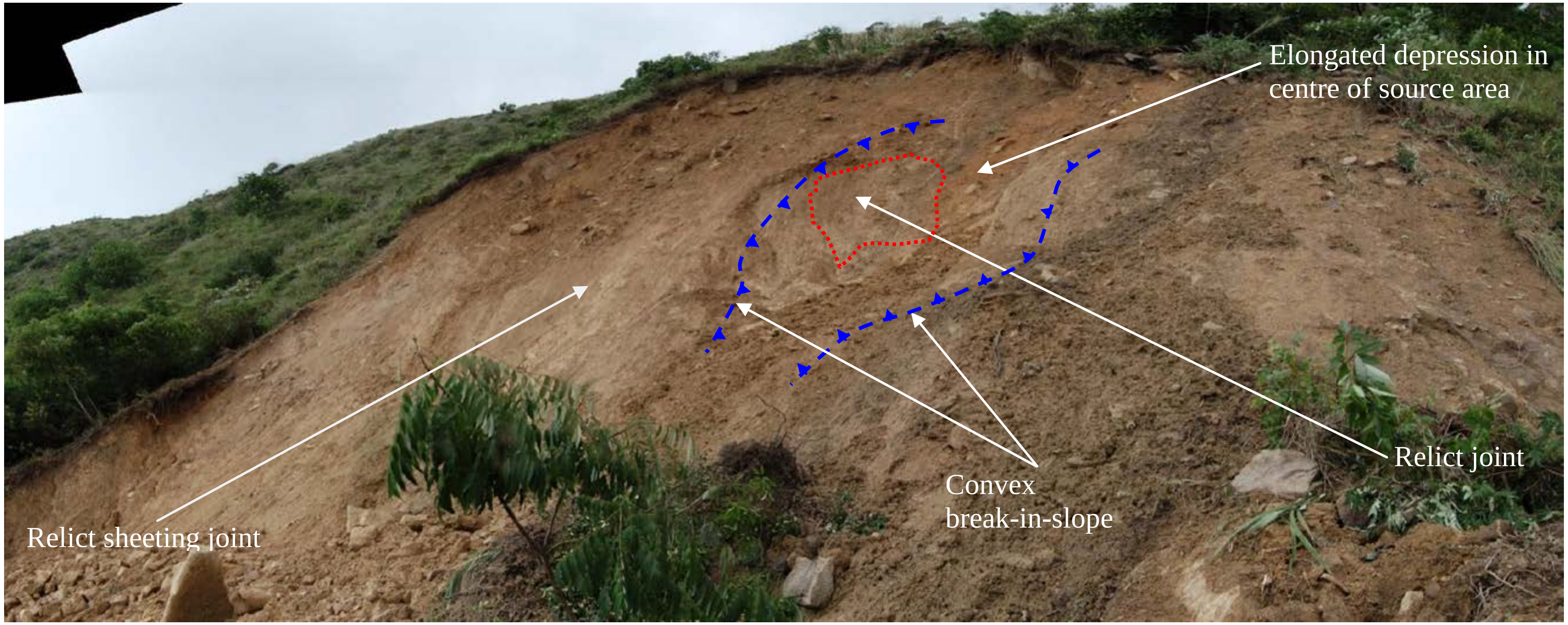

Plate 24 - Panoramic View of the Source Area from the East Flank (Photograph taken on 10 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 25 - Close-up View of the Quartz Vein Exposed in the Lower Portion of the Source Area (Photograph taken on 10 June 2008)

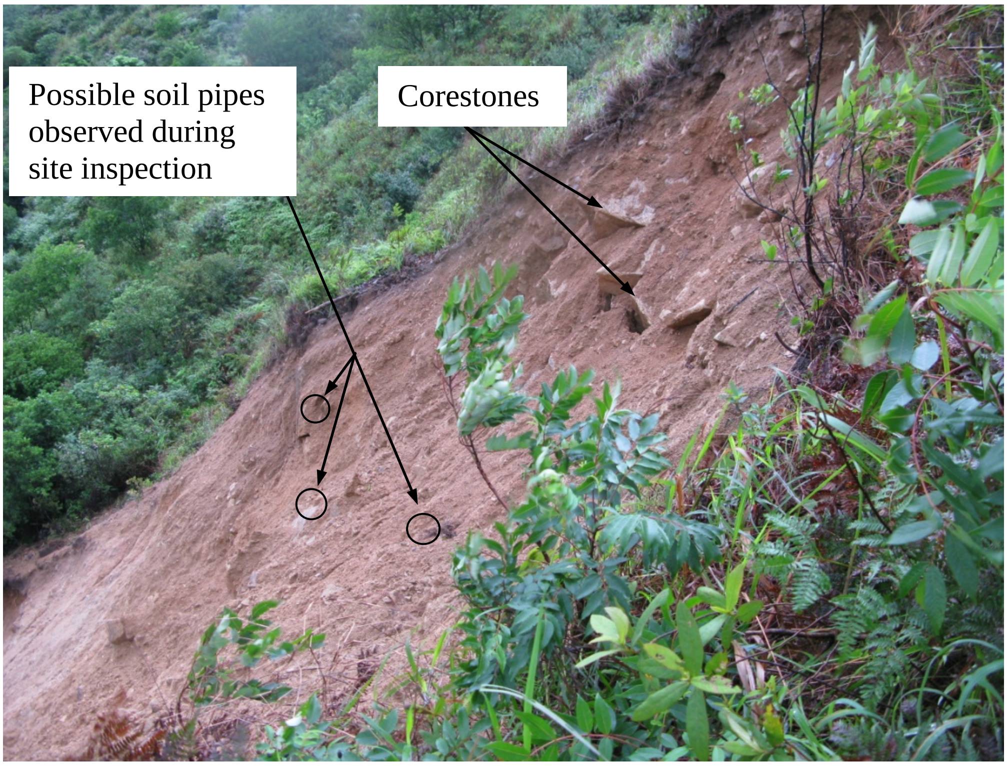

Plate 26 - Possible Soil Pipes and Presence of Corestones Exposed on Surface of Rupture (Photograph taken on 26 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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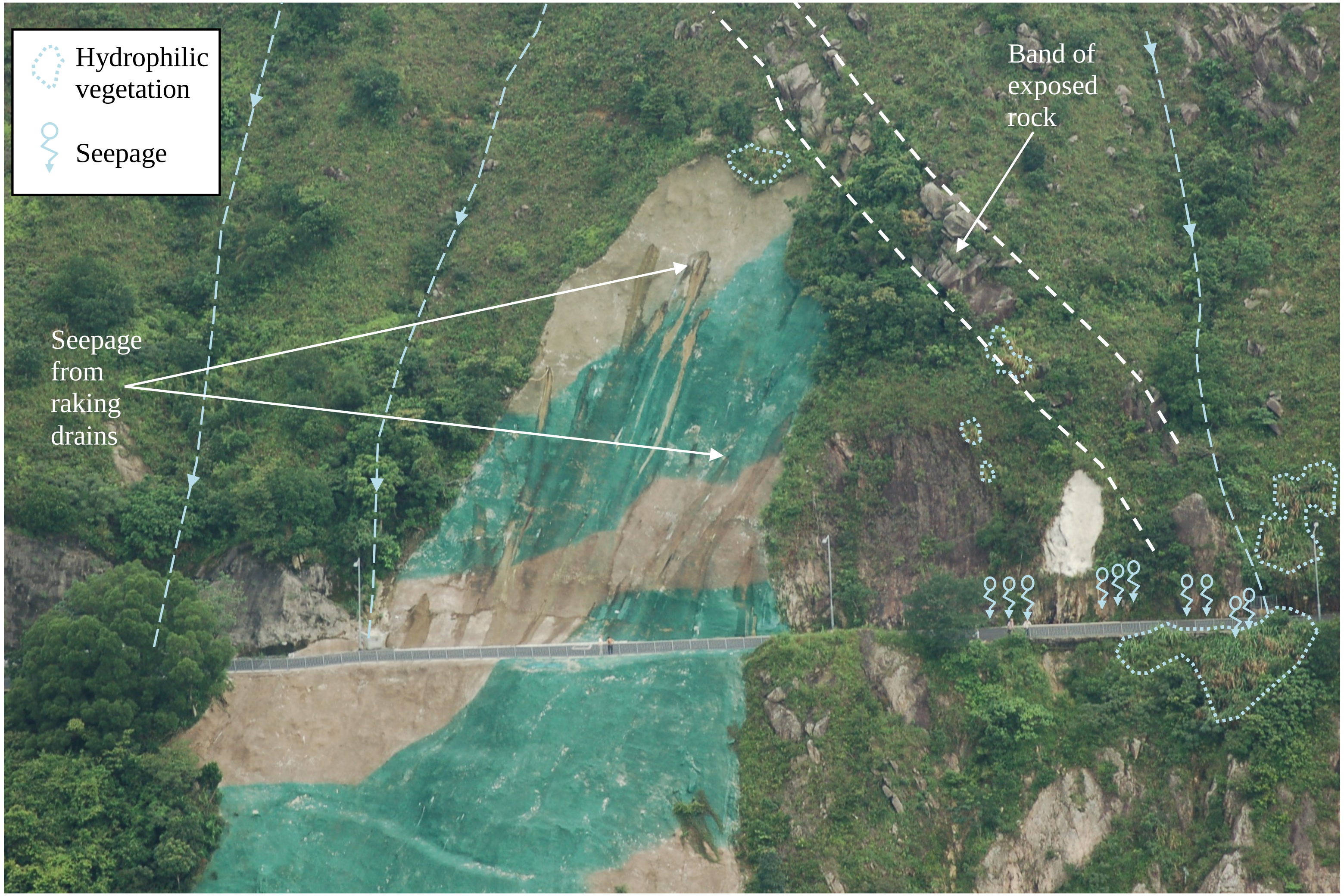

Plate 27 - Oblique Aerial View Showing Locations of Hydrophilic (Water Loving) Vegetation and Seepage (Photograph taken on 19 August 2009)

Note: See Figure 18 for locations and directions of photographs.

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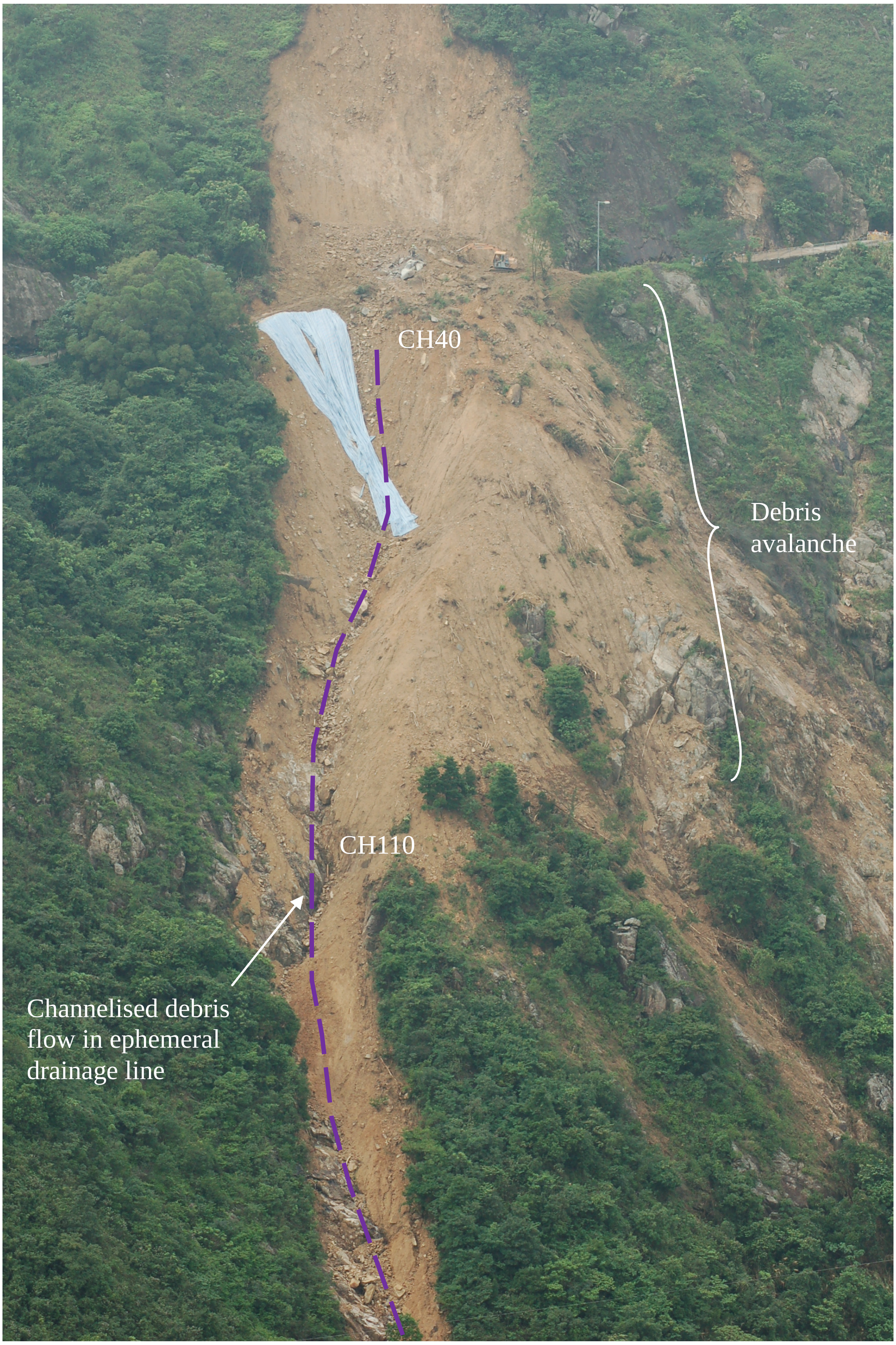

Plate 28 - Oblique Aerial View of the Upper Channelised Debris Flow Path (Photograph taken on 16 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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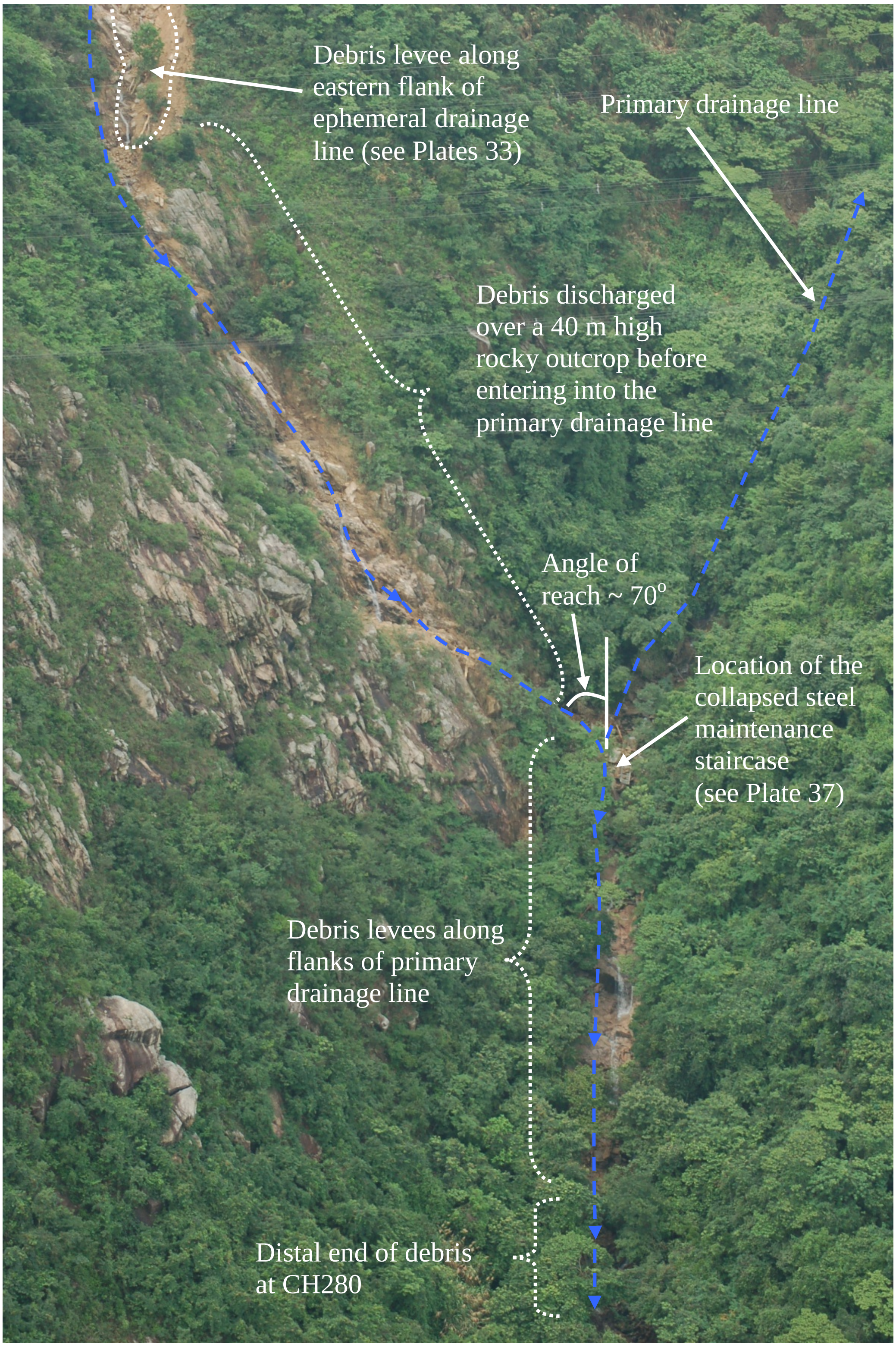

Plate 29 - Oblique Aerial View of the Lower Channelised Debris Flow Path
(Photograph taken on 16 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 30 - View of the Upper Channelised Debris Flow Path
(Photograph taken on 23 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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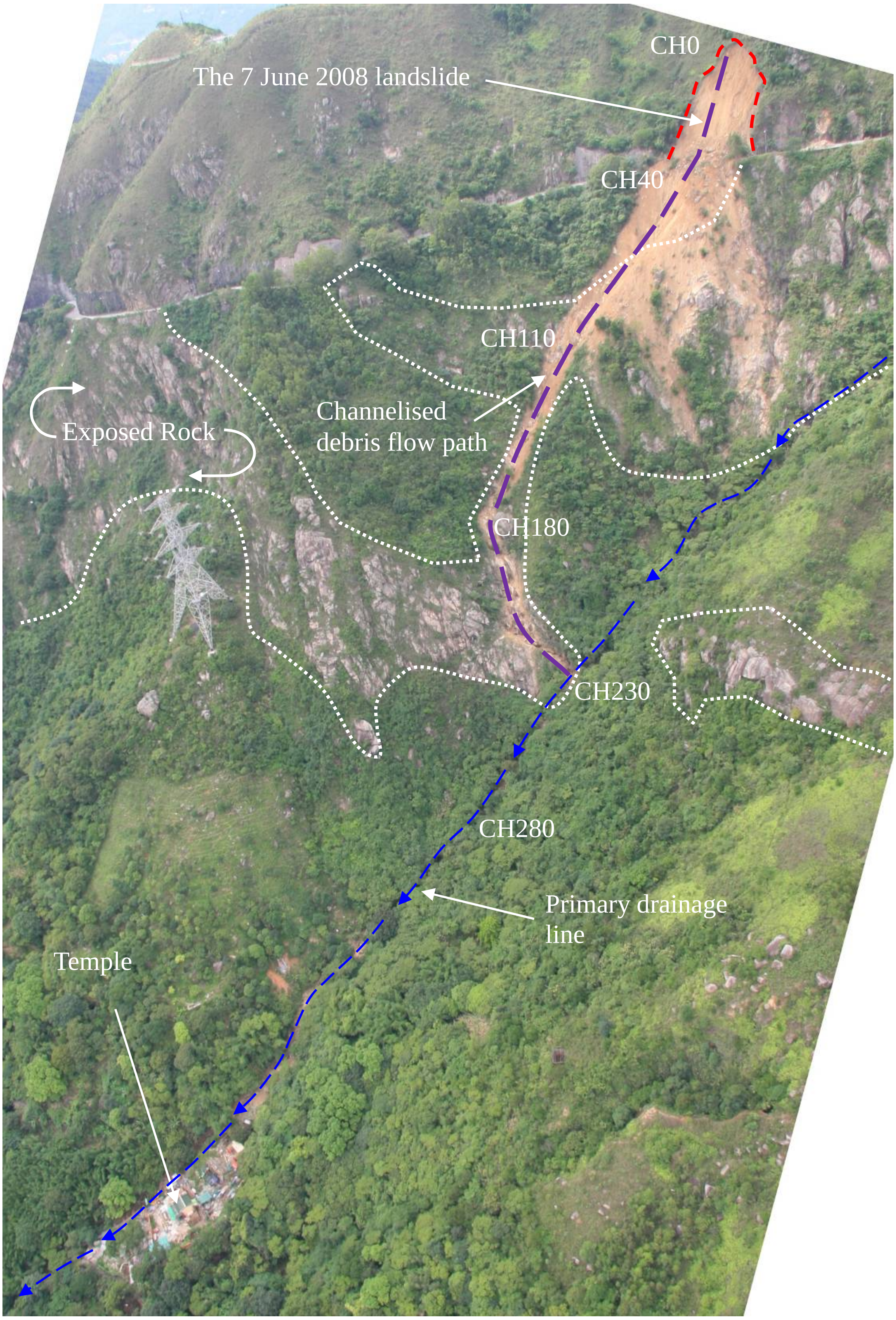

Plate 31 - Oblique Aerial View of the Debris Trails and Surrounding Terrain
(Photograph taken on 9 June 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 32 - Upslope View along Channelised Debris Flow Path at about CH185
(Photograph taken on 29 July 2008)

Plate 33 - Debris within Channelised Debris Flow Path at about CH170
(Photograph taken on 29 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 34 - Prominent Pegmatite Intrusion near CH170
(Photograph taken on 6 January 2010)

Plate 35 - Change of Direction of Debris Flow near a Pegmatite Intrusion near CH170 (Photograph taken on 29 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 36 - Deposit of "Oversplashed" Debris at about CH170
(Photograph taken on 29 July 2008)

Plate 37 - Upstream View of Primary Drainage Line at about CH280
(Photograph taken on 28 October 2009)

Note: See Figure 18 for locations and directions of photographs.

Plate 38 - Upstream View of Primary Drainage Line at about CH320
(Photograph taken on 11 June 2008)

Plate 39 - View of Collapsed Section of Steel Maintenance Staircase of
Slope No. 11NE-A/C351 at Primary Drainage Line at about CH250
(Photograph taken on 23 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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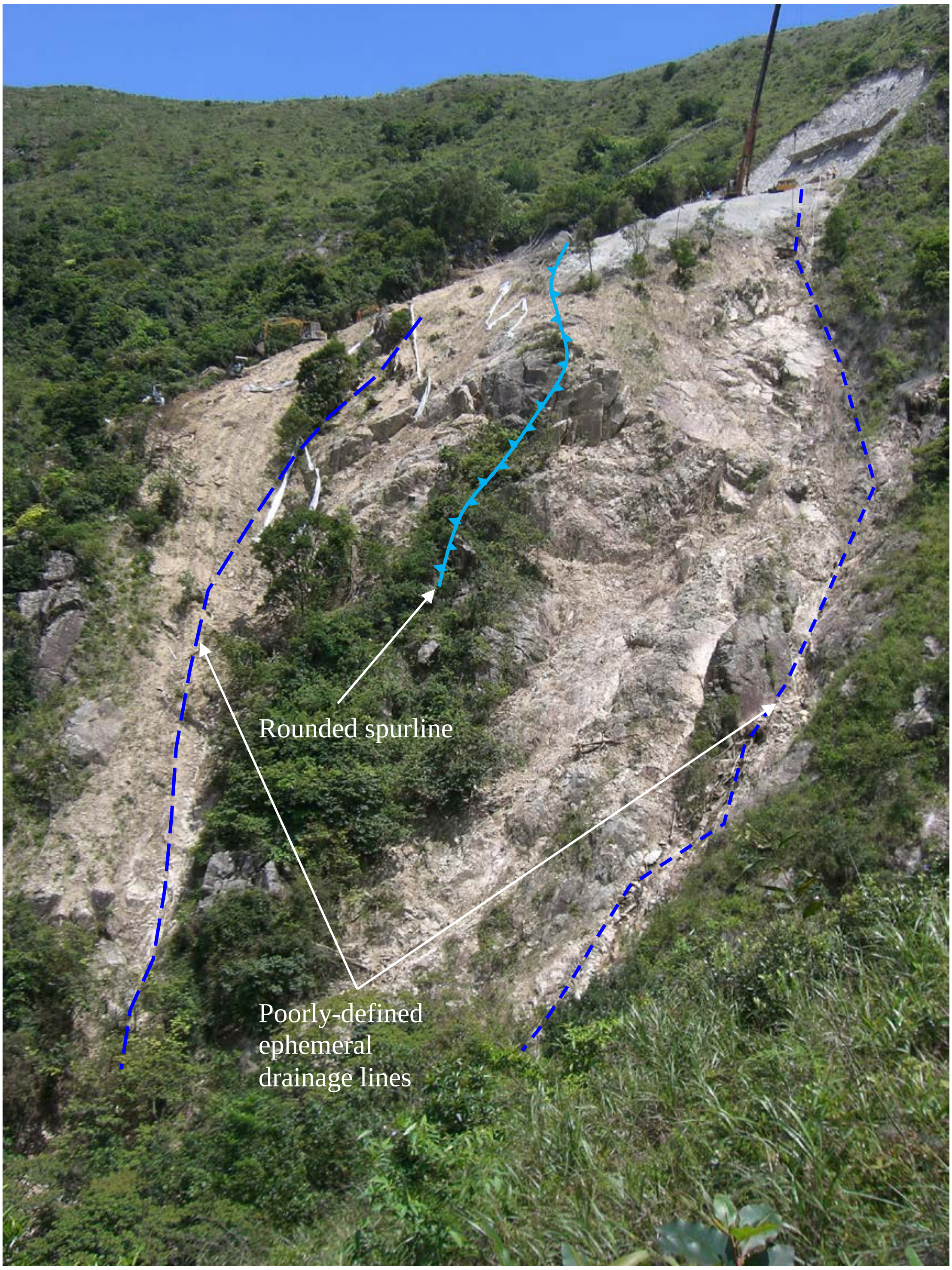

Plate 40 - Debris Travelled along Poorly-Defined Ephemeral Drainage Lines towards the Primary Drainage Line (Photograph taken on 23 July 2008)

Note: See Figure 18 for locations and directions of photographs.

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Plate 41 - Post-landslide Slope Profile in January 2010 when the Ground Investigation Works were Undertaking, and Contrasting with the Pre-failure Slope Profile in 2003

Note: See Figure 18 for locations and directions of photographs.

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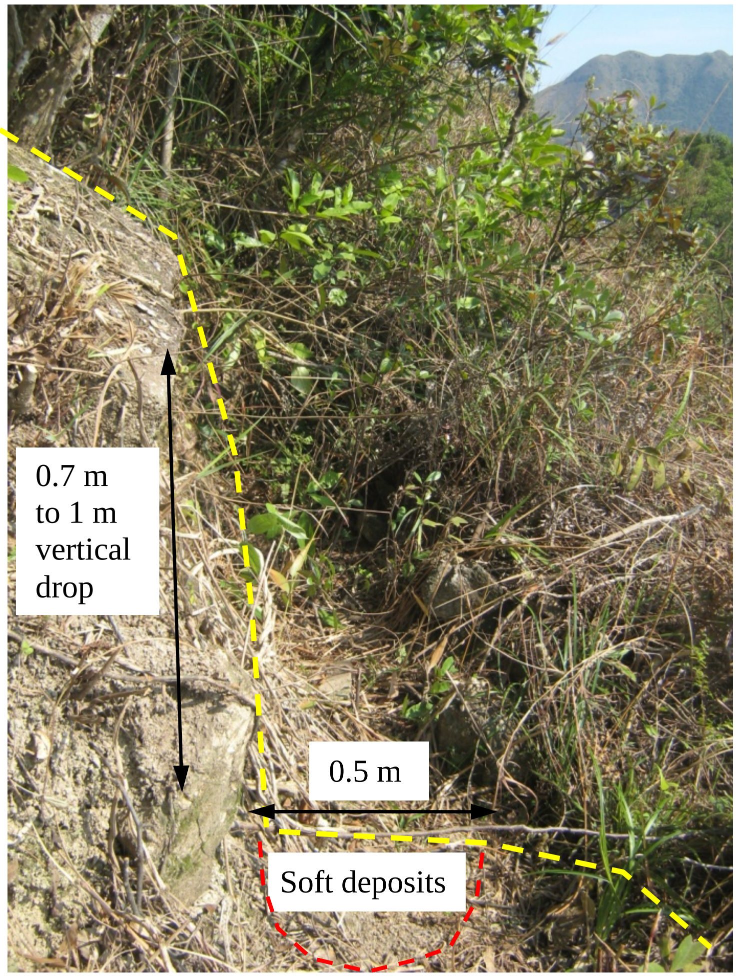

Plate 42 - Vertical Drop Observed at the Crest of Slope No. 11NE-A/C351 after Vegetation Clearance (Photograph taken on 21 January 2010)

Note: See Figure 18 for locations and directions of photographs.

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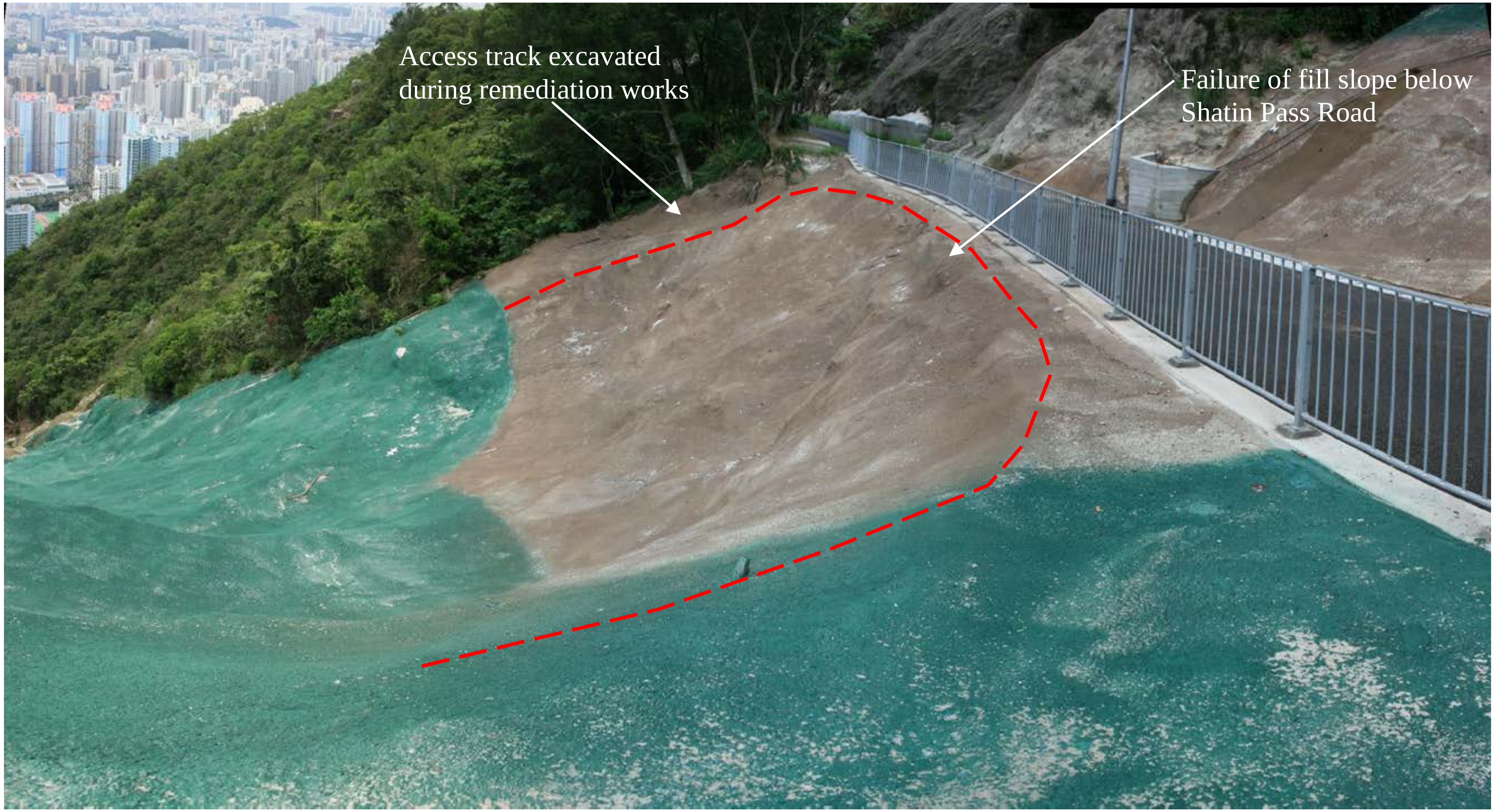

Plate 43 - Panoramic View of Completed Remediation Work below Shatin Pass Road (Photograph taken on 25 June 2009)

Note: See Figure 18 for locations and directions of photographs.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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CONTENTS

A1. INTRODUCTION

The primary aims of the API were to access the geological and geomorphological conditions of the site and to identify any signs of instability in recent and historic aerial photographs. A review of available aerial photographs taken between 1945 and 2008 was undertaken (see list in Table A1). Pertinent site observations, including the location of recent landslide scars, are shown on Figure A1. Based primarily on the 1963 aerial photographs, with some additional observations from the later 1973 aerial photographs a detailed geomorphologic plan of both the landslide catchment (Figure A2) and the terrain in the vicinity of the source of 7 June 2008 landslide (Figure A3) have been prepared. Pertinent observations from selected aerial photographs are presented as Plates A1 to A9.

A2. DETAILED OBSERVATIONS

Detailed observations from an examination of the aerial photographs for the period between 1945 and 2008 are presented below.

YEAR **OBSERVATIONS**

1945 High flight, poor resolution, single aerial photograph. (Plates A1 and A2).

The earliest available aerial photograph shows that by 1945 Shatin Pass Road and the associated cut slopes (including slope No. 11NE-D/C351), had already been formed. It is understood that the road was constructed by the British Army as part of the construction of the “Gin Drinker’s Line” (a military defensive line) sometime between 1939 and 1941. At a number of locations directly below Shatin Pass Road are light toned areas, which are consistent with recent fill or possibly disturbed ground (see Figure A1 and Plates A1 and A2). It is likely these areas represent bodies of fill deposited during construction of Shatin Pass Road. Directly below the western flank of 7 June 2008 landslide an accumulation of possible fill (or disturbed ground) is visible within the drainage line below Shatin Pass Road (Plate A2). At this location, it is likely that the southern (downslope) side of the road is at least partially constructed on this fill body.

Along the eastern end of the northern boundary of the catchment, three possible tunnel entrances are visible (Figure A1 and Plate A1). Below each tunnel a trail of debris, assumed to be the excavated spoil, is clearly visible. The purpose of these tunnels is unknown but is likely to be military in origin. As the tunnels are greater than 100 m away from the source of 7 June 2008 failure and located close to the ridgeline, it is unlikely they presence would have had a significant effect on the drainage at the site of 7 June 2008 landslide.

A wide band of debris/disturbed material is visible within the primary drainage line (Plate A1). The original of this material is probably anthropogenic (a combination of spoil from the construction of Shatin Pass Road and the excavation of the tunnels described above) as there is little evidence of recent landslides within the catchment.

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YEAR **OBSERVATIONS**

The source area of 7 June 2008 landslide is located at the western end of cut slope No. 11NE-A/C351 and the natural terrain directly upslope of the cut slope. To the west of the cut slope, there are two south-draining ephemeral streamcourses (Figure A3).

The western end of slope No. 11NE-A/C351 is light toned (Plate A2), in contrast to the generally darker tone of the rest of the cut slope. The light tone is probably due to local surface erosion, thereby indicating the western end of the slope is cut into weathered rock and/or soil, as opposed to the dark toned rock forming much of the rest of the cut slope. This light toned area almost precisely falls within the source area of 7 June 2008 landslide (Plate A2).

An access track is visible below the southern flank of the ridgeline forming the northern boundary of the landslide catchment. Minor local erosion/failure is visible in places upslope of this track. In general, the landslide catchment appears lightly vegetated.

A southwest trending deeply incised erosional gully is visible running along the spur line forming the western boundary of the catchment (Plate A1), indicating relatively deep saprolite within this area. At the far southern end of the catchment (not shown in Plate A1) the steep slopes forming much of the catchment give way to more gently inclined terrain, which is generally covered with a patchwork of fields and occasional small structures (probably agricultural/residential buildings).

1949 High flight, poor resolution, stereo coverage of central and southern portions of the landslide catchment only.

No significant changes to the study area can be discerned except a prominent recently constructed track has been formed in the southern port of the landslide catchment.

1954 High flight, moderately good resolution, stereo coverage of entire catchment.

A recent failure (54A on Figure A1) is visible below Shatin Pass Road to the west of the source of 7 June 2008 landslide. A second failure, or possible area of erosion, is also visible within the incised gully located in the south of the landslide catchment (labelled 54B on Figure A1).

Sparse shrubs/immature trees are visible within the landslide catchment.

1959 High flight, poor resolution, single aerial photograph.

Two landslides (labeled 59A and 59B on Figure A1) are visible at the western end of slope No. 11NE-A/C351. Landslide 59A is located within the source area of 7 June 2008 landslide. Two further failures are visible, the first is located below Shatin Pass Road (labeled 59C on Figure A1) and the second in the south of the landslide catchment (labeled 59D on Figure A1).

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YEAR	**OBSERVATIONS**

1963 Low flight, excellent resolution, stereo coverage of entire catchment (Plates A3 and A4).

Various anthropogenic features are visible in the terrain surrounding the source area of 7 June 2008 landslide (Plate A4). Directly upslope of slope No. 11NE-A/C351, approximately 5 to 10 m above the crest of the slope, a prominent unlined intercept channel (cut-off channel) is visible connecting to the natural drainage line located to the west of the source area. A much fainter lineament is just visible between 10 to 20 m upslope of this prominent channel, it is not possible to determine if this feature is also a channel or possible an old track.

The possible fill body supporting Shatin Pass Road previously observed in the 1945 aerial photograph is still visible.

The possible tunnels observed in the 1945 aerial photographs are still visible.

A recent landslide and debris trial is visible below Shatin Pass Road at close to the western boundary of the catchment (labeled 63A on Figure A1 and Plate A3). The recent landslide scar (59A) observed on the 1959 aerial photograph located within the source of 7 June 2008 landslide is clearly visible (Plate A4). The crest of the landslide is located along the drainage channel described above.

Site formation works for Tsz Ching Estate located to the south of the landslide catchment are ongoing.

Primarily based on the 1963 aerial photographs detailed geomorphological maps of both the landslide catchment (Figure A2) and terrain surrounding the source area (Figure A3) of 7 June 2008 landslide have been prepared.

The geomorphological characteristics of the landslide catchment can be broadly divided into three main terrain units:

- The upper hillslope terrain extends along the northern boundary of the catchment and along the western and eastern flanks of the upper catchment. It consists of relatively steep terrain (typically 25° to 45°), and generally comprising rounded poorly developed saprolitic spur lines separated by generally shallower incised ephemeral and occasional perennial drainages lines. Superficial deposits are generally restricted to minor accumulations of colluvial material within the drainage lines.

- The central hillslope terrain extends as a broad band across the middle portion of the landslide catchment and extends in a broad triangle along the central portion of the catchment to above Shatin Pass Road. It generally consist of steep rock outcrop that becomes intermittent in places and has a typical slope angle of between 40° to 55°, locally becoming 60° to 70° rock cliffs. Colluvial and talluvial deposits are developed below these cliffs and

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YEAR **OBSERVATIONS**

areas of exposed rock. Drainage lines within these areas of exposed rock are generally poorly developed ephemeral streams and follow a typically sinuous route, although at the boundary between the exposed rock and saprolite a number of more deeply incised perennial linear drainage lines have developed.

- The lower hillside terrain generally consists of relatively shallower-gradient terrain (typically 20 to 35°) forming the western and eastern flanks of the primary drainage line. The upper flanks generally consist of saprolite, whilst the shallower gradient lower flanks, often defined by a concave break in slope, are draped in a cover of hillside colluvium. Along the centre of the catchment a shallow gradient (typically 10 to 20°) elongated colluvial lobe is present. Two parallel incised drainage lines run down the western and eastern margins of the lobe. Much bouldery colluvial material is visible within the drainage lines, with boulder in excess of 4 m wide.

Many relict landslide scars are visible within the landslide catchment (Figure A2). Typically these relict landslides are located:

- below convex breaks-in-slopes marking erosional fronts,
- at the heads of drainage lines,
- open hillside within area of saprolite, and
- directly above area of exposed rock and rock cliffs.

The geomorphology of the terrain surrounding the source area of 7 June 2008 landslide (Figure A3 and Plate A4) is dominated by a erosion front, that has retrogressively incising into the mostly saprolite covered terrain present to the west of the source area. The erosion front is delineated by a prominent convex break in slope trending north-south and approximately following the western scarp of 7 June 2008 landslide (Plate A4). Upslope of the source area, the erosion front terminates along the west to east trending ridgeline forming the northern boundary of the landslide catchment. A series of poorly defined depressions below are interpreted as relict landslide scars.

Initiating close to the crown of the source area of 7 June 2008 landslide a rounded poorly developed spur line extend downslope bisecting the source area of 7 June 2008 landslide (Plate A4). This minor spur line forms a slight bulge of the ground profile above slope No. 11NE-A/C351, and accounts for the relatively deep seated nature of the landslide. Below Shatin Pass Road the spur lines becomes more pronounced.

To the northeast of the source area a prominent band of exposed rock traverse the slope following a northwest to southeast trend (Plate A4 and Figure A3). To both the southwest and northeast of this rock exposure numerous corestones and

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YEAR	**OBSERVATIONS**
	or boulders are visible along a 10 to 20 m wide zone either side of the outcrop. This area is interpreted as a zone of intermittent rock exposure or possibly *in situ* weathered rock with corestones. The presence of this band of competent rock has likely controlled the northern extent of the 7 June 2008 landslide.
	To the west of the source area of the 7 June 2008 landslide a concave break-in-slope within the two minor drainage lines directly above Shatin Pass Road, marks the location of possible colluvial deposits (Figure A3), which are exposed along the western flank of 7 June 2008 landslide.
1964	High flight, moderate resolution, stereo coverage of entire catchment.
	A minor failure, of a possible area of fill, located directly below Shatin Pass Road (labelled 64A on Figure A1) is visible.
	Ground formation works for Tsz Ching Estate are ongoing.
1967	High flight, moderate resolution, stereo coverage of entire catchment.
	In the south of the landslide catchment construction of Tse Ching Estate and associated cut slopes appears to be completed. The location and boundaries of the cut slopes above the Estate differ from the current extent shown on the 1:1000 topographic plan. Construction of the TV transmitting station on the ridgeline along the northeast boundary of the landslide catchment is ongoing.
	A large portion of the northern catchment has been affected by hillfire, the extent of which is shown on Figure A1.
1973	Low flight, excellent resolution, stereo coverage of entire catchment (Plate A5).
	Two minor recent landslide scars (labelled 73A and 73B on Figure A1 and Plate A5) can be discerned on the mid slope terrain of the catchment.
	Local areas of surface erosion are visible below the ridgeline forming the northern boundary of the catchment. These possibly developed as a result of the hillfire observed in the 1967 photographs.
	Construction of the television transmitter station located on the ridgeline in the northeast of the landslide catchment has been completed (Plate A5).
	A marked increase in the density of vegetation below Shatin Pass Road is visible; the terrain above the road remains sparsely vegetated.
1974	Low flight, good resolution, stereo coverage of entire catchment.
	No significant change within the landslide catchment is visible.
1975	High flight, moderate resolution, stereo coverage of entire catchment.

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YEAR **OBSERVATIONS**

No significant change within the landslide catchment is visible.

1976 Low flight, good resolution, stereo coverage of entire catchment.

By 1976 many agricultural terraces and a number of possible dwellings or agricultural structures are visible on the hillside flanks in the south of the landslide catchment.

1977 Low flight, good resolution, single photograph coverage of entire catchment.

No significant change within the landslide catchment is visible.

1979 Low flight, good resolution, single photograph coverage of entire catchment plus oblique aerial photograph showing the source area of 7 June 2008 landslide (Plate A6).

The unlined drainage channel previously observed is still just visible in places above slope No. 11NE-D/C351, indicating it may be partially infilled.

Above the eastern portion of slope No. 11NE-A/C351 the exposed rock forms an irregular crenulated boundary with the saprolite above (Plate A6). This is probably due to a series of failures of the natural terrain above the cut slope which probably occurred during and soon after construction.

1980 Low flight, good resolution, single photograph coverage of southern catchment.

Previously identified agricultural areas in the south of the catchment have been cleared and many dwelling are now visible covering the hillside in the south of the landslide catchment. Associated access footpaths and platforms are also visible.

1981 High flight, moderate resolution, stereo coverage of entire catchment.

Most of the landslide catchment (apart from the dense ribbons of vegetation within the primary drainage line) has recently been affected by a hillfire (FigureA1).

1983 High flight, moderate resolution, stereo coverage of entire catchment.

Extensive upgrading works on the slopes above Tsz Ching estate is ongoing, including channelization of the primary drainage line along the southern portion of the landslide catchment.

Darker strip along Shatin Pass Road indicate that recent maintenance of the road has been carried out. The dark toned areas correspond to area of possible fill, where the road crosses preexisting drainage lines.

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YEAR	**OBSERVATIONS**
1984	High flight, moderate resolution, stereo coverage of entire catchment. No significant change within the landslide catchment is visible.
1985	High flight, moderate resolution, stereo coverage of entire catchment. No significant change within the landslide catchment is visible.
1986	High flight, moderate resolution, stereo coverage of entire catchment. No significant change within the landslide catchment is visible.
1987	High flight, moderate resolution, single photograph coverage of entire catchment. No significant change within the landslide catchment is visible.
1988	Low flight, good resolution, stereo coverage of entire catchment. No significant change within the landslide catchment is visible, apart from a continuing increasing in the density of the vegetation cover across the landslide catchment.
1989	Low flight, good resolution, single photograph coverage of western portion of the catchment (Plate A7). Two recent landslide scars are visible above Shatin Pass Road (labelled 89A and 89B on Figure A1 and Plate A7). Landslide 89B corresponds to Incident No. K89/5/109 (the location of which was incorrectly recorded some 60 m to the east of the actual location). The landslide is located at the eastern end of slope No. 11NE-D/C350, where the slope cuts a minor north south trending spur line between two ephemeral drainage lines. Much of the resulting debris appears to have been deposited directly below Shatin Pass Road, possibly blocking the unlined drainage channel observed in previous images (Plate A4).
1990	Low flight, good resolution, stereo coverage of central and southern catchment. The two previously observed recent landslide scars (89A and 89B) remain clearly visible. The agricultural terraces previously observed in the south of the landslide catchment, no longer appear to be in use. There has also been a gradual increase in the number dwelling within this area; generally these have been constructed on platforms previously used for cultivation.
1993	Low flight, good resolution, stereo coverage of central and southern catchment. A minor failure or possibly an area of local erosion (labeled 93A on Figure A1) is visible on slope No. 11NE-A/C351 within the source area of 7 June 2008

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YEAR	**OBSERVATIONS**
	landslide (no incident report has been identified for this possible failure). A dark toned area on the road surface directly below the source area of 7 June 2008 landslide possibly indicates seepage, although similar possible signs of seepage have not been observed in any preceding photograph. Many of the structures previously observed on the shallow gradient footslopes in the south of the catchment have been demolished. On the lower western flank of the catchment a large area of hillside (approximately 45 by 40 m) has been cleared and many terracettes cover the area, probably as a result of farm animals.
1995	Low flight, good resolution, stereo coverage of central and southern catchment. No significant changes to the study area can be discerned except that construction of pylons on both flanks of the study area is currently underway. The lower catchment is densely vegetated with shrubs and trees, whilst the upper catchment is sparsely vegetated mostly with grasses and small shrubs.
1996	Low flight, good resolution, stereo coverage of southern catchment. Two residential blocks of Tsz Ching Estate have been demolished and construction work for replacement blocks is underway.
1998	Low flight, good resolution, stereo coverage of entire catchment. The western end of slope No. 11NE-A/C351 and the eastern end of slope No. 11NE-A/C350 have been shotcreted, together with many other slopes along Shatin Pass Road. The extent of the shotcrete on slope No. 11NE-A/C351 closely matches both the source area of 7 June 2008 landslide and the light toned area (interpreted as weathered rock or soil) observed on the 1945 aerial photograph. The shotcreted area extends upslope to the unlined drainage channel previously described. Within this area the drainage channel is no longer visible and was probably naturally infilled by the time the shotcreting was carried out. The remaining blocks of Tsz Ching Estate have been demolished and construction of replacement residential blocks is ongoing.
1999	Low flight, good resolution, stereo coverage of entire catchment (Plate A8). The extent of the recent shotcrete is clearly visible (Plate A8). The scar of the 1989 landslide (labelled 89A on Figure A1) is largely clear of vegetation indicating further failure or soil erosion has occurred. A moderately large landslide is visible on the west flank of the primary drainage line in the southern portion of the landslide catchment (labelled 99A on Figure 1A).
2000	Low flight, good resolution, stereo coverage of entire catchment.

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YEAR **OBSERVATIONS**

No significant changes to the study area can be discerned.

2001 Low flight, good resolution, stereo coverage of entire catchment.

No significant changes to the study area can be discerned.

2002 Low flight, good resolution IR photographs, stereo coverage of entire catchment.

No significant changes to the study area can be discerned.

2003 Low flight, good resolution, stereo coverage of entire catchment.

No significant changes to the study area can be discerned.

2004 Low flight, good resolution, stereo coverage of entire catchment.

Hillfire has affected much of the north and east of the landslide catchment (Figure A1), otherwise no significant changes to the study area can be discerned.

2005 High flight, good resolution, stereo coverage of entire catchment.

The temple located adjacent to the primary drainage line in the south of the landslide catchment has been constructed.

2006 Low flight, good resolution, stereo coverage of entire catchment.

No significant changes to the study area can be discerned.

2007 Low flight, good resolution, stereo coverage of entire catchment.

A slope inspection ladder has been installed at the far western end of slope No. 11NE-A/C351.

2008 Low flight, good resolution, stereo coverage of entire catchment (Plate A9).

The 7 June 2008 landslide is clearly visible and remediation work consisting of shotcreting the scar and removal of spoil from the drainage lines below is ongoing. The four separate debris flows are visible and labelled DF1 to DF4 on Plate A9.

The rock failure that occurred on slope No. 11NE-A/C351 approximately 25 m east of 7 June 2008 landslide is visible and labelled Landslide B on Plate A9.

An access track has been cut into the hillside below Shatin Pass Road to the west of the landslide, to allow access for construction plant to remove the debris that had accumulated within the drainage channel.

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

Date taken	Photograph Number	Altitude (ft)
1945	Y610	20000
1949	Y1812-13	8000
1954	Y2687-88	29200
1956	Y3438-39	16700
1959	Y4631	40000
1961	Y4914-15	30000
1963	Y8647-49 Y8248-50	4100 2700
1964	Y12929-30	12500
1967	Y13462-63	6250
1973	5329-31 6859-60	6000 3000
1974	10449-50	4000
1975	11990-91	12500
1976	15421-22 14297-98	4000 2500
1977	20216	4000
1979	28101-02	10000
1980	30133-34	4000
1981	36582-83	5500
1983	51962-63 52143-44	5000 10000
1984	57030-31	4000
1985	66995 A2686-87	4000 15000
1986	A4240-41 A8164-65	3500 10000
1987	A10248-49	3500
1988	A12841-42	4000

Note: Photographs are black and white apart from those prefixed CN, CS and CW. Photographs with RW prefix are Infra-red.

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

Date taken	Photograph Number	Altitude (ft)
1989	A17177-78 A19217, A19362	4000 10000
1990	A23610-11	4000
1993	A36083-84	4000
1995	CN11365-66 CN12313-14	3500 10000
1996	CN15840-41	4000
1998	A48436-37	4000
1999	CN25304-05	4000
2000	CN28178-79	4000
2001	CW32495-96	4000
2002	CW45064-65 RW1660-61	8000 4000
2003	CW53085-86	4000
2004	CW58915-16	4000
2005	CW64653-64 RW4883-84	3500 6000
2006	CW74739-40	8000
2007	CS05778-80	6000
2008	CS15391-93	6000

Note: Photographs are black and white apart from those prefixed CN, CS and CW.
Photographs with RW prefix are Infra-red.

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LIST OF FIGURES

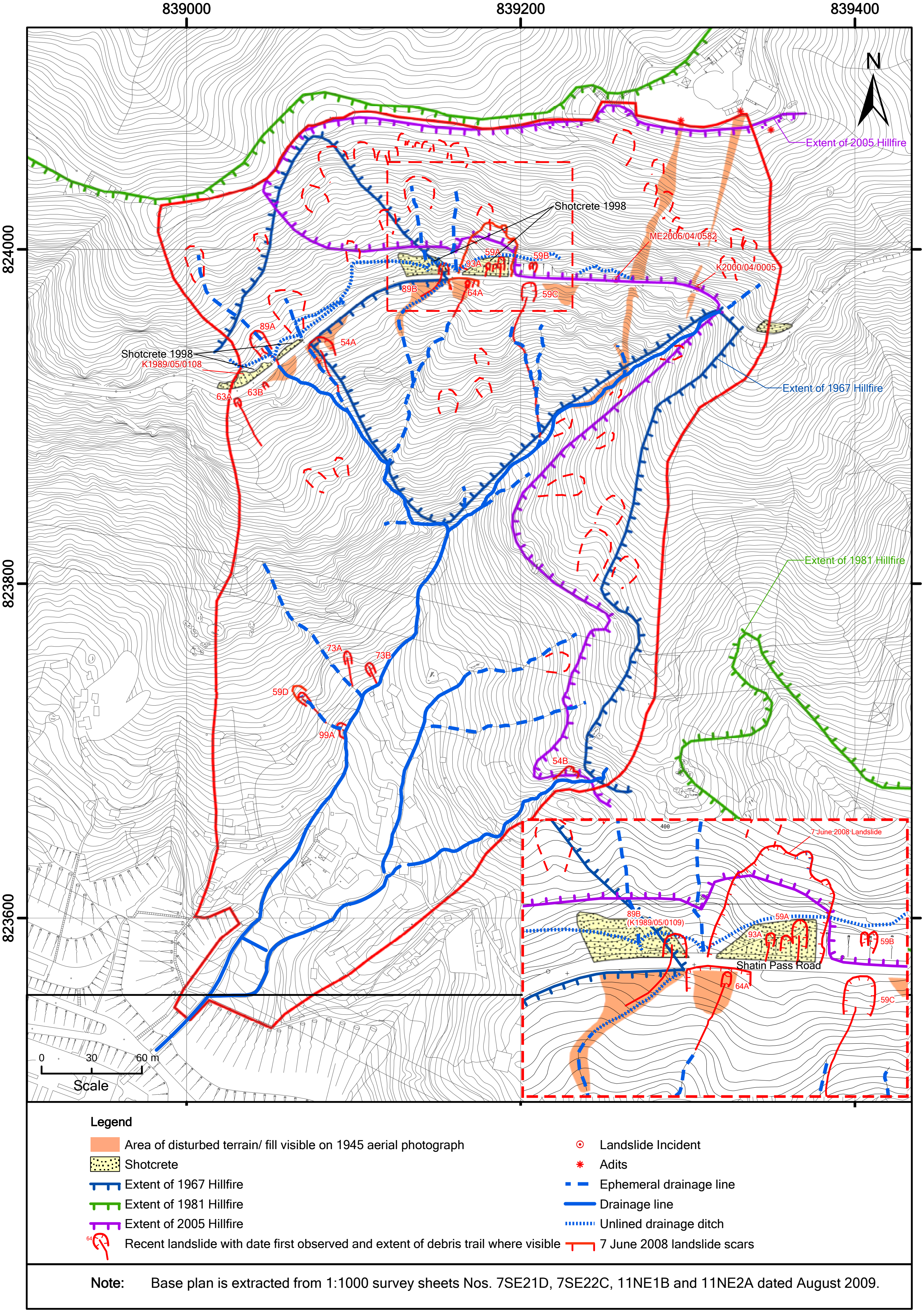

Figure A1 - Site History

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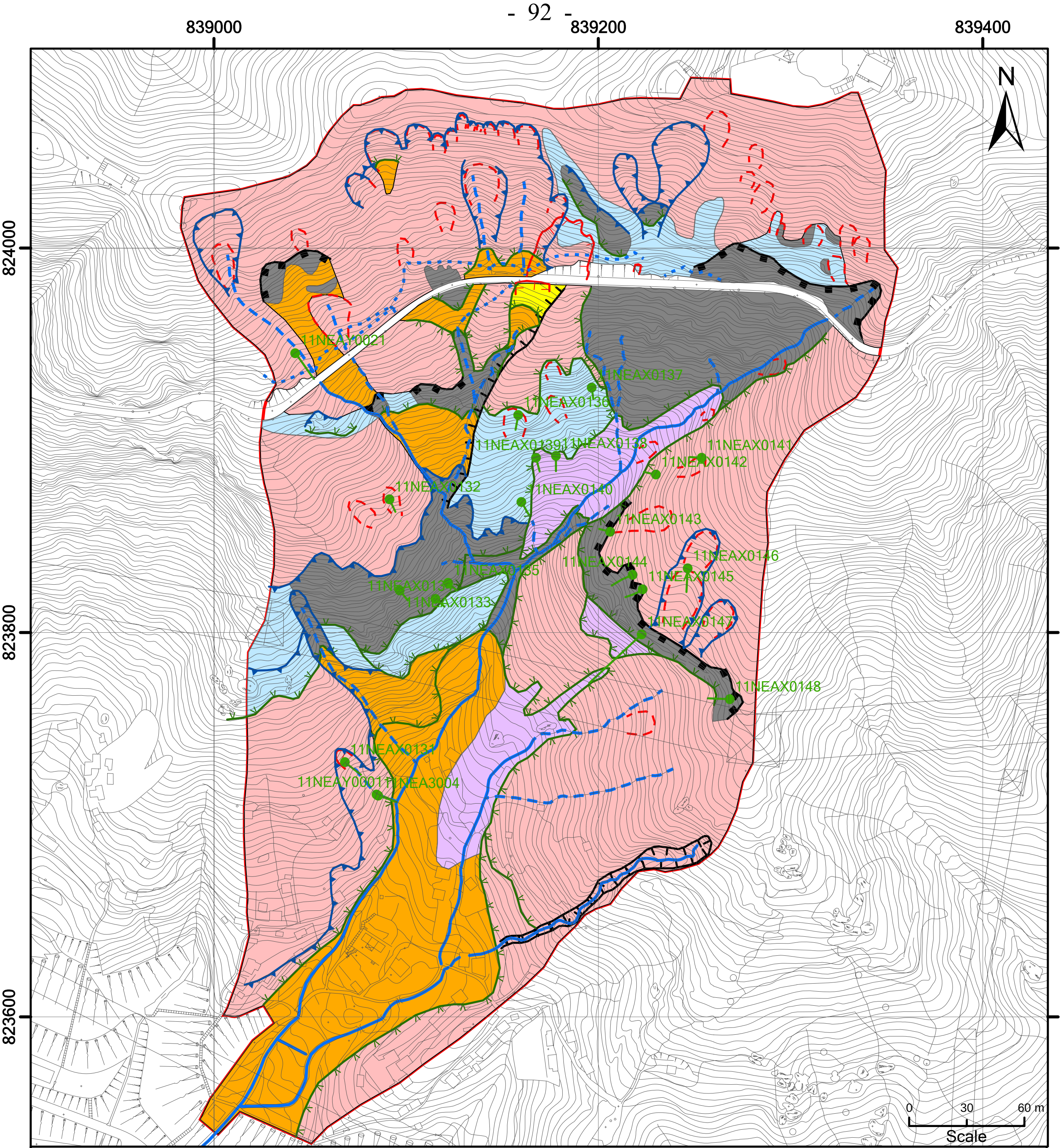

Legend

Convex break-in slope	**Morphography**	**Drainage line**
Concave break-in slope	Rock outcrop	Drainage line
Concave / Convex in close proximity	Intermittant rock grading to saprolite in places /in-situ weathered rock with corestones	Ephemeral drainage line
Rock cliff	Talluvium	Unlined drainage ditch
Relict landslide scar	Colluvium	
7 June 2008 landslide scar	Saprolite	
ENTLI and numbers	Fill	

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE21D, 7SE22C, 11NE1B and 11NE2A dated August 2009.

Figure A2 - General Geomorphology Plan of the Catchment

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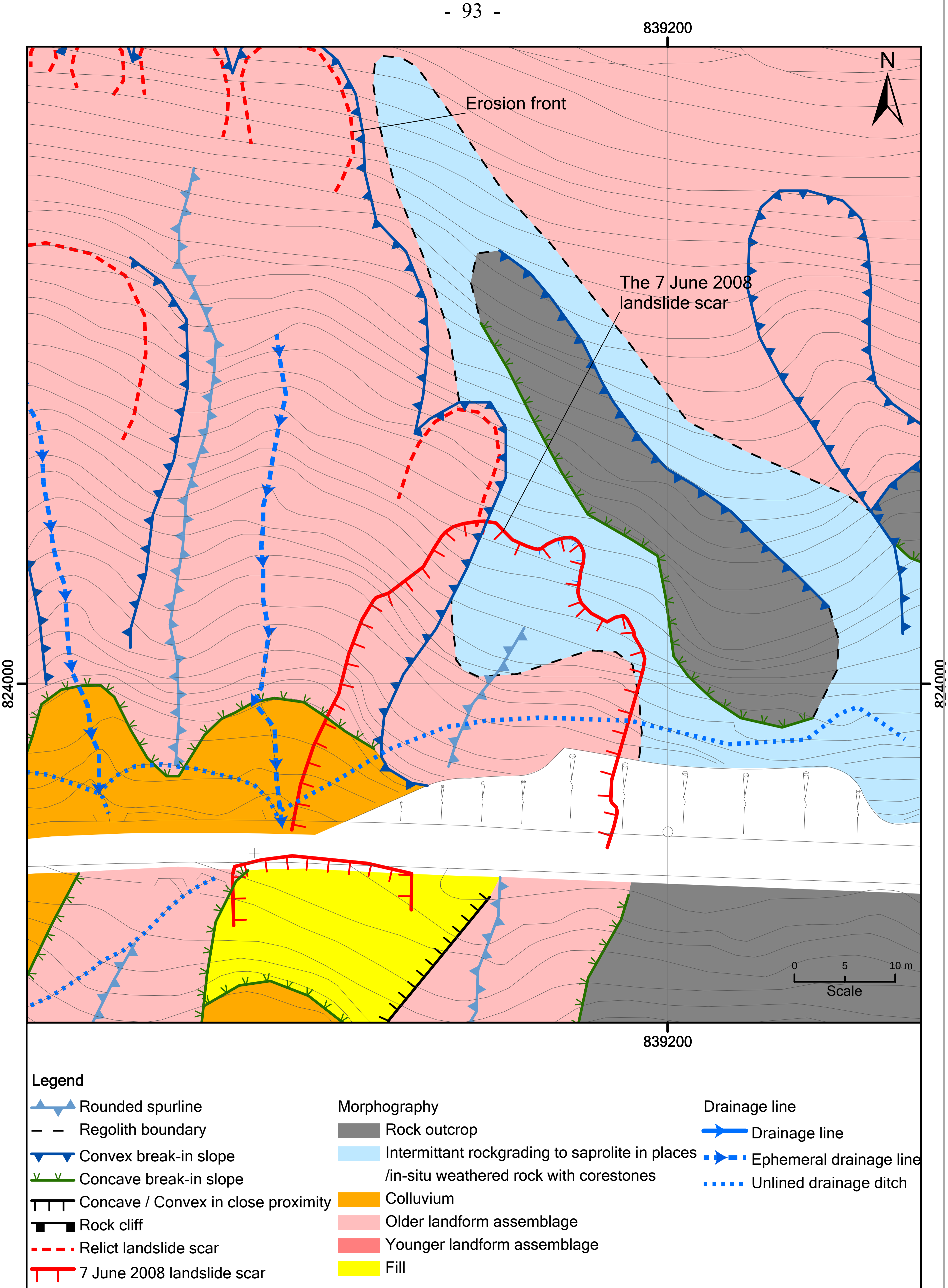

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE22C and 11NE2A dated August 2009.

Figure A3 - Geomorphology Plan of Source Area

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LIST OF PLATES

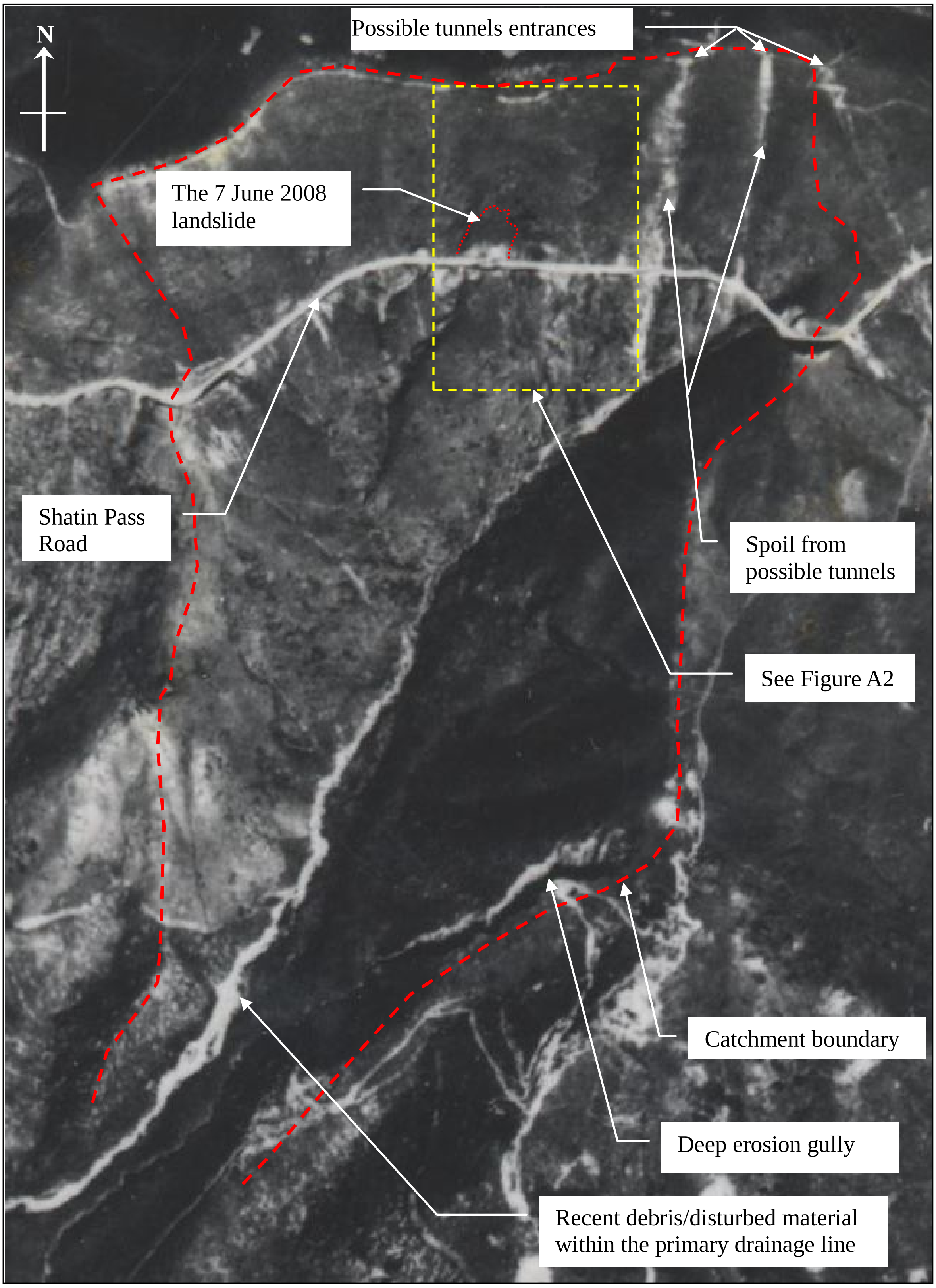

Plate A1 - Interpretation of the 1945 Aerial Photograph Showing the Landslide Catchment

Note: Interpretation carried out using aerial photographs No. Y00610.

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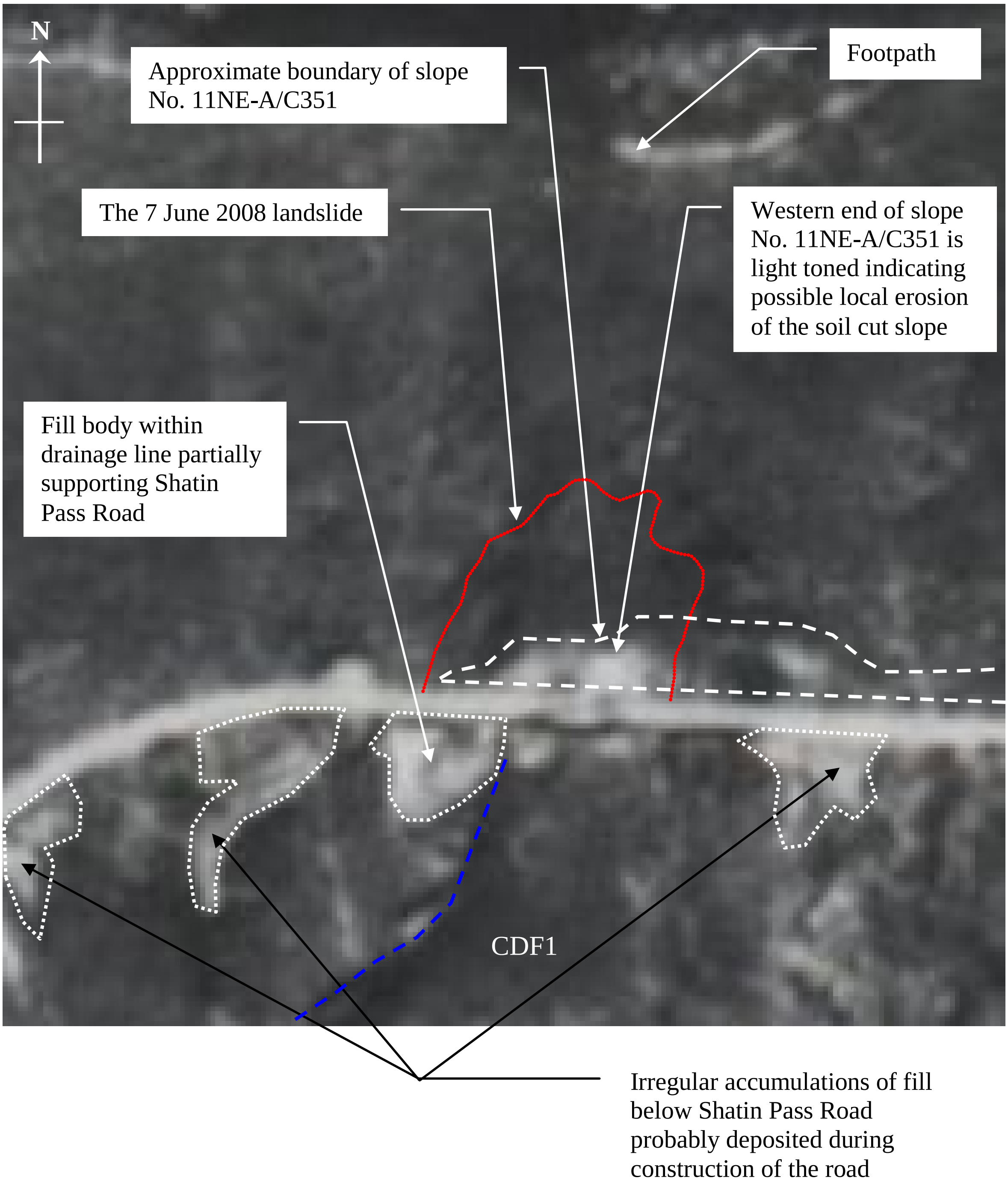

Plate A2 - Interpretation of the 1945 Aerial Photograph Showing the Landslide Source

Note: Interpretation carried out using aerial photographs No. Y00610.

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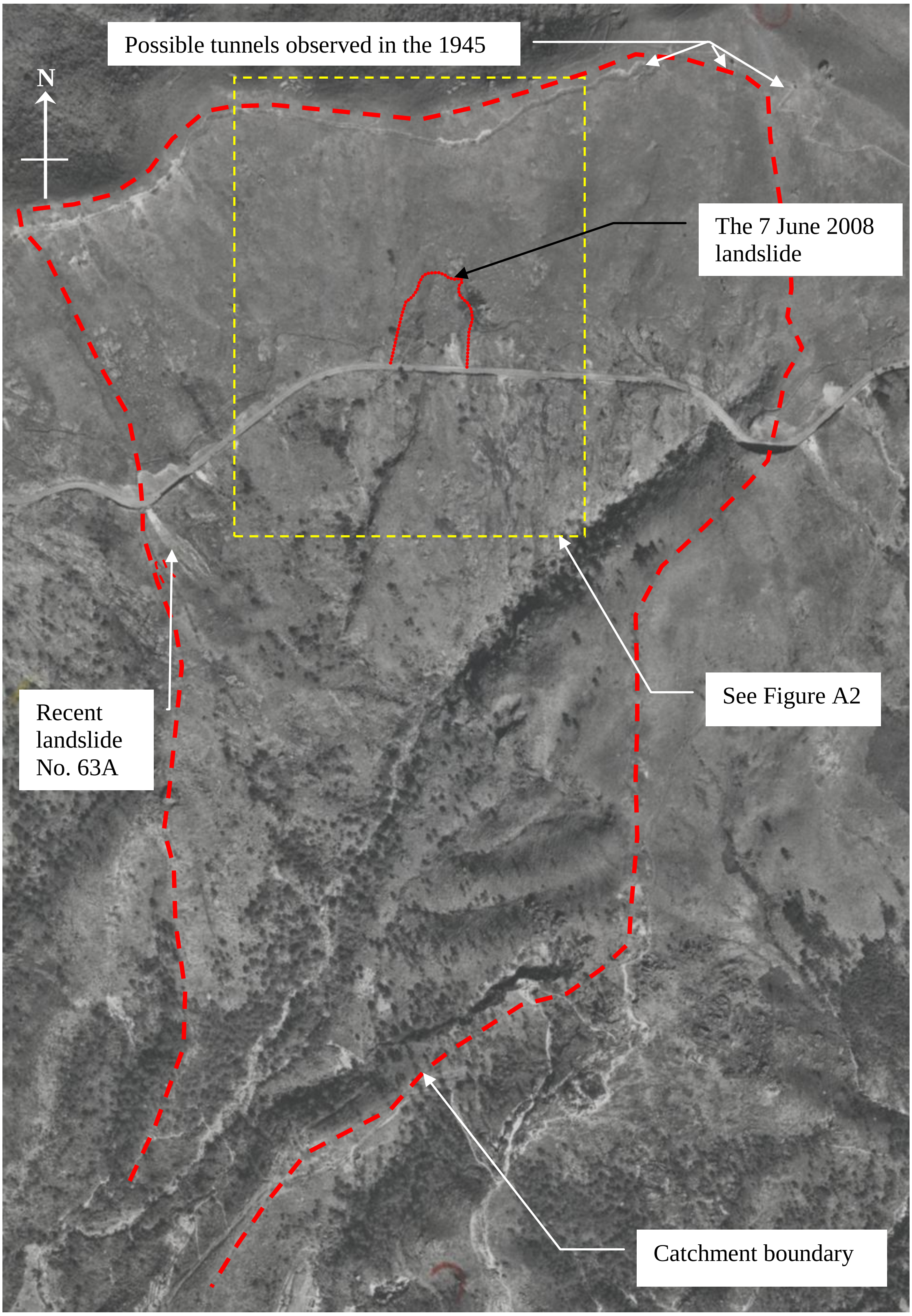

Plate A3 - Interpretation of the 1963 Aerial Photograph Showing the Landslide Catchment

Note: Interpretation carried out using aerial photographs Nos. Y08648 - Y08649.

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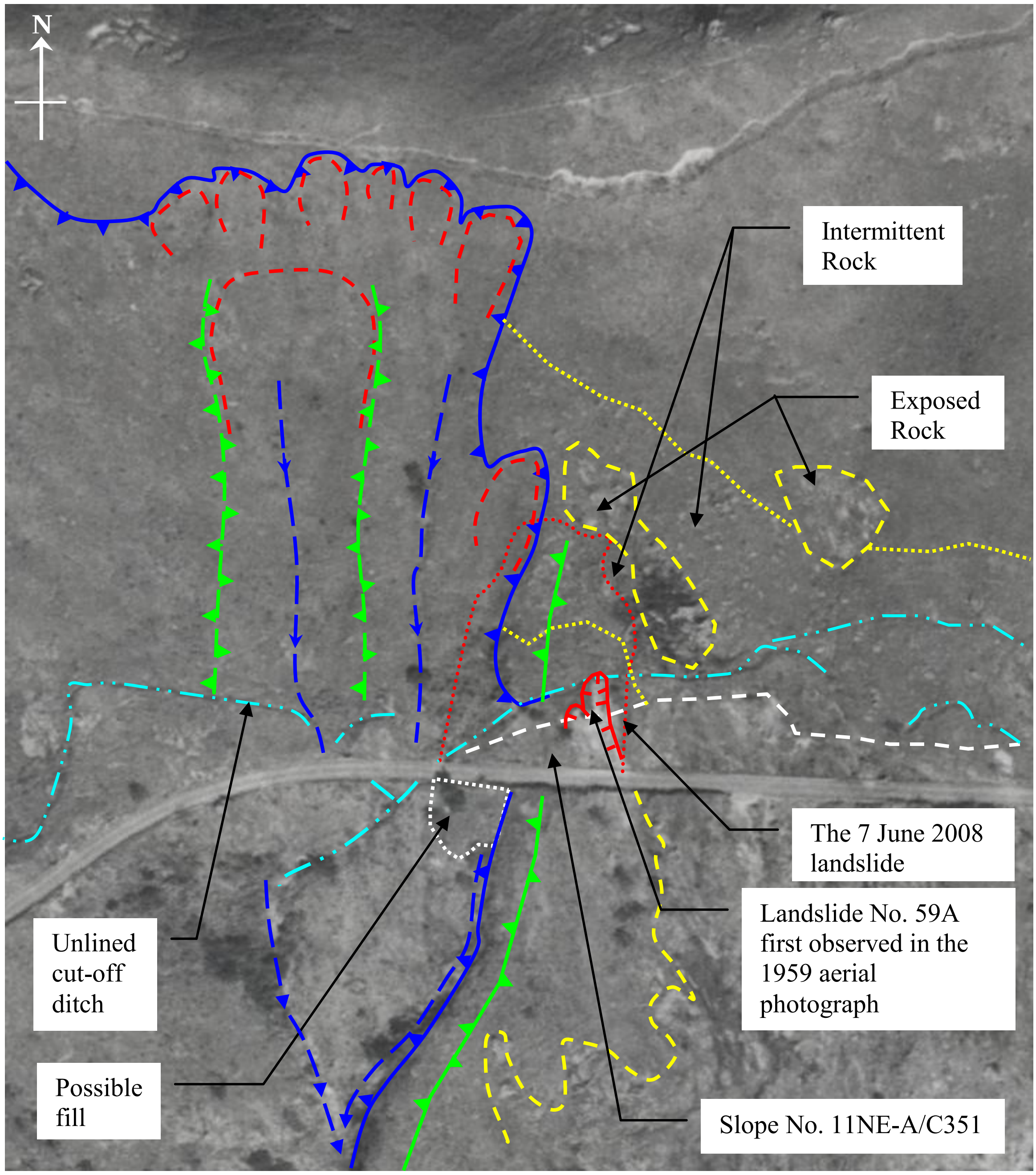

Plate A4 - Interpretation of the 1963 Aerial Photograph Showing the Landslide Source

Legend:

Rounded spur line	Relict landslide
Convex break in slope	Recent landslide
Ephemeral drainage line	Area of exposed rock
Open unlined drainage channel / ditch	Area of intermittent exposed rock

Note: Interpretation carried out using aerial photographs Nos. Y08648 - Y08649.

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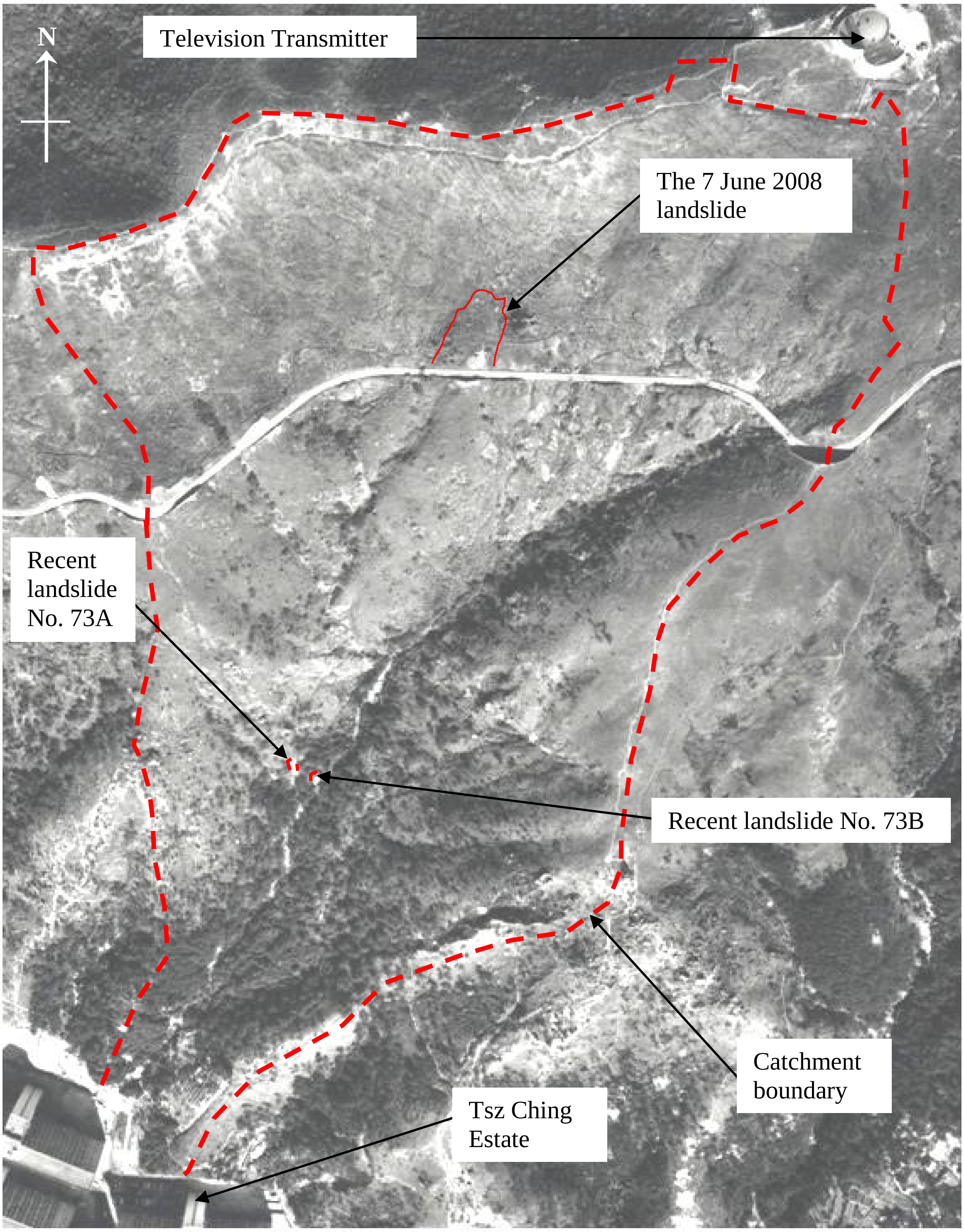

Plate A5 - Interpretation of the 1973 Aerial Photograph Showing the Landslide Catchment

Note: Interpretation carried out using aerial photographs Nos. 6859 - 6860.

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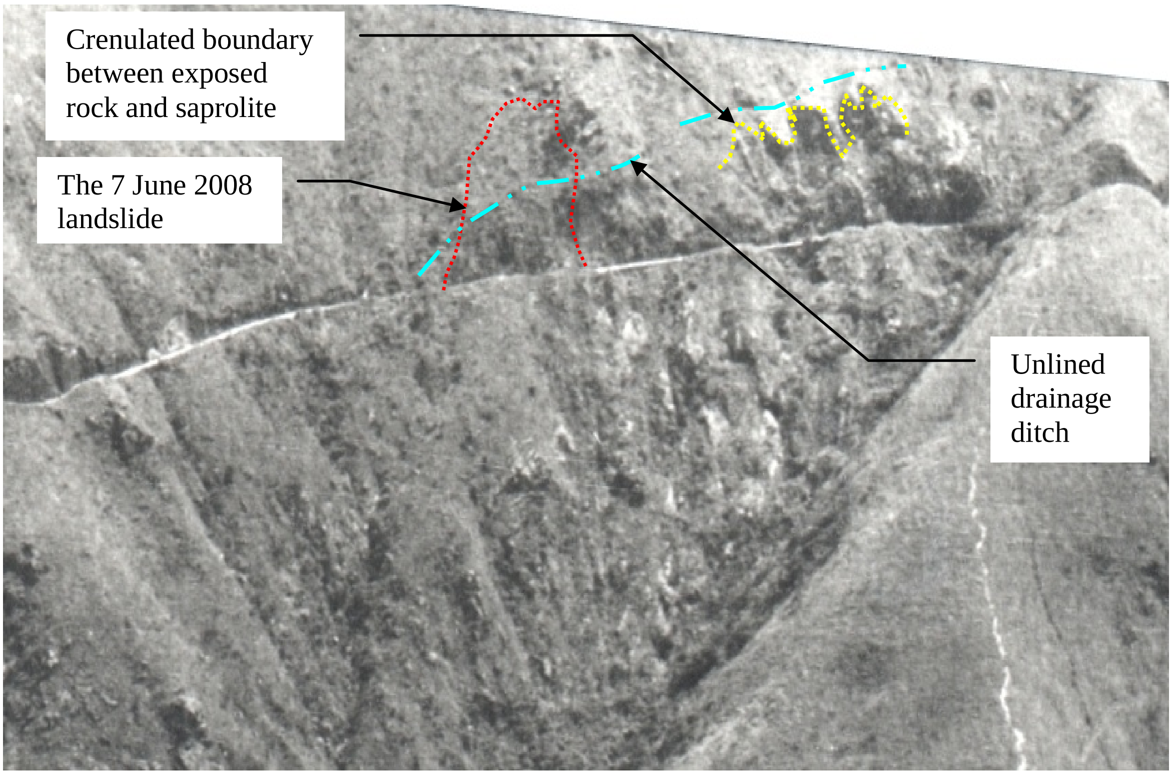

Plate A6 - Interpretation of the 1979 Oblique Aerial Photograph Showing the 7 June 2008 Landslide Source

Note: Interpretation carried out using aerial photographs Nos. 6859 - 6860.

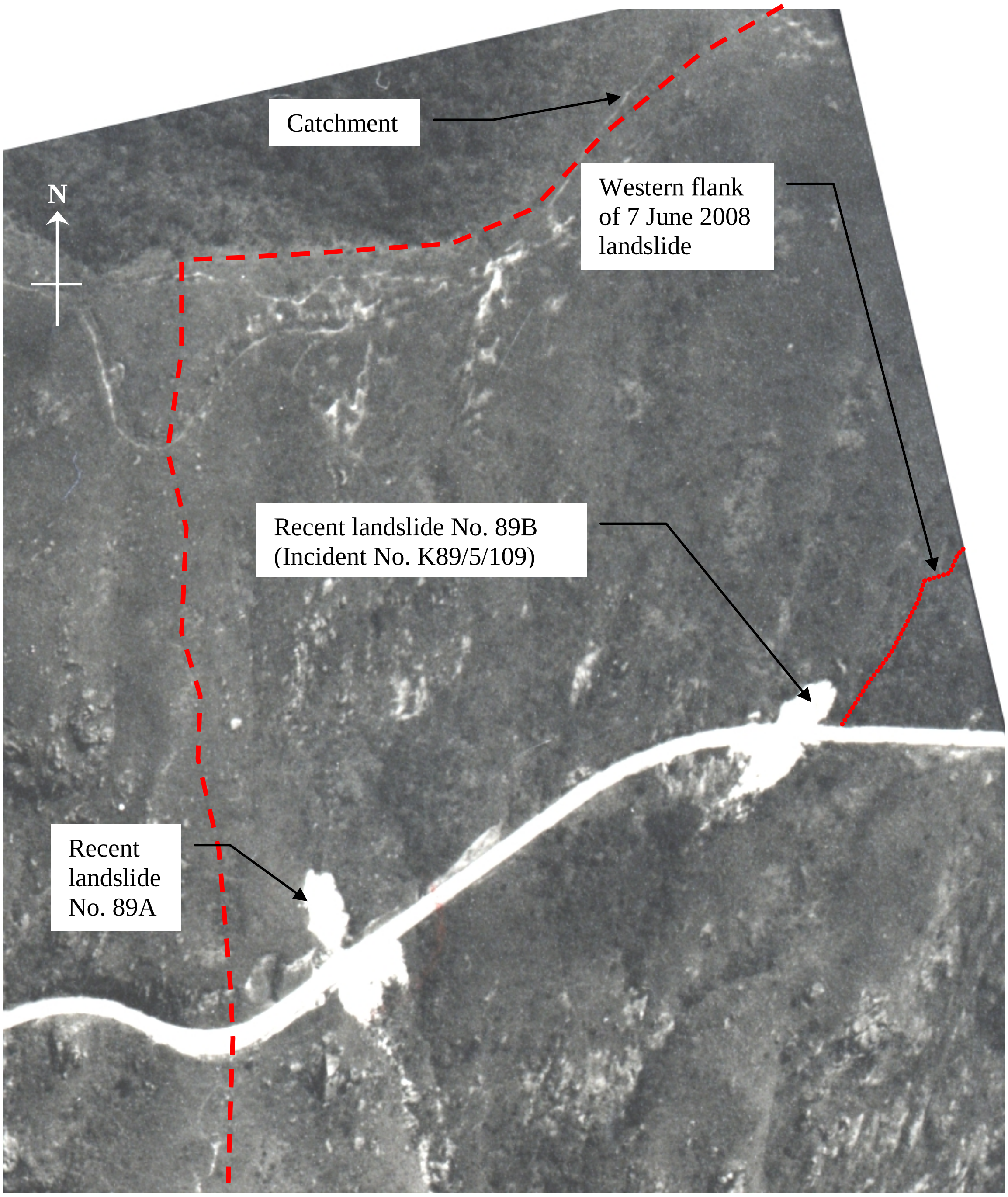

Plate A7 - Interpretation of the 1989 Aerial Photograph Showing the Northwest Section of the Landslide Catchment (Note image is highly elongated as site is located on the edge of image)

Note: Interpretation carried out using aerial photographs No. A17178.

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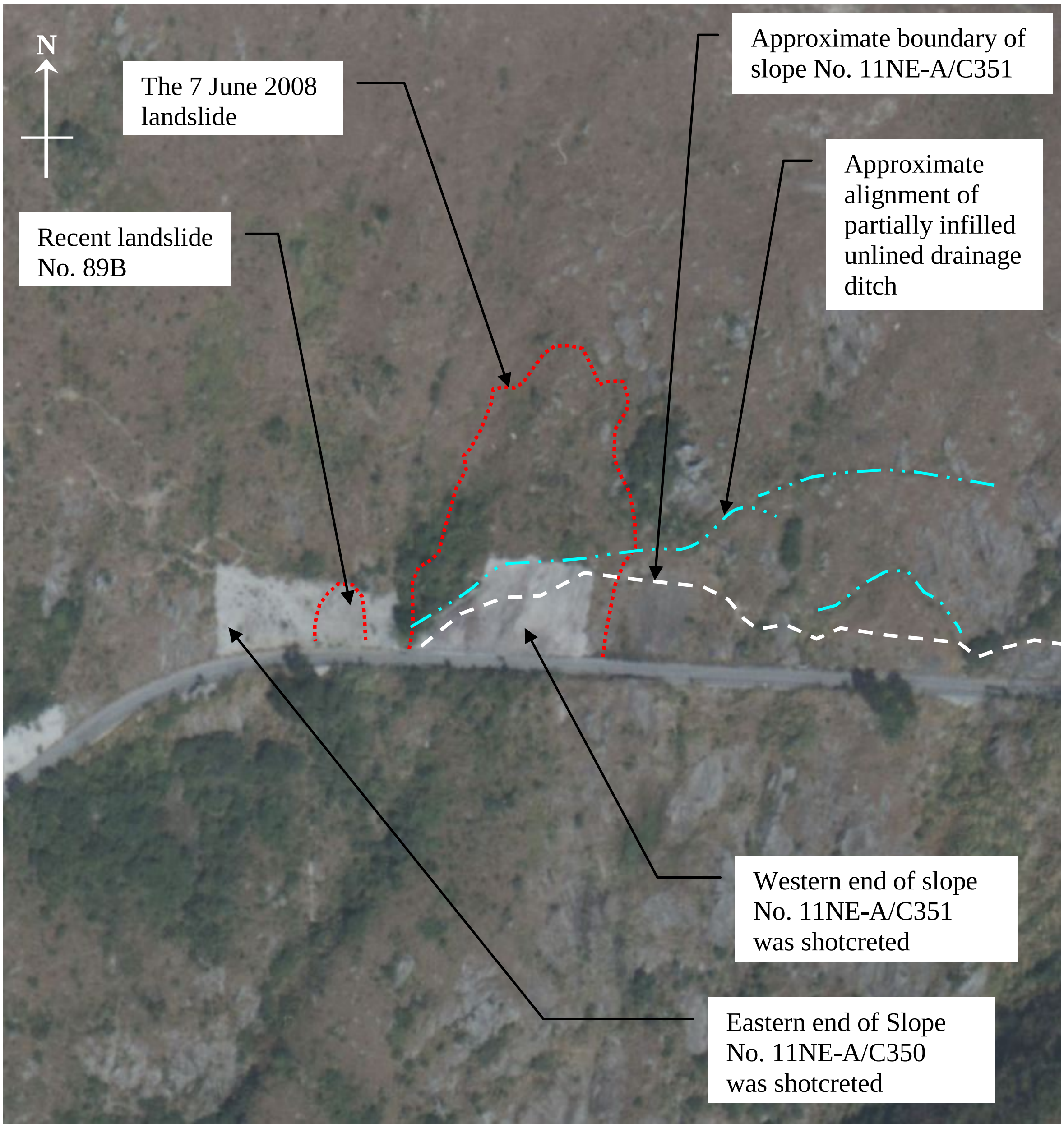

Plate A8 - Interpretation of the 1999 Aerial Photograph Showing the Landslide Source

Note: Interpretation carried out using aerial photographs Nos. CN25304 - 05.

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Plate A9 - Interpretation of the 2008 Aerial Photograph Showing the Source of the 7 June 2008 Landslide

Note: Interpretation carried out using aerial photographs Nos. CS15391 - 93.

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APPENDIX B

SOURCE VOLUME DETERMINATION

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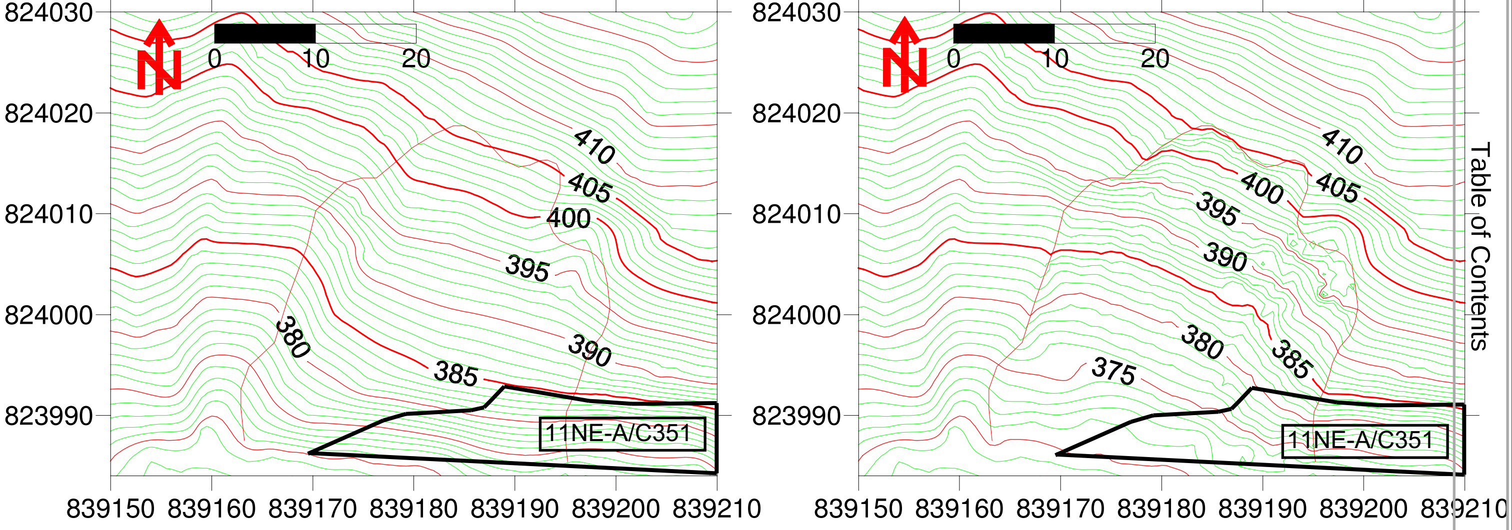
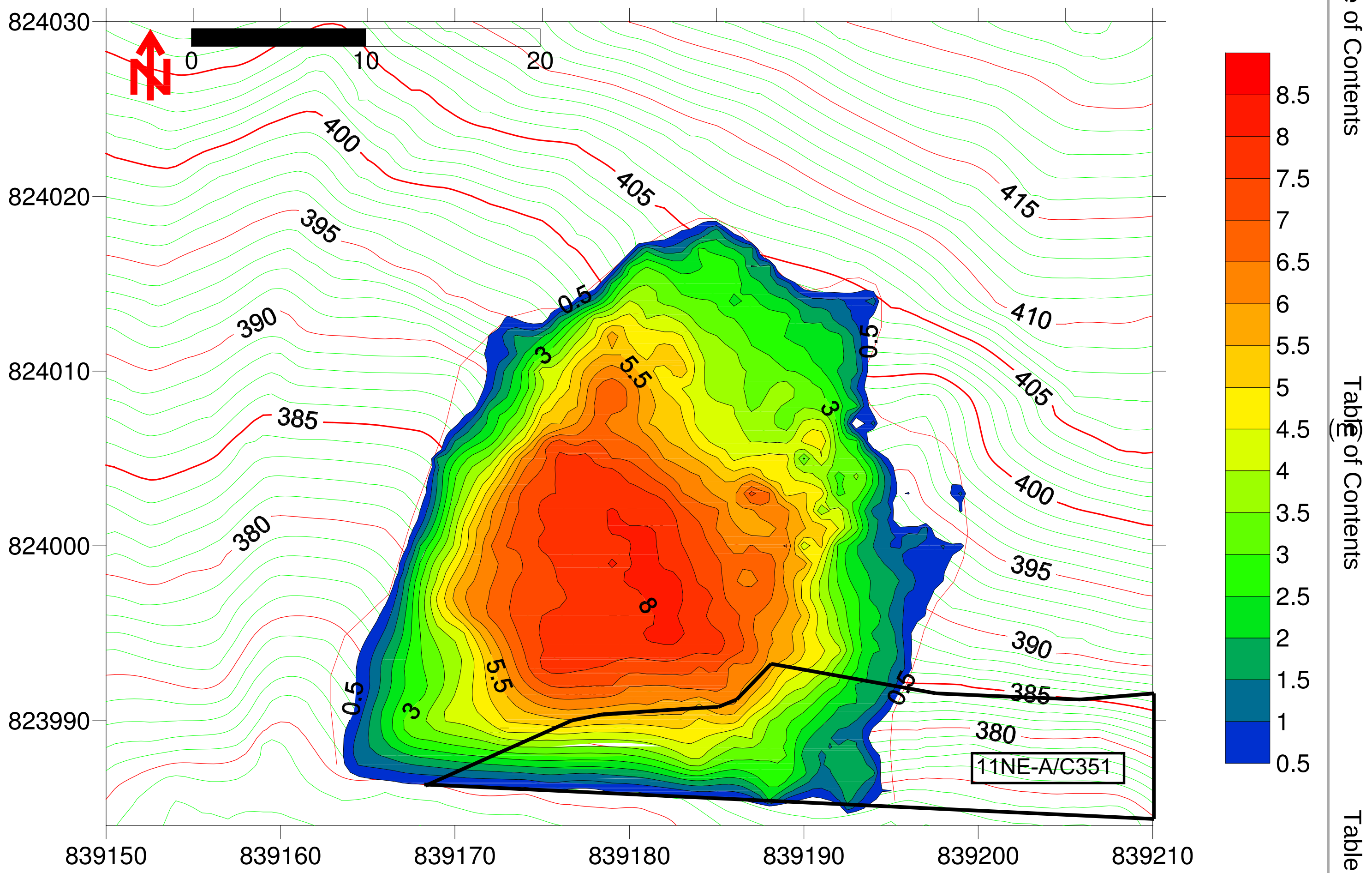


Pre-failure ground model based on photogrammetric analyisis of aerial photographs CS05778 and CS05779 dated 06 Jan 2007

Post failure ground model of surface of rupture based on laser scan and spot level surveys carried out by HyD in June 2008

The source volume of the 7 June 2008 landslide was determined to be 3,500 m^3 by comparing the pre-failure and post-failure ground models.



Contoured isopach vertical thickness of source area

Figure B1 - Source Volume Determination

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APPENDIX C

CHRONOLOGICAL SUMMARY OF FLOODING/INUNDATION EVENTS WITHIN TSZ CHING ESTATE

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Table C1 - Chronological Summary Table of Recorded Flooding/Inundation Events within Tsz Ching Estate and Observatory Warning Signals (Sheet 1 of 4)

Date	Rainstorm Warning Signals from the Observatory +	Recorded Observation within Tsz Ching Estate
3 June	Amber from 18:35 to 20:10	
6 June	Amber from 13:20 to 16:10	
7 June	Amber from 5:15 to 5:55 Red from 5:55 to 6:40 Black from 6:40 to 11:00 Red from 11:00 to 11:30 Amber 11:30 to 13:30	At 12:05 pm, Security Officer No. CSO 30423 reported that a landslide occurred on the hillside behind Ching Tai House. The security Officer described that substantial amount of muddy water travelled down to the area behind Ching Tai House and caused flooding. At 12:10 pm, Security Officer No. CSO 30666 arrived at the site and reported that landslide debris had blocked the drainage culvert behind Ching Tai House. As a result, muddy water was flowing from the blocked culvert along the access road behind Ching Tai House. The estate drainage became blocked with debris, resulting in flooding of the estate.
8 June		It was reported that flooding problem was being alleviated by opening the drainage culvert. DSD reported that about 2000 tonnes of debris (a very approximate estimate) was deposited within Tsz Ching Estate. The debris completed blocked the U-channel behind Ching Tai House resulting in further inundation of the estate with muddy water and outwash debris.
10 June		The inlet trap above slope No. 11NE-A/C300 was totally blocked with outwash debris. Catchpit within the estate were found to be choked by mainly sand with some gravel and small boulders. The washout materials within Tsz Ching Estate largely consisted of sand/silt. Clearance work was ongoing within the estate to remove the outwash debris.
11 June		Clearance of outwash debris within the estate was ongoing. Both the catchpit and channel behind Ching Tai House remained totally blocked with debris.
13 June	Amber from 21:40 to 22:15 Red from 22.15 to 00:00	**A large volume** of **new debris has been deposited within the estate and associated drainage**. A mini excavator being used for clearance of the debris was partially buried by this new debris.
14 June	Red from 0:00 to 2:50 Amber from 2:50 to 4:10	**A large volume of new debris has been deposited within the estate and associated drainage**, almost completely filling the area behind the fence along the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10.

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Table C1 - Chronological Summary Table of Recorded Flooding/Inundation Events within Tsz Ching Estate and Observatory Warning Signals (Sheet 2 of 4)

Date	**Rainstorm Warning Signals from the Observatory +**	**Recorded Observation within Tsz Ching Estate**
15 June		Clearance work was ongoing within the estate to remove the outwash debris. The debris being removed predominately consisted of fine material. Both the inlet trap located at the crest of slope No. 11NE-A/C300 and the catchpit and U-channel located at the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10 remains totally blocked with outwash debris.
18 June		Clearance work was ongoing within the estate to remove the outwash debris. The inlet trap at the crest of slope No. 11NE-A/C300 is shown as partially cleared. Barriers have been places around the western end of Ching Tai House.
19 June		Clearance work was ongoing within the estate to remove the outwash debris. The inlet trap at the crest of slope No. 11NE-A/C300 is approximately 95% of the debris has been removed.
20 June		Clearance work was ongoing within the estate to remove the outwash debris. The inlet trap at the crest of slope No. 11NE-A/C300 is shown as 100% cleared of debris. Very minor water flow is visible within the channel. About 80% of the outwash debris deposited in the catchpit and U-channel located at the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10 has been removed.
23 June	Fengshen (No. 1) from 7:40 to 0:00	
24 June	Fengshen (No. 1) from 0:00 to 16:40 Fengshen (No. 3) from 16:40 to 22:45 Fengshen (No. 8) from 22:45 to 0:00	Small amounts of sand were washed into the catchpit and the U-channel behind Ching Tai House. Additional barriers have been placed around Ching Tai House.
25 June	Fengshen (No. 8) from 0:00 to 11:15 Amber from 5:15 to 6:00 Red from 6:00 to 10:10 Amber from 10:10 to 12:20 Fengshen (No. 3) from 11:15 to 22:15	Relatively small quantities of cobbles have been deposited within the inlet trap above slope No. 11NE-A/C300. Strong water flow is visible within the channel.

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Table C1 - Chronological Summary Table of Recorded Flooding/Inundation Events within Tsz Ching Estate and Observatory Warning Signals (Sheet 3 of 4)

Date	Rainstorm Warning Signals from the Observatory +	Recorded Observation within Tsz Ching Estate
26 June	Amber from 8:30 to 8:50 Red from 8:50 to 10:00	Relatively small quantities of cobbles are still visible within the inlet trap above slope No. 11NE-A/C300. Strong water flow is visible within the channel.
27 June		The inlet trap above slope No. 11NE-A/C300 is about 10% blocked with generally fine debris with some cobbles. Strong water flow is visible within the channel.
4 July		Both the inlet trap at the crest of slope No 11NE-A/C300 and the catchpit and U-channel located at the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10 have been cleared of all debris.
6 July	Amber from 17:35 to 19:20	
8 July	Amber from 9:15 to 10:45	Much sandy debris was reported to have been washed into the catchpit located at the toe of slope No. 11NE-A/C610.
10 July	Amber from 6:35 to 11:15	
11 July		Site record report a minor flow of muddy water into the U-channel located at the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10. Record photographs show the inlet trap above slope No. 11NE-A/C300 to be clear of debris with a moderate water flow.
12 July	Red from 3:00 to 7:10 Amber from 7:10 to 7:45	**A large volume of new debris has been deposited within the estate** and associated drainage. Record photographs show the area behind the fence along the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10 to be about 50% filled with landslides debris generally consisting of cobbles and occasional small boulders, the catchpit is totally filled with debris. A large quantity of finer outwash debris has been deposited on the levels area surrounding Ching Tai House.
14 July	Amber from 23:25 to 0:00	Record photographs show clearance work was ongoing within the estate to remove the outwash debris.
15 July	Amber from 0:00 to 1:30	
8 Aug		Record photographs show clearance work within the estate to remove the outwash debris has generally been completed. Additional sandbags have been places along the toe of slopes Nos. 11NE-A/C610 and 11NE-A/C10 and around Ching Tai House.

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Table C1 - Chronological Summary Table of Recorded Flooding/Inundation Events within Tsz Ching Estate and Observatory Warning Signals (Sheet 4 of 4)

Date	Rainstorm Warning Signals from the Observatory +	Recorded Observation within Tsz Ching Estate
21Aug		Record photographs show the estate to have been cleared of debris.

Legend:

\+ Amber - Amber Rainstorm Warning Signals
Red - Red Rainstorm Warning Signals
Black - Black Rainstorm Warning Signals
Fengshen (No. x) - Tropical Cyclone Warning Signal No. x - Fengshen

APPENDIX D

GROUND INVESTIGATION RECORDS

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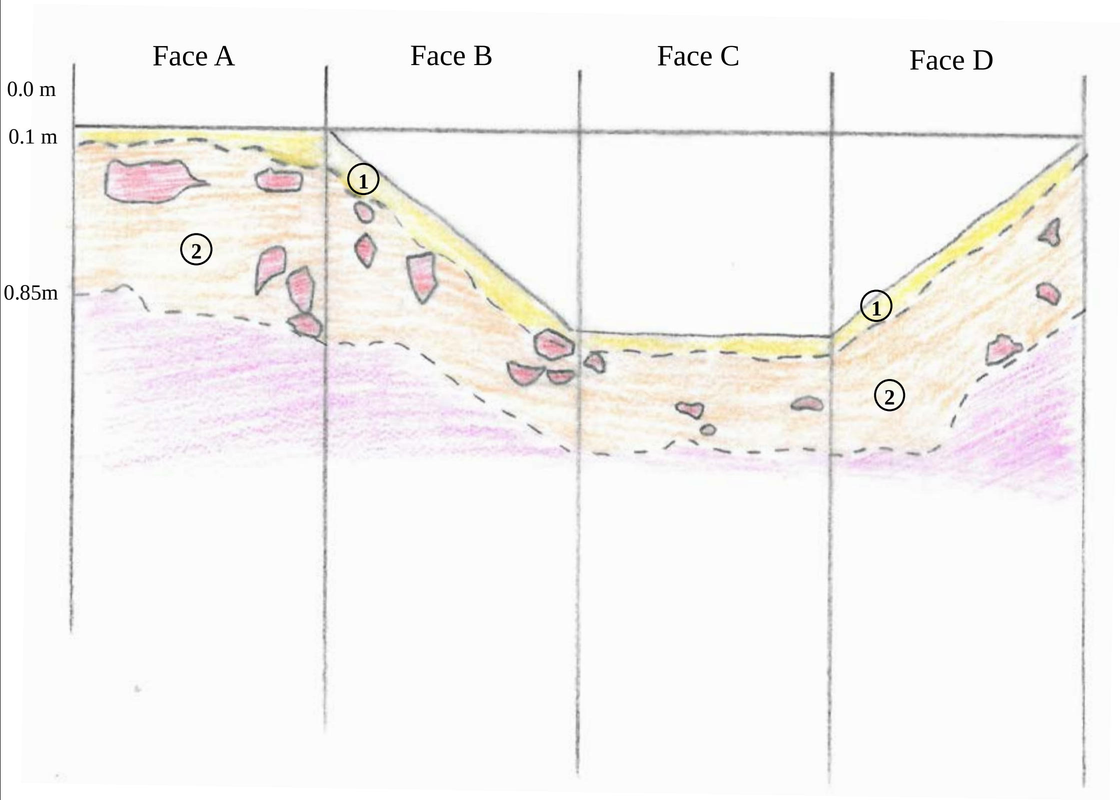
LIST OF FIGURES

Trial Pit No. TP1 Logged by: L. Zhang Checked by: Martin Devonald Date: 14/12/09



Descriptions

(1) Loose, dry, brown (7.5YR5/2), clayey silty fine to medium SAND with some subangular fine to medium gravel, occasional cobbles of rock and quartz fragments and rootlets. [TOP SOIL]

(2) Dense, moist, grey (7.5YR6/1) to light yellowish brown (10YR6/4) mottled very pale brown, clayey silty sandy angular to subangular fine to coarse GRAVEL with some cobbles occasional cobbles of moderately weak to moderately strong granite fragments. [COLLUVIUM]

Bottom: Moderately strong, very pale brown, moderately decomposed medium grained GRANITE with very closely to closely spaced rough planar, extremely narrow, manganese and oxide stained joints. Joints are measured as following: J1:070°/69° (Mn and sandy clayey silt coating), J2:083°/83° (Mn and sandy clayey silt coating), J3:145°/48° (Mn and sandy clayey silt coating), J4:050°/68° (Mn and sandy clayey silt coating), J5:164°/181(Fe)

Figure D1 - Trial Pit Record for TP1

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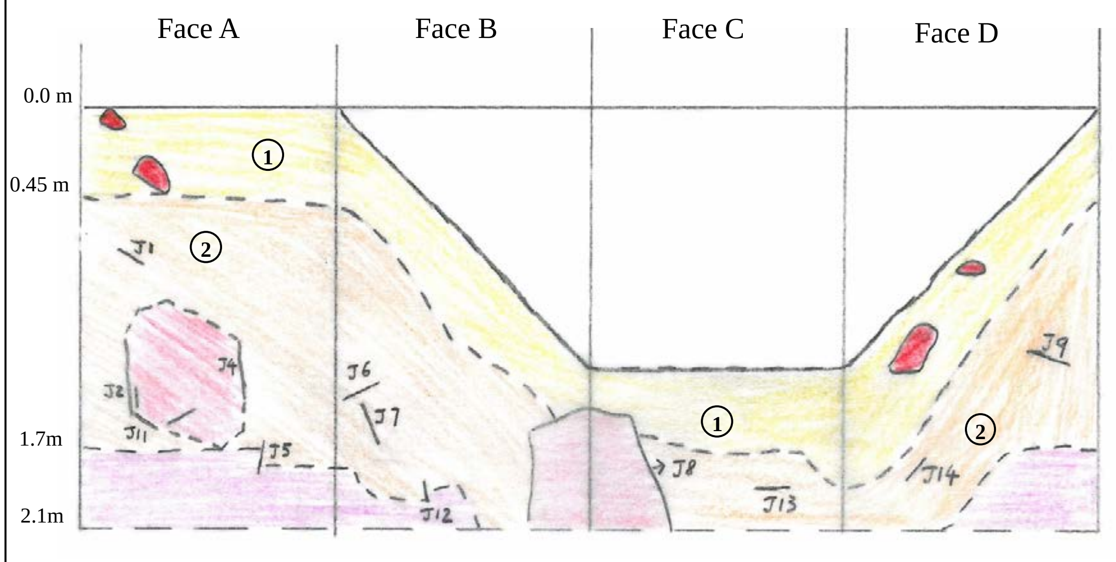
Trial Pit No. TP2 Logged by: L. Zhang Checked by: Martin Devonald Date: 14/12/09



Descriptions

① Dense, locally loose, grey (7.5YR6/1) to light yellowish brown (10YR6/4), clayey silty fine to medium SAND with some angular to subangular tine to coarse gravel and cobbles of weak to moderately strong granite and rootlets. [COLLUVIUM]

② Very weak to weak, locally moderately weak to moderately strong, very pale brown, highly locally moderately decomposed medium grained GRANITE microfractured. (Sandy fine to coarse GRAVEL) with very closely to closely spaced, rough planar, tight to extremely narrow, iron and manganese oxide stained kaolin (<2mm) joints measured as following: J1:060°/50° (Fe), J2:095°/76° ((kaolin (<3mm)), J3:035°/58°((Fe and soil (<2mm)), J4: 100°/72°((kaolin (<3mm)), J5: 145°/73° (Fe), J6:145°/77°((Fe), J7:145°/77° (Fe), J8:230°/65°, J9:100°/70°(Fe), J10:066°/34° (Fe), J11:050°/59° (Fe), J12:110°/71° (Fe), J13:190°/80° (Fe), J14: 205°/85° (Fe).

1.70m to 2.10m: Moderately strong, moderately decomposed medium grained GRANITE.

Figure D2 - Trial Pit Record for TP2

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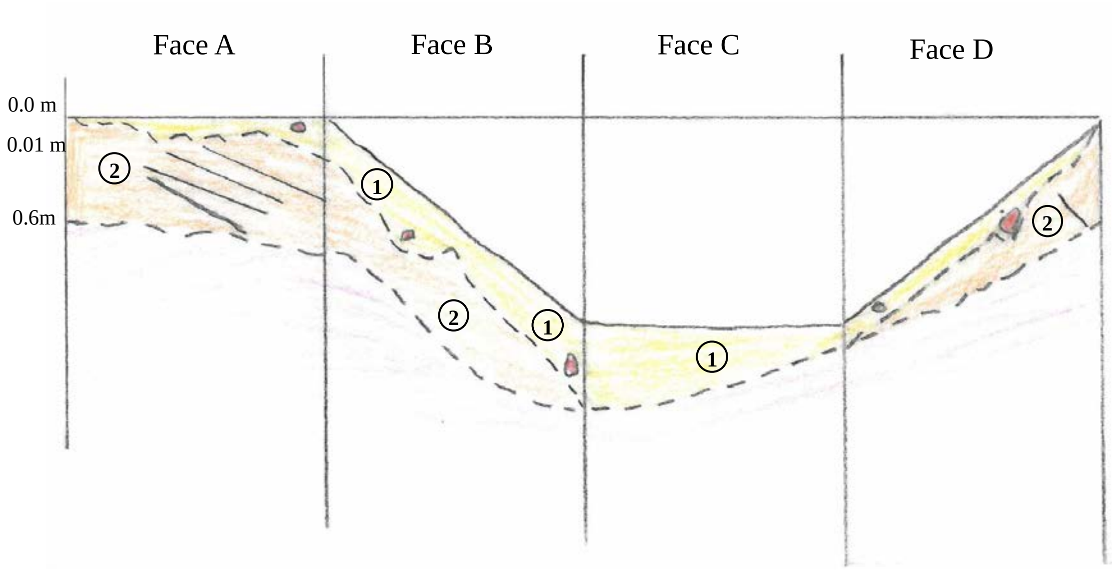
Trial Pit No. TP3 Logged by: L. Zhang Checked by: Martin Devonald Date: 14/12/09



Descriptions

(1) Loose, dry to moist, grey (7.5YR6/1), clayey silty fine to medium SAND with some angular to subangular fine to coarse gravel and cobbles, occasional boulders of rock and quartz fragments and rootlets. [TOP SOIL]

(2) Extremely weak to very weak, very pale brown (10YR8/2), completely to highly decomposed medium grained GRANITE. (Slightly silty fine to coarse SAND with some fine to medium gravel) with closely spaced, extremely narrow to very narrow, iron and manganese oxide stained or colluviums soil infilled.

Bottom: Moderately strong, moderately decomposed joints measured as following:

J1:057°/47° (Fe+Mn), J2:170°/48° (Fe+Mn), J3:350°/22° (Mn), J4:156°/47° (Fe+Mn)

Figure D3 - Trial Pit Record for TP3

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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。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Unit,
Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港北角渣華道333號
北角政府合署6樓626室
政府新聞處
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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.
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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.

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