# DETAILED STUDY OF THE 7 JUNE 2008 LANDSLIDES ON THE HILLSIDE ABOVE THE NORTH LANTAU HIGHWAY AND CHEUNG TUNG ROAD, NORTH LANTAU

**GEO REPORT No. 272**

**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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**AECOM Asia Company Limited**

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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.

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

Y.C. Chan
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October 2012

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# FOREWORD

This report presents the findings of a detailed study of the natural terrain landslides that occurred on the hillside above North Lantau Highway (NLH), Tung Chung, Northern Lantau, on 7 June 2008 during a Black Rainstorm.

A total of 38 landslides occurred on the hillside above NLH; four of them developed into channelised debris flows (CDFs). The debris flows terminated within the drainage lines without affecting any toe facilities. However, debris flood occurred in three catchments, transporting a total of approximately 540 $m^3$ of sediment/debris further downstream. The sediment/debris blocked the drainage system at the hillside toe along Cheung Tung Road, resulting in severe flooding of the adjoining NLH. The highway, which is the critical transport corridor to the Hong Kong International Airport, was temporarily closed for about 16 hours and reopened around 1:00 a.m. on 8 June 2008. No casualties were reported as a result of the landslides.

The study focuses on selected landslides with long runout distances. The key objectives were to document the facts about the long runout landslides, present relevant background information, establish the probable causes of the landslides and debris movement processes. The scope of the study comprised desk study, site reconnaissance, detailed field mapping, 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 the 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

During the intense rainfall in the early morning of 7 June 2008, a total of 38 landslides occurred on the hillside above North Lantau Highway (NLH), Northern Lantau (Figure 1, Plate 1). Of the 38 landslides, four that occurred in catchments Nos. 15, 19 and 21 developed into channelised debris flows (CDFs) after the landslide debris entered nearby prominent drainage lines. The runout distance of the debris flows ranged from 200 m to 735 m (Figure 1 and Table 1). The CDF with the longest runout distance occurred in catchment No. 15, and was reported as incident No. 2008/06/0346. All the CDFs terminated within the drainage lines, without reaching the toe of the hillside.

The remaining 34 landslides generally involved open hillslope failures. In some cases, the debris entered a less prominent drainage line or topographic depression and the debris movement process involved a mechanism mixed between an open hillslope landslide and a CDF, with a runout distance up to 170 m (Table 1). All the debris was deposited on the hillside or within the drainage lines.

Debris floods occurred in three hillside catchments (Nos. 15, 16 and 17).

The debris flood in catchment No. 15 probably occurred as a longitudinal extension of the CDF. While the coarse material deposited as a CDF boulder front deposit at CH735, the more dilute, sediment charged flow (i.e. debris flood) continued further downstream probably due to a large water flow arising from the merging of the two prominent drainage lines some 40 m upstream. The debris flood transported some 400 $m^3$ of sediment/debris further downstream. The sediment/debris blocked the drainage system along Cheung Tung Road and resulted in severe flooding affecting the adjoining NLH (Figure 1, Plates 2 and 3). Consequently, the west bound lanes of the NLH, which are the sole vehicular access to the Hong Kong International Airport, were temporarily closed for about 16 hours and reopened around 1:00 a.m. on 8 June 2008.

In catchments Nos. 16 and 17 (Incidents No. LI/2008/06/2003 and LI/2008/06/2004), the debris flood washed some 120 $m^3$ of sediment/debris down to Cheung Tung Road (Plates 3 to 7), blocking the roadside drainage system and inundating a 400-m section of Cheung Tung Road. The road was closed for more than 27 hours and reopened in noon of 8 June 2008.

No casualties were reported as a result of the landslides.

Following the incidents, AECOM Asia Company Limited (AECOM), the Landslide Investigation Consultants for Kowloon and the New Territories in 2008 and 2009, carried out a detailed study for the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD), under Agreement No. CE 41/2007 (GE). The findings are presented in this report.

# 2. DESCRIPTION OF THE SITE

## 2.1 General

The area under study is subdivided into 21 catchment areas (i.e. catchments Nos. 1

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to 21), covering the hillside above NLH and Cheung Tung Road, located to the southeast of Tung Chung New Town, Lantau (Figure 1).

The hillside is northwest-facing and forms part of the Por Kai Shan and Pok To Yan (Figure 1) above NLH. The hillside has an elevation varying between 7 mPD and 17 mPD at the toe and rises to about 520 mPD at the crest at Pok To Yan (Figure 1). The hillside is generally densely vegetated with shrubs and bushes.

The upper portion of the hillside is relatively steep, with a slope angle ranging between 30° and 40° (Figure 8). It becomes steeper than 45° locally at areas of rock exposure. In mid-slope area, the hillside is inclined between 15° and 30°, with the slope angle decreasing to less than 15° towards the toe of the hillside.

Several footpaths run cross the hillside and an electricity cable is present on the hillside within the toe-slope area (Figure 2).

## 2.2 Regional Geology and Geotechnical Area Studies Programme

According to the Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 9 (GEO, 1994), the southern portion of the study area (i.e. catchments Nos. 15 to 21) is underlain by metamorphosed rhyolite lava and tuff of the undivided Lantau Formation (Langford et al, 1995), which has been reassigned to the Lantau Volcanic Group (Sewell et al, 2000). The geology underlying the northern portion (i.e. catchments Nos. 1 to 14) comprises a complex of feldsparphyric rhyolite dykes that intrude granite. The study area is covered locally by debris flow deposits (Qd) (Figure 3).

Photogeological lineaments are present within the study area, and faults are indicated in the geological map trending northwest, sub-parallel to the drainage lines in catchments Nos. 15 and 19 (Figure 3). Notably the fault along catchment No. 15 separates the volcanic rocks in the north from the granitic rocks to the south. In addition, a regional fault zone, the North Lantau Fault (an extension of the Sham Tseng/Sha Tau Kok fault), is located beneath the NLH trending northeast (Figure 3).

Based on the Geotechnical Area Studies Programme (GASP) Report No. VI, North Lantau (GCO, 1988), the study area is located in a zone of general instability associated with predominantly insitu terrain and colluvial terrain.

# 3. DESCRIPTION OF THE LANDSLIDES

According to the incident reports and information from the Police, the landslides and subsequent flooding of the NLH occurred at around 9:00 a.m. on 7 June 2008.

Thirty eight landslides occurred in the southern part of the study area, in catchments Nos. 15 - 21. The landslides were shallow, typically within 2 to 3 m of the superficial colluvium/talluvium, overlying saprolite. The displaced volume (terminology after Cruden & Varnes, 1996) at the landslide source areas ranged from less than 5 $m^3$ to 400 $m^3$, and generally less than 100 $m^3$ (Table 1).

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The largest failure was landslide No. L21 in catchment No. 15, which occurred at the flank of a perennial drainage line in the northern catchment (Figure 1). It involved a translational slide with a displaced volume of about 400 $m^3$. About 350 $m^3$ of landslide debris (together with about 120 $m^3$ of landslide debris from adjacent landslides Nos. L22 and L41) entered a nearby drainage line less than 10 m away and developed into a CDF (Plate 8). The maximum active volume of the CDF is 720 $m^3$. The CDF did not reach the toe of the hillside and terminated within the drainage line at CH735[1], about 40 m downstream of the confluence of two major drainage lines at CH695 (Figure 7b) in the catchment. While the coarse material deposited as a boulder front deposit at CH735, the more dilute, sediment charged flow (i.e. debris flood) may have continued (Hungr, 2002). The debris flood transported some 400 $m^3$ of sediment/debris further downstream. The sediment/debris, containing small boulders, blocked the drainage culvert at Cheung Tung Road and resulted in severe flooding of the adjoining NLH.

Three other landslides also developed into CDFs. They were: landslide No. L40 in catchment No. 15; landslide No. L33 in catchment No. 19; and landslide No. L4 in catchment No. 21. The former two (landslides Nos. L40 and L33) occurred adjacent to the head of the drainage lines and the latter (landslide No. L4) occurred at the drainage line flank. The runout distances ranged from 200 m to 320 m (Figure 1 and Table 1). The debris terminated within the drainage lines, without reaching the toe of the hillside.

The remaining 34 landslides generally involved open hillslope failures. Fifteen of them were major failures (i.e. landslides Nos. L22, L41, L20, L38, L39, L19, L14a, L15, L13, L8, L9, L10, L35, L47 and L53). Landslides Nos. L22 and L41 involved debris slides, where the debris moved as intact rafts. The remaining landslides involved debris avalanche. Eight of the major landslides (Nos. L22, L41, L20, L38, L19, L14a, L13 and L8) were located relatively far away (more than 30 m) from the nearby drainage lines. The debris was deposited on the hillside without reaching the drainage lines. For the other seven major landslides (Nos. L10, L35, L53, L39, L15, L9 and L47), the debris entered the drainage lines or topographic depressions and subsequently travelled in a manner intermediate between a debris slide and a CDF (Table 1).

In addition, there were 19 minor landslides (i.e. Nos. L17, L18a, L18b, L18c, L23, L16a, L16b, L16c, L14b, L36, L37, L12, L46a, L46b, L7, L11, L34, L45 and L6). Although some of the debris entered the drainage lines, the amount involved was relatively small and scattered, and terminated within about 100 m from the failure source areas (Table 1).

In catchments Nos. 16 and 17, water flow charged with sediment, probably from the landslide deposits along the drainage lines, may have developed into debris flood. The debris flood transported approximately 120 $m^3$ of sediment/debris to the drainage line outlets along Cheung Tung Road, blocking the roadslide drainage system and contributing to the severe flooding and inundation of a 400 m section of Cheung Tung Road (Plates 6 and 7). A cut slope at the toe of catchment No. 16 (Plates 3 and 5-7) was also severely eroded.

At landslides Nos. L22 and L41 (in catchment No. 15), a number of fresh tension cracks were observed at and around the crowns of the two landslides and on the hillside area

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[1] In the context of this report, CHx refers to x m plan distance from the crown of the landslide.

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in-between (Plates 9 and 11). The tension cracks were up to 20 m long and 1 m deep, and were probably caused by the 7 June 2008 rainstorm. No other fresh tension cracks were observed within the study area.

## 4. SITE HISTORY AND PAST INSTABILITIES

### 4.1 General

The history of the study area has been determined from an interpretation of available aerial photographs, together with a review of relevant documentary information (Figure 4). Detailed observations from the aerial photograph interpretation (API) are summarised in Appendix A, with the salient observations given below.

### 4.2 Site History

Anthropogenic disturbance of the hillside, which comprises primarily footpaths and some agricultural terracing, is observed in the 1945 aerial photographs on the lower portion of the hillside towards the sea in catchments Nos. 10, 17 and 19 (Figures A1 and A2). In 1963, the extent of the agricultural terracing at the toe of the hillside appears greater and several small dwellings are observed adjacent to the terracing at the distal end of a colluvial fan (see Section 4.4) that emerges from catchment No. 17 to catchment No. 19.

The man-made features (Figure 2) along the toe of the study area were formed in association with the construction of Cheung Tung Road and the reclamation for Tung Chung New Town northwest of the study area between 1992 and 1996. Development on the newly reclaimed area took place from 1996 onwards. There is little change to the subject hillside between 1996 and 2008.

### 4.3 Past Instabilities

#### 4.3.1 Enhanced Natural Terrain Landslide Inventory and Historical Landslide Catchments

A total of 434 landslides were identified within the study area under the GEO's Enhanced Natural Terrain Landslide Inventory (ENTLI). Of these 434 ENTLI features, 84 were classified as recent[2] landslides and the remaining 350 as relict[3] landslides. The ENTLI features were located mainly in catchments Nos. 15 to 21 (Figure 5), and were generally small in scale, typically less than 80 $m^3$. They tended to cluster at the relatively steep parts of the hillside.

Within catchments Nos. 15 to 21, about 80% of 7 June 2008 landslides occurred within 50 m of at least one ENTLI feature. For example, in catchment No. 15, landslide No. L21

[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.

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

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was located 25 m from an ENTLI feature No. 09SEB0047E (Figures 5 and A7, Plate 8). The ENTLI feature is a relict landslide that appears as a minor depression, measuring about 10 m wide by 7 m long. Two other relict ENTLI features Nos. 09SEB0942E and 09SEB0943E, are located about 30 m and 40 m respectively, above landslide No. L40 within the same catchment (Figure 5). The former ENTLI feature measures about 12 m wide by 11 m long and the latter measures about 10 m wide by 6 m long. In catchment No. 21, there is an ENTLI feature (No. 09SEB0769E) about 30 m below landslide No. L4, which has led to another CDF event on 7 June 2008. This ENTLI feature measures about 13 m wide by 6 m long, with an estimated volume of about 80 $m^3$ (Figure 5).

Three historical landslide catchments[4] (HLC) had been identified within the study area prior to the June 2008 event (Figure 5), two (with HLCs Nos. 09SEB-C01 and 09SEB-O6) in catchment No. 4 and the other in catchment No. 16 (with HLC No. 09SEB-O05). On 7 June 2008 no landslides occurred in catchment No. 4, and only three minor landslides (Nos. L16a, L16b and L16c) occurred at the southern edge of the HLC in catchment No. 16 (Figure 5).

### 4.3.2 GEO's Large Landslide Database and Landslide Database

The GEO's large landslide database (Scott Wilson, 1999) contains records of seven large landslides within the study area (Figure 5), five of them were located in catchment No. 19. A large landslide No. 09SEBL027 is located on the flank of the drainage line on the northern part of catchment No. 15, about 125 m below landslide No. L21 that occurred on 7 June 2008 (Figure 5). The remaining large landslide No. 09SEBL023 is on the hillside above catchments Nos. 1 and 2 (Figure 5).

No landslide incidents in the immediate vicinity of the study area were recorded in the GEO's landslide database prior to 7 June 2008.

## 4.4 Aerial Photograph Interpretation

Based on a review of the earliest aerial photograph taken in 1945, the southern portion of the study area (catchments Nos. 15 to 21) is a northwest-facing natural hillside, characterised by well-defined drainage catchments separated by rounded spurlines. The catchments are dissected by several drainage lines that typically trend northwest (Figure 4). In contrast, the northern portion of the study area (catchments Nos. 1 to 14), comprising a north-facing hillside, has a gently undulating morphology with only one well-defined drainage line in catchment No. 8 (Figure 4). Further details are given in Appendix A. In the rest of this section, due focus will be placed on catchments Nos. 15, 19 and 21 where the 7 June 2008 CDFs occurred.

Based on the 1963 aerial photographs, poorly-defined topographic depressions encircled by weakly convex breaks-in-slope are seen at the head of catchment No. 15, and

[4] A Historical Landslide Catchment is a catchment with a history of landslides that occurred close to existing buildings and important transport corridors (Wong et al, 2006).

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coincide with the locations of landslides Nos. L22 and L41 that occurred on 7 June 2008 (Figure A6). The topographic depressions may correspond to relict landslide scars. These topographic depressions form channels for ephemeral water flows into the drainage line (Figure A6). Another possible minor relict landslide is located at landslide No. L21 (Figure A7), which was the largest failure that occurred in the study area on 7 June 2008. There were no obvious accumulations of colluvial materials at the locations of landslides Nos. L21, L22 and L41, nor perched boulders along the northern drainage line in catchment No. 15. The total catchment area of catchment No. 15 is about 220,000 $m^2$, with about 125,000 $m^2$ containing the northern drainage line where the longest 7 June 2008 CDF occurred.

The largest catchment in the study area is catchment No. 19, with a plan area of about 630,000 $m^2$. The catchment can be further subdivided by several north-trending and northwest-trending drainage lines (Figure 4). The upper portion of the catchment consists of relatively steep, rugged terrain and the middle slopes are characterized by an extensive stretch of intermittent rock outcrop. Based on the 1963 aerial photographs, there are many relict landslide scars and erosion gullies that form sharp topographic depressions on the general hillsides, with convex break-in-slopes encircling their crests. These topographic depressions form channels for ephemeral water flows. Sheet erosion is also observed on the upper hillslopes and boulders are found scattering the general hillsides. A large colluvial fan is located at the toe of the catchment probably reflecting the large catchment area and consequently potential debris volume transported down the drainage lines over time (Figure A3).

Catchment No. 21 is a relatively narrow catchment at the western end of the study area with a catchment size of about 90,000 $m^2$. The middle portion of the catchment is characterised by a section (about 330 m) of relatively incised terrain which coincides with the location of the 7 June 2008 CDF that occurred in this catchment. The upper catchment is characterized by some subtle, broad, rounded topographic depressions, and the lower catchment is characterized by relatively planar terrain of lower gradient which probably reflects the start of deposition process for contribution of sediment to the western part of the large colluvial fan described in the above section. Possible colluvial debris could be observed within the drainage line section where the 7 June 2008 CDF occurred.

The 1963 aerial photographs also show well-defined debris fans at the drainage line outlets in catchments Nos. 9, 10, 16, 17 and 19 to 21 (Figures 4, A1 to A4). It is difficult to assess the relative age of these debris fans, except that the small debris fan at the outlet of catchment No. 16 appear relatively younger compared to the larger adjacent fan to the south near catchment No. 17[5] (Figure A4). The larger fan is about 220 m wide and may have partly blocked or dammed the drainage line within catchment No. 16, diverting the streamcourse. The smaller fan abuts against this fan to the east and from the texture and morphology (principles of superposition), the smaller fan is considered to be relatively younger than the larger fan and appears to have formed at the outlet of the diverted streamcourse.

In 1993, about 42 minor landslides occurred on the hillside following the 5 November

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[5] Based on the results of radiocarbon age dating carried out by the GEO in a previous study in 2001 (Sewell & Campbell, 2005), the debris fan at the outlet of catchment No. 17 was aged between 1,800 and 13,500 years before present ($^{14}C$ yr BP).

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1993 rainstorm. Most of the landslides were located in catchments Nos. 15 to 19 (Figures A1 and A2). Seven landslides occurred in close proximity to some of the 7 June 2008 landslides (notably near landslides Nos. L8, L10, L11, L13, L20, L48a and L53). None of the 42 landslides developed into a CDF, as the source volumes were relatively small and were mostly located far away from the drainage lines. Several of the landslides were also documented in GEO Report No. 57 (Franks, 1998).

### 4.5 Summary

There are many relict and recent landslides on the hillside above NLH, notably within catchments Nos. 15 to 21 (Figure 5). These landslides are generally small in scale, typically less than 80 $m^3$, and tend to cluster on the relatively steep parts of the hillside. The 7 June 2008 landslides also tended to occur within or close to these clustered zones. Some relict landslide scars result in topographic depressions which facilitate ephemeral water flows into the drainage lines, notably in catchments Nos. 15 and 19.

## 5. FIELD OBSERVATIONS AND LANDSLIDE PROCESS

### 5.1 General

Four CDFs occurred within the study area on 7 June 2008 (Table 1 and Figure 1), in catchments Nos. 15, 19 and 21. Besides the one in catchment No. 19 which could not be assessed safely, detailed mapping was carried out for the other three CDFs in catchments Nos. 15 and 21.

Catchment No. 15 contains two prominent drainage lines, one in the northern part of the catchment and another to the south which merges with the northern drainage line at about CH695. Landslide No. L21 (Plate 10) occurred at the flank of the northern drainage line and developed into a CDF with a runout distance of 735 m. Another landslide No. L40 occurred at the head of the southern drainage line, and developed into a CDF with a runout distance of about 200 m (Plate 12).

In catchment No. 21, landslide No. L4 occurred at the flank of a north-flowing drainage line and developed into a CDF with a runout distance of about 320 m (Plate 13).

Salient observations from the longest CDF, i.e. landslide No. L21 in catchment No. 15, which resulted in the temporary closure of NLH, are given below. Observations related to the debris movement process for two other CDFs associated with landslides Nos. L4 and L40 are given in Appendix B.

### 5.2 Landslide No. L21 in Catchment No. 15

#### Failure source area

Landslide No. L21 is located at the northeast-facing flank of the drainage line at an elevation of about 285 mPD. The gradient of the landslide source area is about 35°

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(Figure 6). The landslide measured 25 m wide, 34.5 m long and generally less than 1 m deep, involving a displaced volume of about 400 $m^3$ (Plate 8).

The failure appeared to have mainly involved a thin layer of fine colluvium, with the rupture surface running along the interface between the colluvium and underlying insitu completely to highly decomposed tuff (Plate 10). At the western flank of the landslide, the rupture surface extended to the underlying moderately decomposed tuff where the failure depth increased to about 3 m, exposing surface release planes including an adversely oriented (70/340) relict joint dipping out of hillside (Plates 10 and 14). A large soil pipe (150 mm diameter) was observed at the lower portion of the landslide (Plate 10).

A plan and longitudinal section through the landslide and the debris trail, together with the estimated of material entrainment and deposition are presented in Figures 6 and 7.

Debris Trail

Of the 400 $m^3$ displaced material from landslide No. L21, about 50 $m^3$ remained as intact rafts within the landslide source area. This indicates that the landslide probably initiated as a translational slide. The remaining 350 $m^3$ of landslide debris subsequently broke up and travelled downhill as a debris avalanche (Plate 15). The debris, together with another 120 $m^3$ of debris from nearby landslides Nos. L22 and L42 (Figure 7a), entered the drainage line at about CH30 and developed into a CDF.

Between CH30 and CH670 was the main transport zone (Figure 6), in which the channel bed was generally rocky. Throughout the runout path, erosion was mainly observed between CH140 to CH285 at the central portion of the drainage line, where the width is about 2 m to 3 m (Plate 16), exposing rock and in places partially lithified old colluvium (Plate 17). From CH285 onwards, erosion of the channel bed or side slopes was minimal. Based on field evidence, there was no significant amount of perched material in the channel prior to the June 2008 event (Plate 18). This was also later confirmed by API (Section 4.4). The maximum active volume of the CDF was about 720 $m^3$ at about CH330. Deposits of super-elevated debris were observed at about CH440 (Plate 19), and measured super-elevation indicates that the debris velocity was about 7 m/s at this location (Hungr et al, 1984). In general, the channel gradient in the transport zone is over 20° with occasional rock steps up to 8 m high (Figure 6 and Plate 20). The channel is not particularly incised (with a channelization ratio[6] (CR) of 6 to 7) throughout the transport zone (Plate 21), but is very smooth and rocky (Plates 22 and 23).

The channel gradient decreases sharply to 12° at about CH630 with limited debris deposition, where the drainage line remains confined with a CR of about 4 to 5. Debris started to deposit beyond CH670, where the slope angle decreases further to 5° - 10° (Figures 6 and 7b). About 350 $m^3$ of debris was deposited (Plates 24 and 25) between CH670 and CH735. The deposits comprised clast- and matrix- supported bouldery debris, with a prominent boulder front (boulders up to 1.5 m in diameter) at CH735 (Plate 25). The southern drainage line merges with the northern drainage line at CH695 (Figure 7b), some

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[6] Channelization 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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40 m upstream of the boulder front deposits. The additional catchment area discharging runoff at this point is about 95,000 $m^2$, increasing the effective catchment size to 220,000 $m^2$.

As the coarse material deposited as a boulder front at CH735, the more dilute sediment charged flow probably continued as a debris flood, transporting some 400 $m^3$ of sediment/debris further downstream. The debris flood deposits spreaded out between CH735 and CH850 with no levees. The deposits comprised sorted, clast-supported fine debris (i.e. sediment) with occasional matrix-supported bouldery debris (Plate 26). Approximately 170 $m^3$ of the sediment/debris containing small boulders up to 0.5 m in diameter was observed blocking the culvert inlet at CH850 along Cheung Tung Road (Plates 27 and 28). The sediment/debris did not cause any impact marks or significant damage on the concrete head wall connecting the culvert (Plate 29), indicating that the debris flood was not fast moving. According to Drainage Services Department (DSD), approximately 250 $m^3$ sediment/debris almost fully filled up the 2 m x 2 m culvert (Plate 31) and reached a junction chamber located at 67 m downstream of the inlet (Plate 32). The debris at the junction chamber comprised vegetation and coarse material (Plate 32). As a result, Chung Tung Road and the adjoining NLH were severely flooded.

## 6. EMERGENCY REMEDIAL WORKS

The emergency remedial works included clearing the debris deposited in the affected drainage facilities at the toes of the catchments, provision of temporary rock fence along Cheung Tung Road below catchments Nos. 15 to 18, installation of a CCTV for monitoring below catchment No. 15, etc.

The DSD also provided three numbers of temporary rock traps immediately upstream of the drainage inlets at catchments No. 15, 16 and 17, and the Highways Department (HyD) constructed additional road gullies along the low-lying areas in NLH and Cheung Tung Road below catchment No. 15. A high level (i.e. by-pass) drain pipe was provided between the existing manhole and culvert at the toe of catchment No. 15 to minimise the impact of blockage at the manhole. Both departments stepped up regular maintenance to the existing drainage system along the NLH.

## 7. PREVIOUS STUDIES

### 7.1 General

The hillside within the study area has been subject to several previous studies. One of them was carried out by the GEO in 1998 (GEO Report No. 57), which documents some of the landslides that occurred in the November 1993 rainstorm (Franks, 1998). Two natural terrain hazard studies have also been carried out in the area, as detailed below.

### 7.2 Natural Terrain Hazard Study in 2005

A Natural Terrain Hazard Study (NTHS) was carried out by Ove Arup & Partners Hong Kong Ltd. in 2005 (OAP, 2005), covering the study area above NLH under this

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investigation. Both Quantitative Risk Assessment (QRA) and Design Event approaches were adopted to assess the natural terrain hazards associated with debris flow events. The study concluded that no CDFs would likely occur in catchments Nos. 1-7, 9-14 and 19-21. Based on aerial photograph interpretation and field verification, the worst credible event (Ng et al, 2002) with a source volume of 2,600 $m^3$ was recommended for the other catchments (i.e. catchments Nos. 8, 15 - 18 above NLH, as well as the catchments above Yu Tung Road). With this, a hypothetical debris flow was stimulated using the mass balance approach for these catchments. The results showed that an active debris volume of 240 $m^3$, 40 $m^3$, 1,085 $m^3$ and 1,060 $m^3$ could reach Cheung Tung Road from catchments Nos. 8, 15, 17 and 18 respectively (Table 2). For the other catchments, the results indicated that the landslide debris would unlikely reach Cheung Tung Road.

### 7.3 Natural Terrain Hazard Mitigation Works at North Lantau Highway and Yu Tung Road near Tung Chung Eastern Interchange in 2007

In August 2007, MGSL was appointed to carry out a Design and Construction Assignment for the Natural Terrain Hazard Mitigation (NTHM) works at the hillside above NLH and Yu Tung Road (MGSL, 2008). The study included a review of the previous 2005 NTHS (OAP, 2005) and the design of hazard mitigation measures for each catchment.

After reviewing the previous 2005 NTHS, a single design event of 2,600 $m^3$ (worst credible event) for the whole hillside was generally adopted. Dynamic mobility modelling, in contrast to the mass balance approach adopted in the 2005 NTHS, was then carried out using GEO's DMM program (GEO, 2004). The analysis assumed a landslide source volume of 2,600 $m^3$ (i.e. design event), and adopted the Voellmy rheological model (Lo, 2000) with typical parameters (Table 3). The results indicated that debris from catchments Nos. 17 and 18, where the drainage lines were more confined and incised (with a CR $\leq$ 4), would likely reach the toe of the catchments and potentially affect Cheung Tung Road. Debris-resisting barriers with designed retention capacities of 1,000 $m^3$ and 1,250 $m^3$ were subsequently proposed at the toes of catchments Nos. 17 and 18 respectively (Table 2). In the 7 June 2008 rainstorm, only minor landslides occurred in catchments Nos. 17 and 18 and none of them developed into CDFs.

After the June 2008 event, a review of the previously proposed mitigation measures was carried out in the light of additional information available from the June event (see also Section 11.3). Subsequently, mitigation measures were considered necessary in catchments Nos. 15 to 19, and details are summarised in Table 2. Furthermore, a flexible barrier was proposed at the toe of catchment No. 21 as a contingency measure to prevent landslide debris from reaching the downstream drainage facilities.

## 8. PREVIOUS GROUND INVESTIGATION

No ground investigation (GI) was carried out under this study. Records of previous GI carried out within and in the vicinity of the study area in 1978, 1982, 1991 and 2002 were collated and reviewed. Most of the previous GI were located at the toe of the study area and may not be directly relevant to the landslides, which occurred mainly on the upper parts of the hillside. Nevertheless, the GI findings where relevant have been considered in the

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development of the geological model, as detailed below. A summary of the GI results and a location plan of the GI stations are given in Appendix C.

## 9. GEOLOGICAL AND GEOMORPHOLOGICAL MODEL

The solid geology of the study area comprises a complex sequence of porphyritic rhyolitic lavas, rhyolitic fine ash crystal tuffs, granite and feldsparphyric rhyolite (Sewell et al, 2000 & 2002). Several faults run primarily parallel to the drainage lines in the study area (Figure 3), suggesting the orientation of the drainage lines may be fault related.

A regional northwest-trending fault cuts through catchment No. 15 and separates the primarily volcanic rocks that underlie the southern portion of the study area from the granitic rocks below the northern portion of the study area. The underlying geology dictates the morphology of the hillsides, and the volcanic terrain is higher and steeper than the granitic terrain (Figure 8).

Colluvial layers typically 1 m to 2 m thick are present on the upper parts of the hillside, although some layers could be up to 4 m thick. The thickness of the colluvium generally increases towards the toe of the hillside. Previous GI indicated that up to 16 m of colluvium was encountered on the lower portion of the hillside in catchment No. 17 (Table C1).

Debris fans from older and younger phases of landsliding are present at the outlets of catchments Nos. 16 and 17 extending to the pre-reclamation shoreline (Section 4.4 and Appendix A). Debris fans of varying scales are also observed at the outlets of catchments Nos. 19 (including some contribution from adjacent Catchment Nos. 20 and 21) and 10 respectively (Figure 4). All of them could be related to past landslide activities or fluvial action. Possible layering of debris fan deposits, indicating several landslide debris flow events, was observed in areas along the flanks of the lower portion of the drainage lines. The same was also observed in the trial pits carried out for the previous 2005 NTHS (Appendix C).

## 10. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. N17, located at about 1.3 km west of the study area. The raingauge records and transmits rainfall data at 5-minute intervals to the GEO and the Hong Kong Observatory (HKO). However, during the period between 6 and 23 May 2008, raingauge No. N17 was not in operation. A review of a nearby raingauge No. N21 located about 1.6 km east from raingauge No. N17 revealed that only about 100 mm rainfall was recorded throughout this 15-day period. Therefore, the missing data in raingauge No. N17 within this period were taken to be the same as those from the nearby raingauge No. N21 for the purpose of the rainfall analysis (Figure 9).

Rainfall data from another local raingauge, which was installed in 2006 under Agreement No. CE 4/2005 (GE), has also been reviewed. The raingauge is located near the boundary of catchments Nos. 19 and 20 at about 90 mPD (referred as NLH raingauge hereafter).

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The daily rainfall recorded by the NLH raingauge, and raingauge No. N17 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 Figures 9 and 10. The results show that the intensity of rainfall recorded by raingauge No. N17 is generally higher than that by the NLH raingauge (Figure 10).

Based on police records, flooding of the NLH likely occurred shortly before 9 a.m. on 7 June 2008 when a Black Rainstorm Warning was in force. The landslides in the study area were therefore assumed to have occurred at 9 a.m. for the purpose of rainfall analysis.

The maximum 1-hour rolling rainfall recorded preceding the landslide at raingauge No. N17 and the NLH raingauge was 140.5 mm and 133 mm respectively (Tables 4 and 5). An analysis of the return periods for various durations of rolling rainfall has been carried out, with reference made to historical rainfall data at the HKO in Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994). The results show that a rainfall duration of 4 hours was the most severe, with a corresponding return period of exceeding 240 years (Tables 4 and 5).

The maximum rolling rainfall for the 7 June 2008 rainstorm has been compared with the previous major rainstorms recorded by raingauge No. N17, which came into operation in April 1991 (Figure 11). The 7 June 2008 rainstorm is more severe than the previous major rainstorms for rainfall durations between 1 hour and 4 hours.

## 11. DEBRIS MOBILITY

### 11.1 General

Mobility characteristics of the three CDFs from landslides Nos. L4, L21 and L40, where detailed mapping has been carried out, are discussed below. Landslide No. L4 occurred in catchment No. 21, whereas landslides Nos. L21 and L40 occurred in catchment No. 15.

### 11.2 Travel Angle and Distance

The CDF from landslide No. L4 travelled a horizontal distance of 320 m, of which about 65 m occurred in the downhill area where the overall gradient is 15° or less. The travel angle[7] of the debris was about 25°. The CDF is not mobile, based on the empirical classification system of Wong (2005) and comparison with previous events of a similar scale in Hong Kong (Figures 12 and 13).

The CDF from landslide No. L21 travelled a horizontal distance of 735 m (i.e. CH735), and the distal end was marked by a bouldery debris-front deposit. About 105 m of the lowest segment of the CDF trail has an overall gradient of 15° or less. The travel angle from the crown of the landslide to the distal deposit is about 20°. The CDF appeared relatively mobile, based on the empirical classification system of Wong (2005) and comparison with

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[7] 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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previous events of a similar scale in Hong Kong (Figures 12 and 13).

The CDF from landslide No. L40 travelled a horizontal distance of 200 m. The debris was deposited within the drainage line where the channel gradient is about 25°. The travel angle was about 26°. The CDF is not particularly mobile, based on the empirical classification system of Wong (2005) and comparison with previous events of a similar scale in Hong Kong (Figures 12 and 13).

## 12. DISCUSSION

### 12.1 Probable Causes of Landslides

The 7 June 2008 landslides above NLH occurred after intense rainfall, on relatively steep parts of the hillside. The failures were typically shallow, within the top 1 to 3 m surface mantle of colluvium/talluvium. In the case of landslide No. L21, the rupture surface partly penetrated into the underlying saprolite regolith. The shallow nature of the landslides and close correlation between the landslides and preceding intense heavy rainstorm (Section 10) suggest that the failures were probably triggered by the intense 7 June 2008 rainstorm. Infiltration and sub-surface flows as evidenced by the presence of soil pipes would have led to saturation of the near surface groundmass and possible transient build-up of water pressures, resulting in reduction in the shear strength of the soil.

### 12.2 Landslide Locations and Density

The spatial distribution of landslides shows a clear relationship between underlying geology and landslide occurrence on 7 June 2008, with all the landslides occurring within the volcanic terrain at the western part of the study area (Figures 1 and 3). The underlying geology dictates the morphology of the hillsides and the volcanic terrain is higher and steeper than the adjacent granitic terrain (Section 9), making the hillside more susceptible to landslides, for this particular study area setting.

The majority of landslides were located at or close to the locations of past failures (Section 4.5). As such, the possibility of reactivation or retrogression of previous failures cannot be ruled out. In addition, landslide No. L21 in catchment No. 15 was partly influenced by an adversely orientated joint exposed in the back scarp (Section 5.2).

The 7 June 2008 rainstorm triggered 38 shallow landslides on the hillside catchments within the study area. The corresponding landslide density is 29 landslides per km$^2$, over the area where the landslides occurred (i.e. in catchments Nos. 15 to 21). The 7 June 2008 rainstorm also triggered 19 landslides on the hillside within catchments Nos. 22 to 30 above Yu Tung Road (AECOM, 2009). The corresponding landslide density is 45 landslides per km$^2$. The high landslide density within catchments Nos. 15 to 30 might reflect a higher susceptibility of the hillside to landslides in relation to their geological and geomorphological setting (e.g. the relatively steep volcanic terrain with prominent breaks-in-slope, the relatively incised drainage lines and steep adjacent flanks).

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## 12.3 Debris Movement Process

Amongst the landslides that occurred within the study area on 7 June 2008, landslide No. L21 was the largest and had the highest consequence. The landslide process of this landslide was determined based on field observations.

The failure volume of landslide No. L21 at the source was about 400 $m^3$. About 50 $m^3$ of the debris remained at the source area. The rest of the debris, together with another 120 $m^3$ from adjacent landslides Nos. L22 and L42, entered a drainage line at CH30 and developed into a CDF. The drainage line was relatively confined, with a CR of about 6 to 7. Erosion was mainly observed between CH140 to CH285 with limited entrainment thereafter, as the channel bed was rocky and the depletion into the side slopes was limited. Furthermore, it seems that little loose, perched material was present in the drainage line prior to the event. The maximum active volume of the CDF was about 720 $m^3$ at CH330.

The channel gradient decreases sharply to about $12^o$ at CH630 with limited debris deposition, where the drainage line remains confined with a CR of about 4 to 5. Deposition started at about CH670, where the channel opens up and the slope angle decreases further to $5^o$ - $10^o$. The debris deposits comprised remoulded, clast- and matrix- supported bouldery debris, typical of a debris flow deposit. The main pulse of the CDF appeared to have terminated at CH735, as evidenced by the presence of a prominent boulder front deposit.

A debris flood may have occurred as a longitudinal extension of the debris flow, as the coarse material deposited at CH735, whilst the more dilute, sediment charged flood continued further downstream. About 420 $m^3$ of sediment/debris, comprising sorted, clast-supported sediment with occasional matrix-supported bouldery debris (Plate 26) were transported downstream from CH735. The observed debris flood deposits spreaded out between CH735 and CH850 with no levees. About 170 $m^3$ of the sediment/debris containing boulders up to 0.5 m in diameter was observed blocking the culvert inlet at CH850 along Cheung Tung Road (Plates 27 and 28) and another 250 $m^3$ of sediment/debris, continued along the 2 m x 2 m culvert and reached the junction chamber 67 m downstream (Plates 31 and 32). The sediment/debris blocked the drainage culvert and inlet, resulting in severe flooding of Cheung Tung Road and the adjoining NLH. No signs of damage were observed at the drainage inlet structure at CH850 (Plate 29), indicating that the debris flood was not fast moving.

## 12.4 Debris Mobility

### 12.4.1 General

Apart from the rainfall characteristics, past observations indicate that the mobility of CDFs are related to drainage line and catchment characteristics, water content of debris and source volume (AECOM, 2009). These factors are discussed below with due focus on landslide No. L21 in catchment No. 15, which had the longest runout distance.

### 12.4.2 Drainage Line Characteristics

The longest CDF in catchment No. 15 occurred along a relatively steep (with a gradient over 20° and locally 35° in the transport zone) drainage line. The drainage line is relatively confined with a CR of 6 - 7 over most of its course and remains so (with a CR of 4 - 5) when the gradient reduces to about 12° at about CH630. The nature of the streambed is also very rocky and smooth. The combined effect of these characteristics would have contributed to a high debris velocity, even in the lower part of the drainage line, and resulted in mobile debris. Assessment of the super-elevation data indicated that the debris velocity was relatively high, about 7 m/s at CH440 (Section 5.2). In addition, the presence of very steep rock "steps" (up to about 8 m high) in the drainage line may have locally increased the velocity of the debris, further contributing to its mobility.

### 12.4.3 Catchment Characteristics and Water Content

The catchment area for the northern drainage line where the CDF occurred in catchment No. 15 is relatively extensive, covering an area of about 125,000 $m^2$. The 7 June 2008 rainstorm is the most severe rainstorm recorded for the area, in terms of short duration rainfall. The intense rainfall, presence of ephemeral channels connecting to the northern drainage line (Section 4.4) together with additional inflow at CH695 due to merging of the major northern and southern drainage lines in the catchment could have brought a large amount of surface runoff into the drainage line. This would have increased the bulked volume of the debris and its water content, and hence its mobility.

## 12.5 Consequence of Landslide

Field inspections indicated that debris flood may have occurred in catchments Nos. 15, 16 and 17 on 7 June 2008. In total, over 400 $m^3$ of sediment/debris containing small boulders were deposited at and beyond the outlets of the drainage lines, blocking the drainage culverts and causing severe flooding of the low-lying areas along Cheung Tung Road and adjoining NLH. The west bound lanes of NLH were temporarily closed for 16 hours. A similar phenomenon was also observed following the 7 June 2008 landslide above Shatin Pass Road (AECOM, 2010). In this particular case, a total of some 800 $m^3$ of sediment/debris were washed down the drainage line during three rainstorms between 7 June and 12 July 2008. The sediment/debris blocked the drainage system at the toe of the catchment, inundating a large area within a public housing estate.

# 13. CONCLUSION

The severe 7 June 2008 rainstorm triggered 38 landslides on the hillside above NLH. The landslides on the hillside in this rainstorm are characterized by high landslide density and strong clustering in the volcanic terrain compared with the granitic terrain. Of the 38 landslides, four developed into CDFs, with a runout distance ranging from 200 m to 735 m. One of the CDFs had high debris mobility. The possible factors pertinent to these characteristics are discussed in Section 12 of this report.

None of the four CDFs reached the facilities at the toe of the hillside. However, debris flood may have occurred in three hillside catchments Nos. 15, 16 and 17, bringing a significant amount of sediment/debris downstream. The sediment/debris containing small

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boulders blocked the toe drainage systems, resulting in flooding of a 400 m-section of Cheung Tung Road and adjoining NLH. The affected Cheung Tung Road and NLH were temporarily closed for 27 and 16 hours respectively. Temporary closure of NLH, which is a sole vehicular access to the Hong Kong International Airport, caused significant impact and economic loss to the community.

For CDF hazards, the use of typical mitigation measures such as debris resisting barriers will help to contain the landslide debris from reaching the downstream facilities. While such measures are effective in mitigating the landslide risk to life, these would not be adequate in preventing the sediment-charged water from flowing further downstream and discharging into the land drainage system. If not properly dealt with, it could cause flooding in low-lying areas.

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Table 1 - Summary of Landslide Characteristics of Inspected Landslides on Hillside above North Lantau Highway (Sheet 1 of 2)

| Landslide No. | Catchment No. | Distance from Toe of Source to Drainage Line (m) | Crown Elevation (mPD) | Gradient (°) | Slope Aspect (°) | Length L (m) | Width W (m) | Depth D (m) | Volume V ($m^3$) V= 1/2 x L x W x D | Runout[1] (m) | Travel Angle (°) | Landslide Type[2] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L17 | 15 | 91.2 | 72 | 38 | 276 | 4.0 | 2.5 | < 0.5 | 3 | - | - | OHF | |
| L18a | 15 | 85.6 | 54 | 37 | 15 | 6.3 | 6.0 | 0.8 | 15 | - | - | OHF | |
| L18b | 15 | 139.1 | 67 | 40-60 | 328 | 5.0 | 5.6 | 0.55 | 7.7 | - | - | OHF | |
| L18c | 15 | 125.6 | 74 | 40-45 | 347 | 15.0 | 3.5 | 0.5 | 13 | - | - | OHF | |
| L21 | 15 | 9.0 | 285 | 30 | 005 | 34.5 | 25.0 | 1.0, max 2.8 | 400 | 765 | 20 | OHF ⇨ **CDF** | |
| L22 | 15 | 33.3 | 320 | 35 | 340 | 45.5 | 9.5 | 0.8, max 1.2 | 230 | 44.5 | 32 | OHF | Refer to mapping report No. LS08-0239 |
| L41 | 15 | 44.4 | 316 | 27 | 003 | 25.5 | 10.0 | 0.5, max 1.2 | 90 | 35 | 25 | OHF | |
| L23 | 15 | 14.9 | 263 | 31 | 010 | 8.0 | 11.8 | 0.6 | 40 | 8 | 31 | OHF | |
| L40 | 15 | 19.5 | 380 | 38-68 | 320 | 22.0 | 10.0 | 0.75, max 1.5 | 115 | 200 | 26 | OHF ⇨ **CDF** | Refer to mapping report No. LS08-0244 |
| L20 | 16 | 40 | 198 | 40 | 240 | 11.8 | 15.9 | 1.0 | 93.8 | 65 | 32 | OHF | |
| L38 | 16 | 89.7 | 305 | 42 | 238 | 12.5 | 7.2 | 1.2 | 54 | 25 | 30 | OHF | |
| L39 | 16 | 20.9 | 296 | 30 | 335 | 20.0 | 6.0 | 1.0 | 60 | 100 | 25 | OHF ⇨ M | Weekly channelised |
| L16a | 16 | 44.8[3] | 31 | 40 | 326 | | 17.7 | | | | | OHF | |
| L16b | 16 | 7.4 | 18 | 48 | 300 | 8.0 | 7.0 | 0.5-1 | | - | - | OHF | Rigid surface applied prior to inspection, likely minor failures |
| L16c | 16 | 8.2 | 14 | 40 | 296 | 3.5 | 6.5 | 0.5 | | - | - | OHF | |
| L19 | 16 | 63.5 | 164 | 40 | 239 | 16.8 | 10.8 | 1.0 | 91 | 30 | 34 | OHF | |
| L14a | 17 | 50.8 | 275 | 58 | 332 | 10.0 | 8.0 | 2.0 | 80 | 50 | 36 | OHF | |
| L14b | 17 | 100.2 | 275 | 44 | 358 | 7.0 | 6.8 | 2.0 | 33 | | | OHF | |
| L15 | 17 | 47.6 | 208 | 40 | 322 | 12.5 | 10.3 | 2.5 | 161 | 78 | 35 | OHF ⇨ M | Weekly channelised |
| L36 | 17 | 261.5 | 202 | 60 | 320 | 9.0 | 6.2 | 0.7 | 20 | 150 | 27 | OHF ⇨ M | Weakly channelized, locally with CR ≤7 |
| L37 | 17 | 64.6 | 197 | 35-40 | 008 | 9.5 | 6.5 | 0.6 | 19 | 30 | 30 | OHF | |
| L12 | 18 | 97.0 | 203 | 58 | 314 | 9.5 | 6.0 | 1.5 | 43 | 50 | 39 | OHF | |



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Table 1 - Summary of Landslide Characteristics of Inspected Landslides on Hillside above North Lantau Highway (Sheet 2 of 2)

| Landslide No. | Catchment No. | Distance from Toe of Source to Drainage Line (m) | Crown Elevation (mPD) | Gradient (°) | Slope Aspect (°) | Length L (m) | Width W (m) | Depth D (m) | Volume V ($m^3$) V= 1/2 x L x W x D | Runout[1] (m) | Travel Angle (°) | Landslide Type[2] | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L13 | 18 | 50.0 | 161 | 45 | 230 | 20.0 | 10.0 | 1.0 | 100 | 35 | 28 | OHF | |
| L46a | 18 | 89.0 | 125 | 40 | 290 | 4.5 | 3.9 | 0.5 | 4 | 12 | 30 | OHF | |
| L46b | 18 | 55.7 | 136 | 25 | 264 | 4.0 | 2.0 | 0.4 | 2 | 10 | 30 | OHF | |
| L7 | 19 | 149.3 | 246.9 | 31 | 306 | 14.0 | 9.0 | 0.5 | 32 | 95 | 34 | OHF ⇨ M | Weekly channelised |
| L8 | 19 | 85.0 | 165.7 | 38 | 245 | 20.0 | 27.0 | 0.8-1.3 | 216 | 65 | 30 | OHF | |
| L9 | 19 | 179.1 | 120.2 | 30 | 265 | 15.0 | 13.3 | 0.7-1.5 | 100 | 80 | 32 | OHF ⇨ M | Weekly channelised |
| L10 | 19 | 236.5 | 217 | 35-60 | 215-225 | 16.0 | 7.5 | 0.5, max 1 | 66 | 170 | 28 | OHF ⇨ M | Refer to mapping report No. LS08-0275, weakly channelized, locally with CR = 4 |
| L11 | 19 | 198.8 | 286 | 34 | 252 | 8.0 | 8.5 | 1.0 | 34 | 45 | 32 | OHF | |
| L33 | 19 | 13.4 | 438 | 45 | 320 | 15.0[4] | 9.0[4] | 0.8[5] | 54 | 215 | 34 | OHF ⇨ **CDF** | Not accessible due to very steep terrain |
| L34 | 19 | 219.0 | 384 | 45 | 350 | 15.0[4] | 8.0[4] | 0.5[5] | 30 | 60 | 42 | OHF | |
| L35 | 19 | 91.3 | 498 | 40 | 005 | 15.0[4] | 25.0[4] | 0.8[5] | 150 | 145 | 36 | OHF ⇨ M | Weakly channelized, locally with CR ≤ 7 |
| L45 | 19 | 36.7 | 140 | 45 | 300 | 8.0[4] | 7.0[4] | 0.5[5] | 14 | - | - | OHF | |
| L47 | 19 | 104.6 | 202 | 40 | 001 | 8.0 | 10.5 | 1.5 | 63 | 65 | 33 | OHF ⇨ M | Weekly channelised |
| L6 | 20 | 94.5 | 122 | 35 | 300 | 10.0[4] | 8.0[4] | 0.4[5] | 16 | 30 | 30 | OHF | |
| L4 | 21 | 6.6 | 229 | 45-50 | 290 | 18.5 | 9.0 | 1.0, max 2.5 | 94 | 320 | 25 | OHF ⇨ **CDF** | Refer to mapping report No. LS08-0209 |
| L53 | 21 | 77.3 | 140.5 | 46 | 061 | 15.0 | 9.7 | 1.0 | 85 | 18 | 34 | OHF | |

Notes:
(1) Runout distance is the horizontal distance measured from the crown of a landslide to the distal end of the debris in the context of this report
(2) OHF - Open hillside failure
**CDF** - Channelised debris flow (in well-defined drainage line with over 60% of the transport path with channelisation ratio (CR) ≤ 7.5)
M - Mixed debris avalanche and debris flow in poorly-defined channel with no more than 60% of the transport path with CR ≤ 7.5
(3) Distance measured from landslide crown as hard cover was applied prior to inspection
(4) Source dimension estimated based on aerial photographs
(5) Depth estimation based on comparison with adjacent landslides



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Table 2 - Previous Hazard Assessments and Design Events

| Author of NTHS | Catchment (Design Source Volume) | | Barrier Retention Capacity - Max. Active Volume | |
|---|---|---|---|---|
| OAP in 2005 | • C8 (2,600 $m^3$)<br>• C15 (2,600 $m^3$)<br>• C16 (2,600 $m^3$)<br>• C17 (2,600 $m^3$)<br>• C18 (2,600 $m^3$) | based on NTLI^ and API using both QRA and Design Event approaches | • C8 (240 $m^3$)*<br>• C15 (40 $m^3$)*<br>• C16 (-- $m^3$)*<br>• C17 (1,085 $m^3$)*<br>• C18 (1,060 $m^3$)* | Simulating the debris flow event using mass balance approach |
| MGSL before 7 June 2008 | 2,600 $m^3$ in all catchments within the study area | based on CE89/2002, and counterchecked with ENTLI | • C17 (1,000 $m^3$)<br>• C18 (1,250 $m^3$)<br>Nil in other catchments | Simulating the debris flow event with typical debris parameters given in Table 3 for the pre- 7 June 2008 parameters |
| MGSL after 7 June 2008 | • C15 (1,194 $m^3$)<br>• C16 (1,410 $m^3$)<br>• C17 (1,096 $m^3$)<br>• C18 (936 $m^3$)<br>• C19 (2,141 $m^3$)<br>• C20 (936 $m^3$)<br>• C21 (795 $m^3$) | based on a reassessment of design event using Magnitude, Cumulative Frequency analysis (Tattersall et al, 2009) | • C15 (2,969 $m^3$)<br>• C16&17 (3,790 $m^3$)[+]<br>• C18 (1,445 $m^3$)<br>• C19 (2,394 $m^3$)<br>Debris stops in channel<br>Debris stops in channel | Simulating the debris flow event with debris parameters obtained from back-analysis of the 7 June 2008 landslide event in catchment No. 30 (AECOM, 2009) - see Table 3 for the post- 7 June 2008 parameters |

Notes: * Estimated active volume at site boundary
^ NTLI - The Natural Terrain landslide Inventory (NTLI) was later superseded by the ENTLI completed in 2007
[+] Combined barrier due to proximity of drainage lines



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Table 3 - Parameters Adopted in Debris Mobility Modelling

| | Landslide Type | Apparent Friction $\phi$ (deg) | Turbulence Coefficient $\xi$ ($m/s^2$) |
|---|---|---|---|
| Typical Parameters adopted before 7 June 2008 | Channelised debris flow in all catchments | 11 - 15 | 500 |
| Parameters adopted after 7 June 2008 | Channelised debris flow in catchment No. 15 to 19 with incised (i.e. CR ≤ 4) channels and/or large catchment areas | 5.7 - 11.3 | 500 |
| | Channelised debris flow in other catchments | 11.3 | 500 |

Note: Parameters are used with the Voellmy rheological model in debris mobility modelling.



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Table 4 - Maximum Rolling Rainfall at NLH Local Raingauge for Selected Durations Preceding the 7 June 2008 Landslides and the Estimated Return Periods

| Duration | Maximum [1] Rolling Rainfall (mm) | End of Period | Estimated Return Period [2] (Years) |
|---|---|---|---|
| 5 Minutes | - | - | - |
| 15 Minutes | 42 | 8:45 a.m. on 7 June 2008 | 22 |
| 1 Hour | 133 | 9:00 a.m. on 7 June 2008 | 54 |
| 2 Hours | 221 | 9:00 a.m. on 7 June 2008 | 150 |
| 4 Hours | 324 | 9:00 a.m. on 7 June 2008 | 246 |
| 12 Hours | 375 | 9:00 a.m. on 7 June 2008 | 38 |
| 24 Hours | 481 | 9:00 a.m. on 7 June 2008 | 36 |
| 48 Hours | 490 | 9:00 a.m. on 7 June 2008 | 17 |
| 4 Days | 535 | 9:00 a.m. on 7 June 2008 | 11 |
| 7 Days | 551 | 9:00 a.m. on 7 June 2008 | 8 |
| 15 Days | 614 | 9:00 a.m. on 7 June 2008 | 4 |
| 31 Days | 715 | 9:00 a.m. on 7 June 2008 | 3 |

Notes:
(1) Maximum rolling rainfall was calculated from 15-minute rainfall data.
(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(3) Historical rainfall records at Lantau Island do not cover sufficient long period for calculating the return periods, return periods can only be estimated based on rainfall records of the HKO raingauge at Tsim Sha Tsui.
(4) According to the information from the Police, the landslides occurred shortly before 9:00 a.m. on 7 June 2008. For the purpose of rainfall analysis, the landslides were assumed to have occurred at 9:00 a.m. on 7 June 2008.
(5) The local raingauge within the NLH study area was installed under Agreement No. CE 4/2005 (GE) which is situated near the boundary of catchments Nos. 19 and 20 at 90 mPD.

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Table 5 - Maximum Rolling Rainfall at GEO Raingauge No. N17 for Selected Durations Preceding the 7 June 2008 Landslides and the Estimated Return Periods

| Duration | Maximum (1) Rolling Rainfall (mm) | End of Period | Estimated Return Period (2) (Years) |
|---|---|---|---|
| 5 Minutes | 16.5 | 7:25 a.m. on 7 June 2008 | 7 |
| 15 Minutes | 44.5 | 7:25 a.m. on 7 June 2008 | 34 |
| 1 Hour | 141.0 | 8:15 a.m. on 7 June 2008 | 84 |
| 2 Hours | 236.5 | 8:35 a.m. on 7 June 2008 | 269 |
| 4 Hours | 357.5 | 8:40 a.m. on 7 June 2008 | 570 |
| 12 Hours | 429.5 | 9:00 a.m. on 7 June 2008 | 90 |
| 24 Hours | 571.5 | 9:00 a.m. on 7 June 2008 | 108 |
| 48 Hours | 585.0 | 9:00 a.m. on 7 June 2008 | 45 |
| 4 Days | 632.5 | 9:00 a.m. on 7 June 2008 | 26 |
| 7 Days | 648.5 | 9:00 a.m. on 7 June 2008 | 17 |
| 15 Days | 710.0 | 9:00 a.m. on 7 June 2008 | 8 |
| 31 Days | 810.0 | 9:00 a.m. on 7 June 2008 | 4 |

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) Historical rainfall records for Lantau Island do not cover a sufficiently long period for calculating the return periods, return periods can only be estimated based on rainfall records of the HKO raingauge at Tsim Sha Tsui.
(4) According to the information from the Police, the landslides occurred shortly before 9:00 a.m. on 7 June 2008. For the purpose of rainfall analysis, the landslides were assumed to have occurred at 9:00 a.m. on 7 June 2008.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N17 situated at about 1.3 km to the west of the landslide site. Raingauge No. N21 situated at about 2.4 km to the southwest of the landslide site.
(6) GEO raingauge No. N17 has no rainfall data recorded between 6 and 23 May 2008. During this period, about 100 mm rainfall was recorded in raingauge No. N21. For the purpose of this analysis, the missing rainfall data within this period was inferred from raingauge No. N21.

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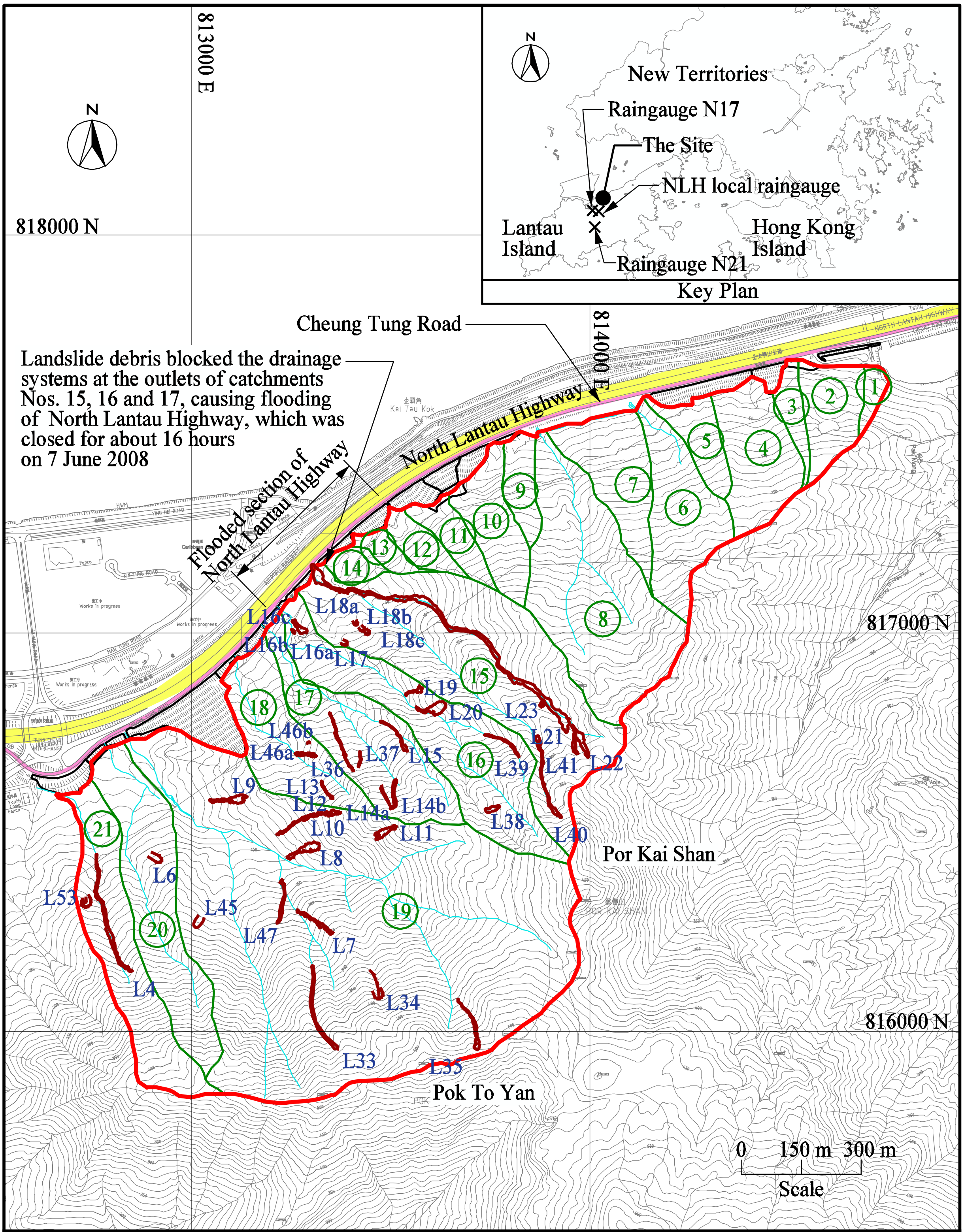


Legend : Study area boundary; Landslide observed after 7 June 2008 and number (L23); Catchment boundary and number (19); Drainage line

Notes : (1) Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.
(2) See Table 1 for details of the landslides.

Figure 1 - Location Plan

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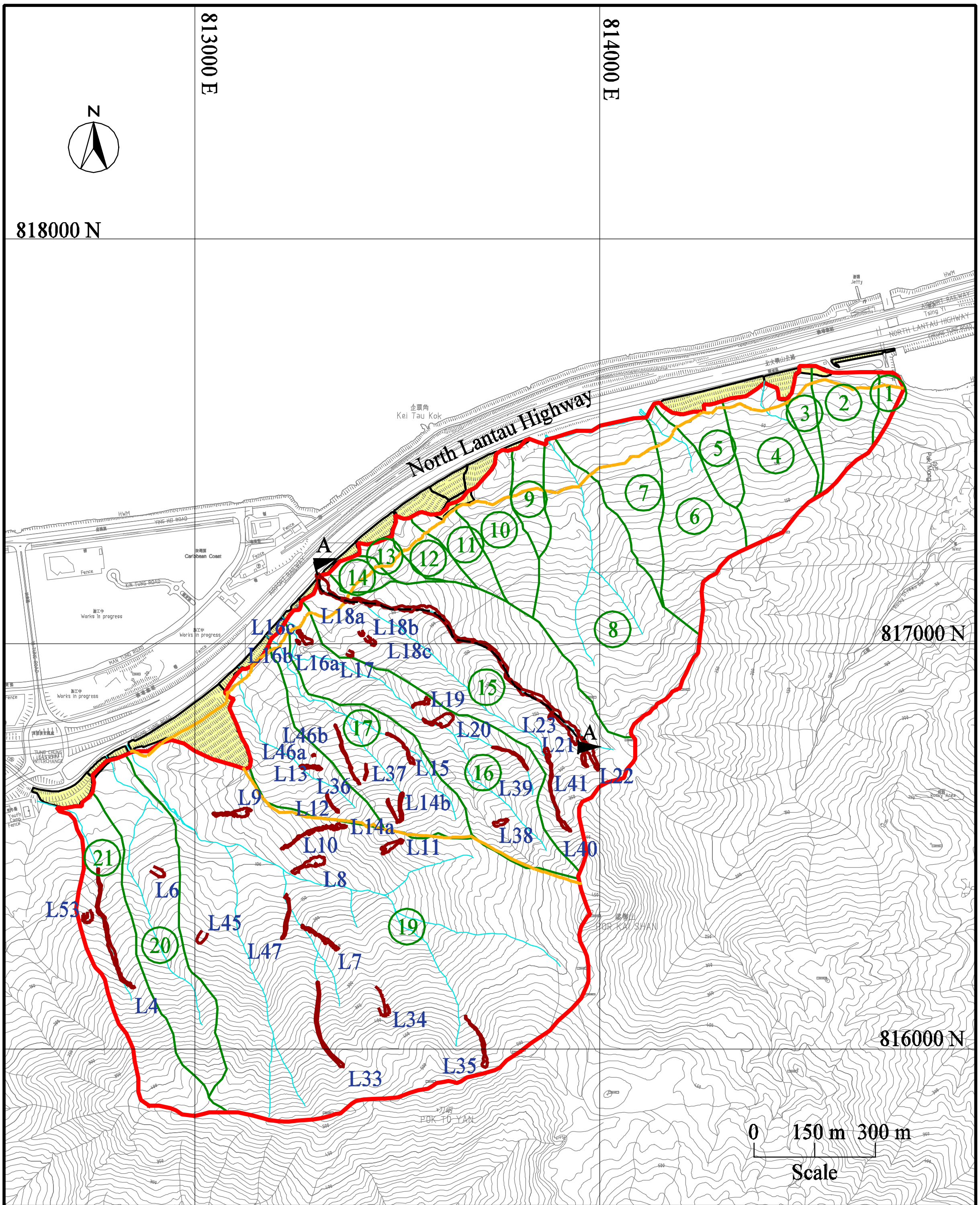


| | | | |
|---|---|---|---|
| Legend : | Study area boundary | L23 | Landslide observed after 7 June 2008 and number |
| | 19 Catchment boundary and number | | Man-made slopes adjoining the toe of the study area boundary |
| | Footpath | | Drainage line |

Notes : (1) Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.
(2) See Figure 6 for Section A-A.

Figure 2 - Site Layout Plan

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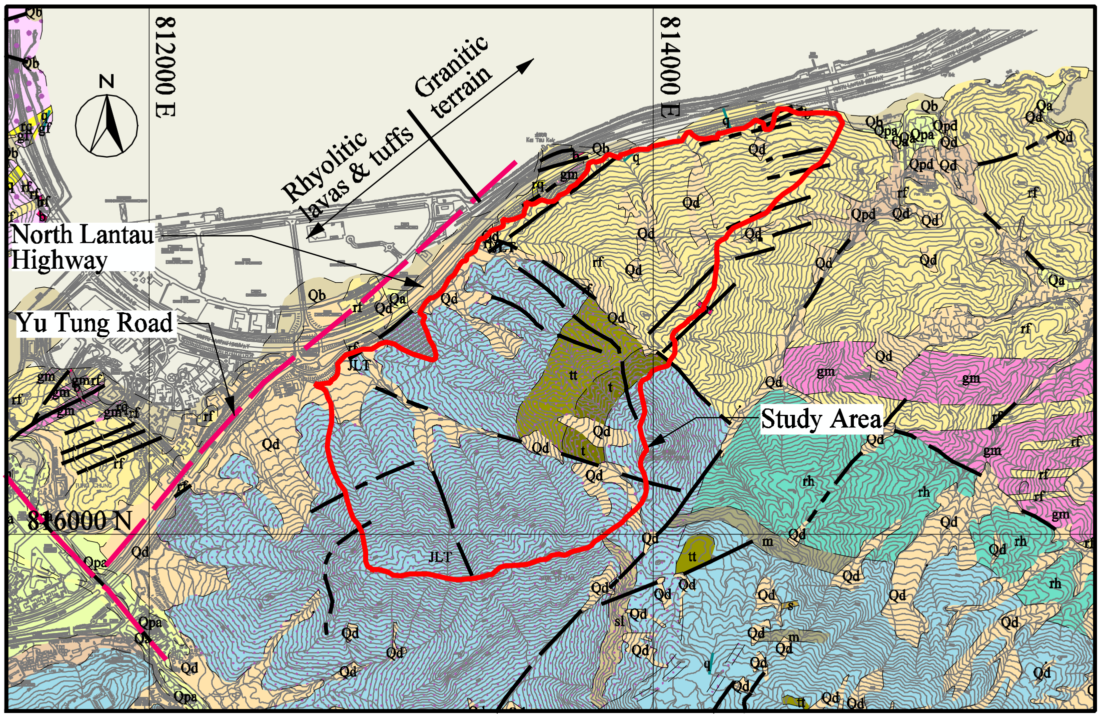


Legend :

0 300 m 600 m
Scale

Superficial deposits

| | | |
|---|---|---|
| Qa | Alluvium | Clay/silt, sand and gravel; well-sorted to semi-sorted |
| Qd | Debris flow deposits | Unsorted sand, gravel, cobbles and boulders; clay/silt matrix |
| Qpa | Terraced alluvium | Clay/silt, gravelly sandy, well-sorted to semi-sorted |
| ms | Marine sand | Sand, part silty |

Solid geology

| | | | |
|---|---|---|---|
| JTL | Tuff and lava | gm | Medium-grained granite, 2 - 6 mm |
| rf | Feldsparphyric rhyolite | b | Basalt |
| tt | Tuff and tuffite | rq | Quartzphyric rhyolite |
| t | Crystal tuff | | |

Metamorphic Rocks

Metamorphosed

Geological lines

- Photogeological lineament
- Fault
- Geological boundary, superficial deposits
- Dyke to dyke contact
- Inferred fault from the Regional Fault Plan (Sewell *et al.*, 2000)

Note : Extracted from Hong Kong Geolgical Survey, Map Series HGM 20, Sheets Nos. 9 and 10. 1:20 000 scale (GCO, 1994).

Figure 3 - Regional Geology

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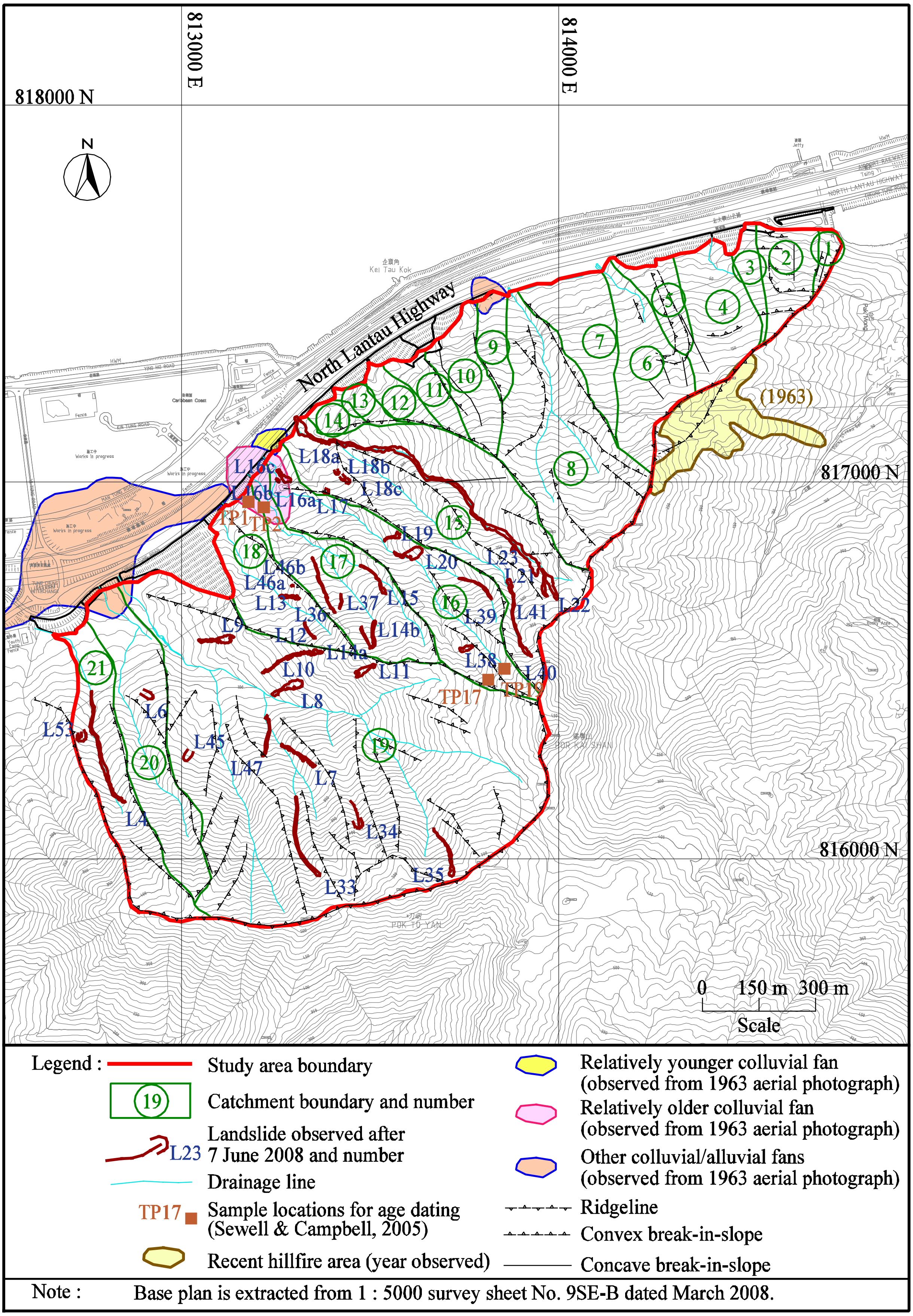


Figure 4 - Site History and Geomorphology

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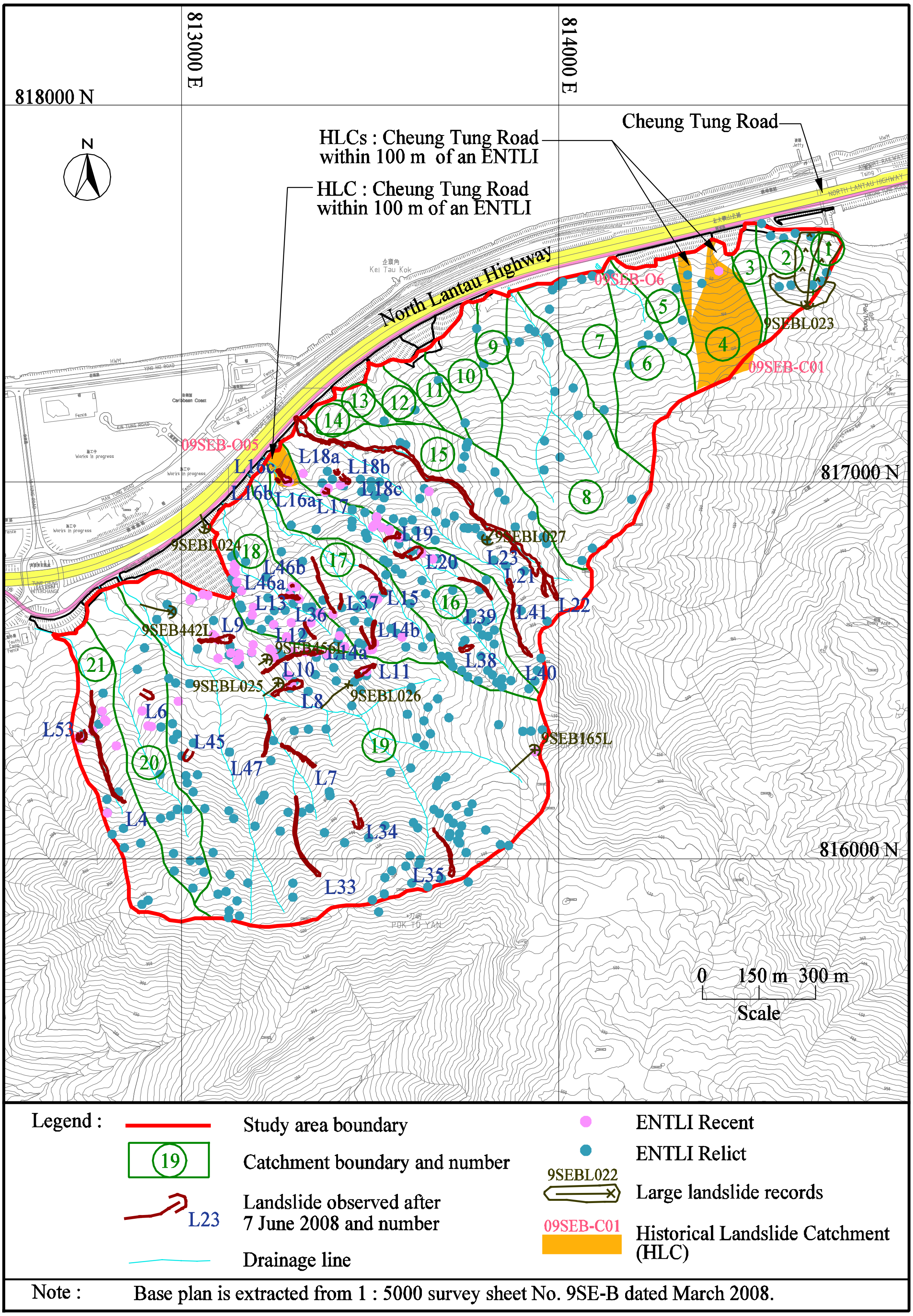


Figure 5 - Past Instability, Large Landslides and Historical Landslide Catchments

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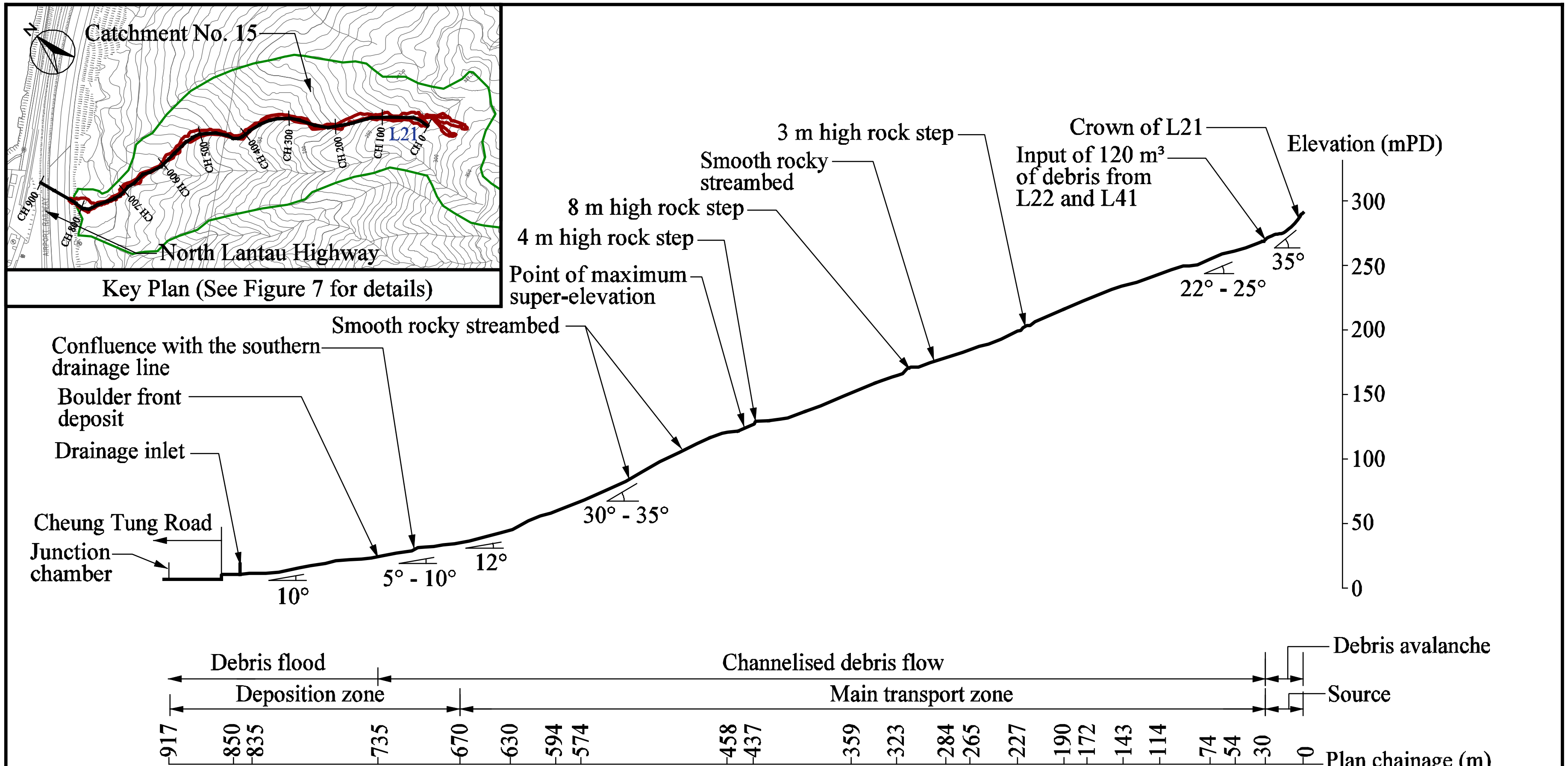


| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 35 | 55 | 3 | 0 | 5 | 0 | 0 | 0 | 20 | 5 | 25 | 55 | 47 | 66 | 65 | 0 | 65 | 15 | 35 | 400 | Erosion ($m^3$) |
| 250 | 170 | 50 | 300 | 5 | 5 | 10 | 10 | 10 | 8 | 3 | 5 | 10 | 25 | 10 | 10 | 5 | 5 | 20 | 25 | 30 | 50 | Deposition ($m^3$) |
| 0 | 250 | 420 | 435 | 680 | 682 | 687 | 692 | 702 | 712 | 720 | 703 | 703 | 688 | 658 | 621 | 565 | 505 | 510 | 465 | 475 | 350 | Mass Balance ($m^3$) |

Note : See Figure 2 for location of Section.

Figure 6 - Section A-A through Landslide No. L21 in Catchment No. 15

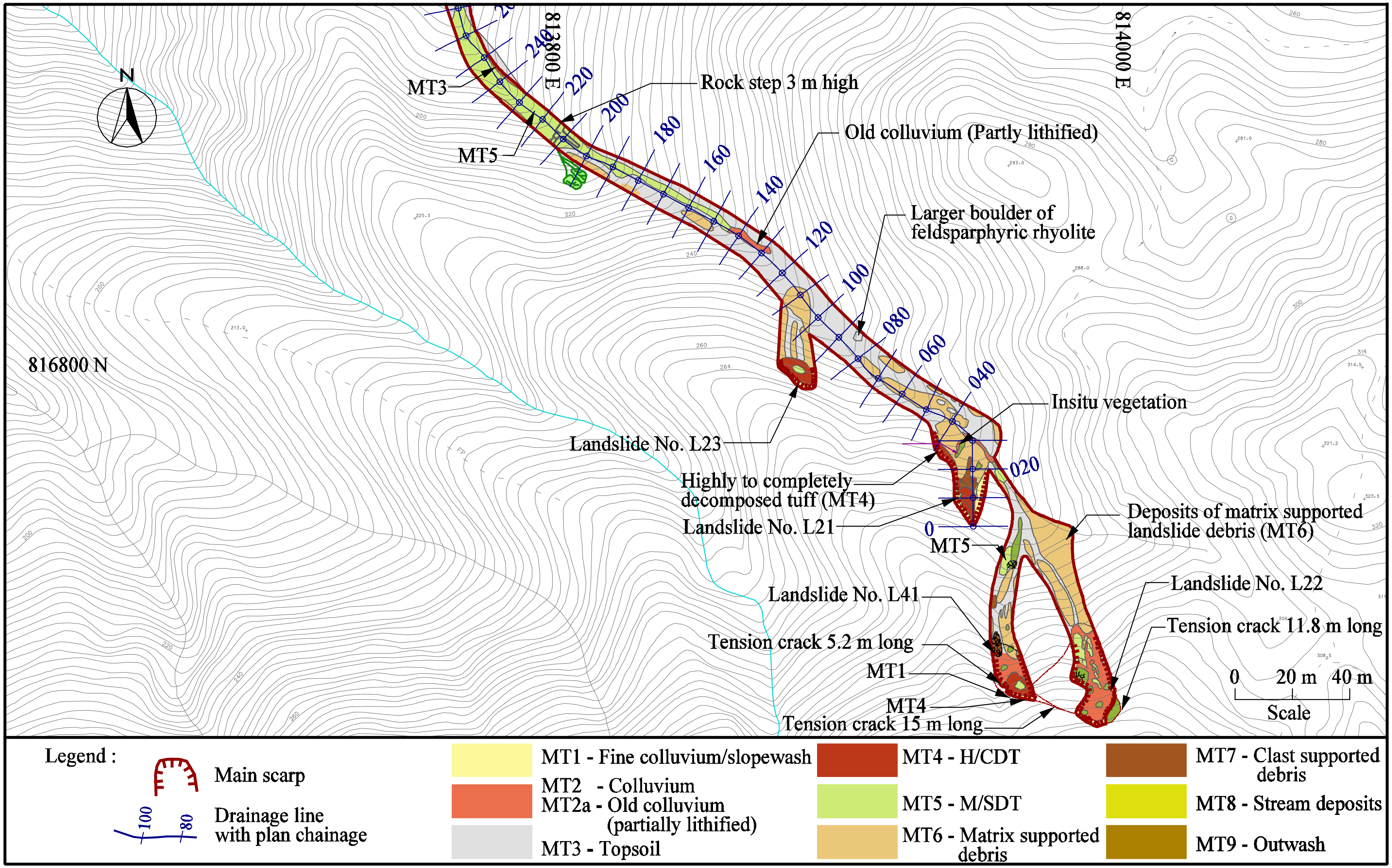


Figure 7a - Detailed Layout Plan of the Longer Channelised Debris Flow in Catchment No. 15 (Sheet 1 of 2)



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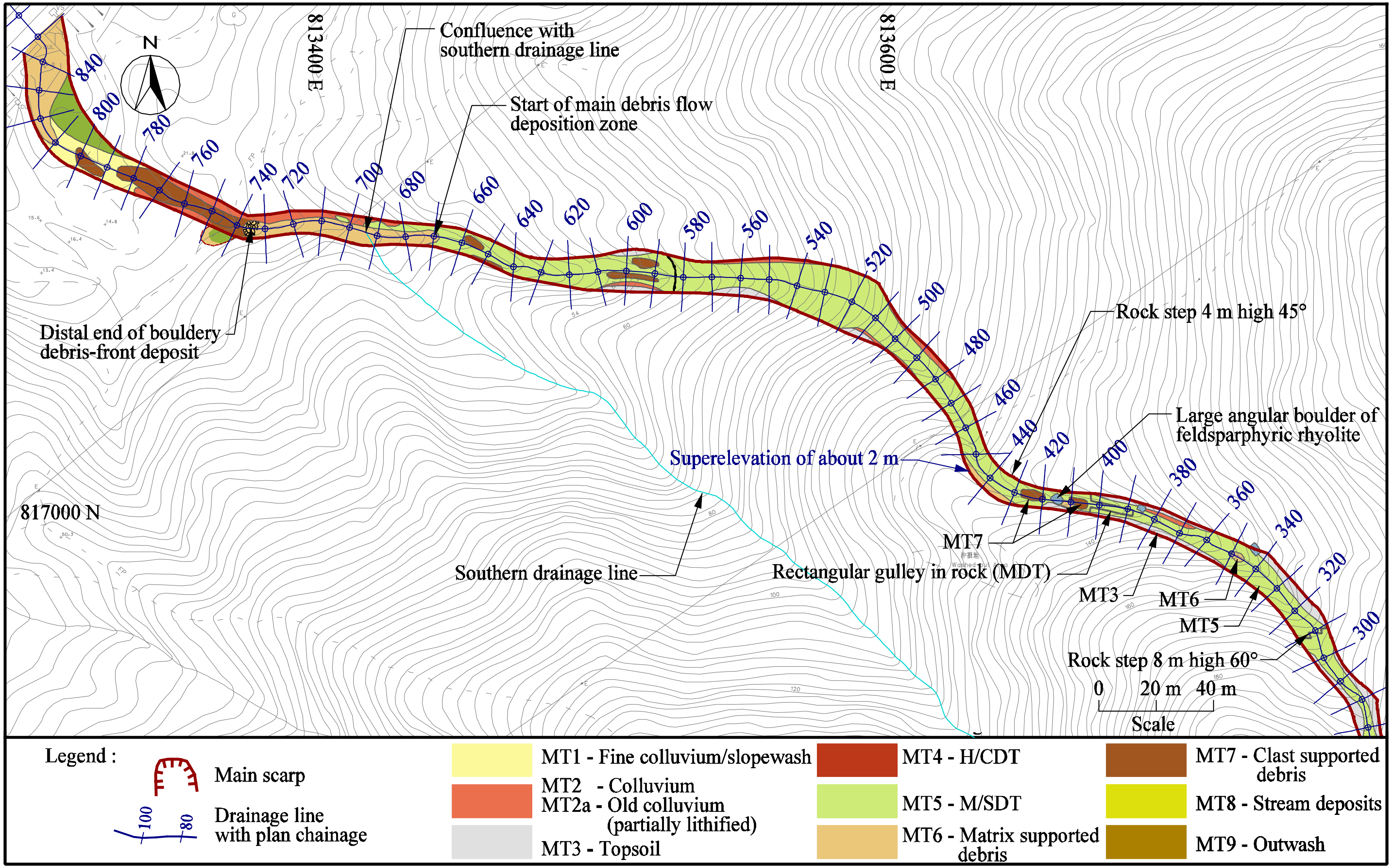


Figure 7b - Detailed Layout Plan of the Longer Channelised Debris Flow in Catchment No. 15 (Sheet 2 of 2)



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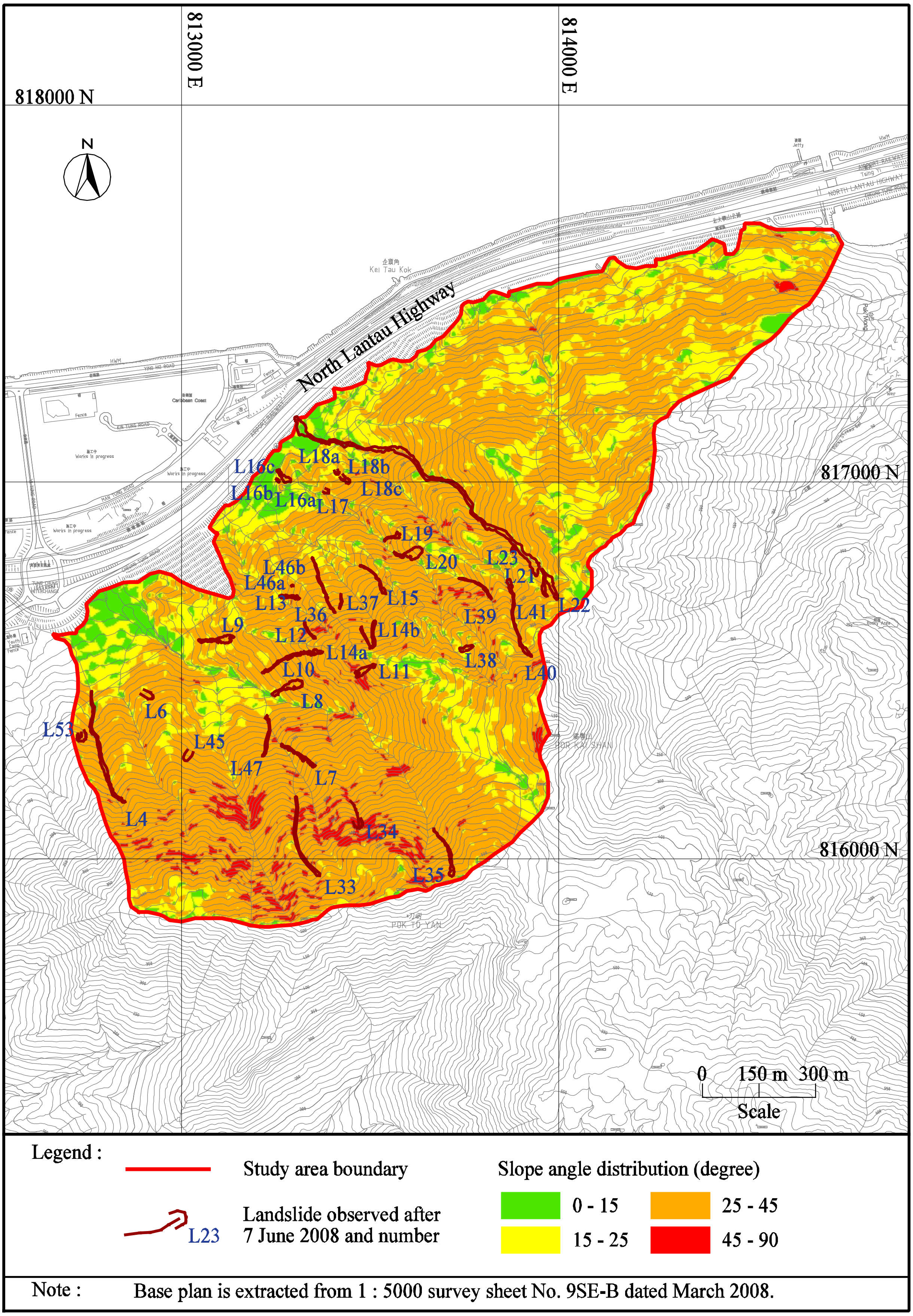


Figure 8 - Slope Angle Distribution Plan

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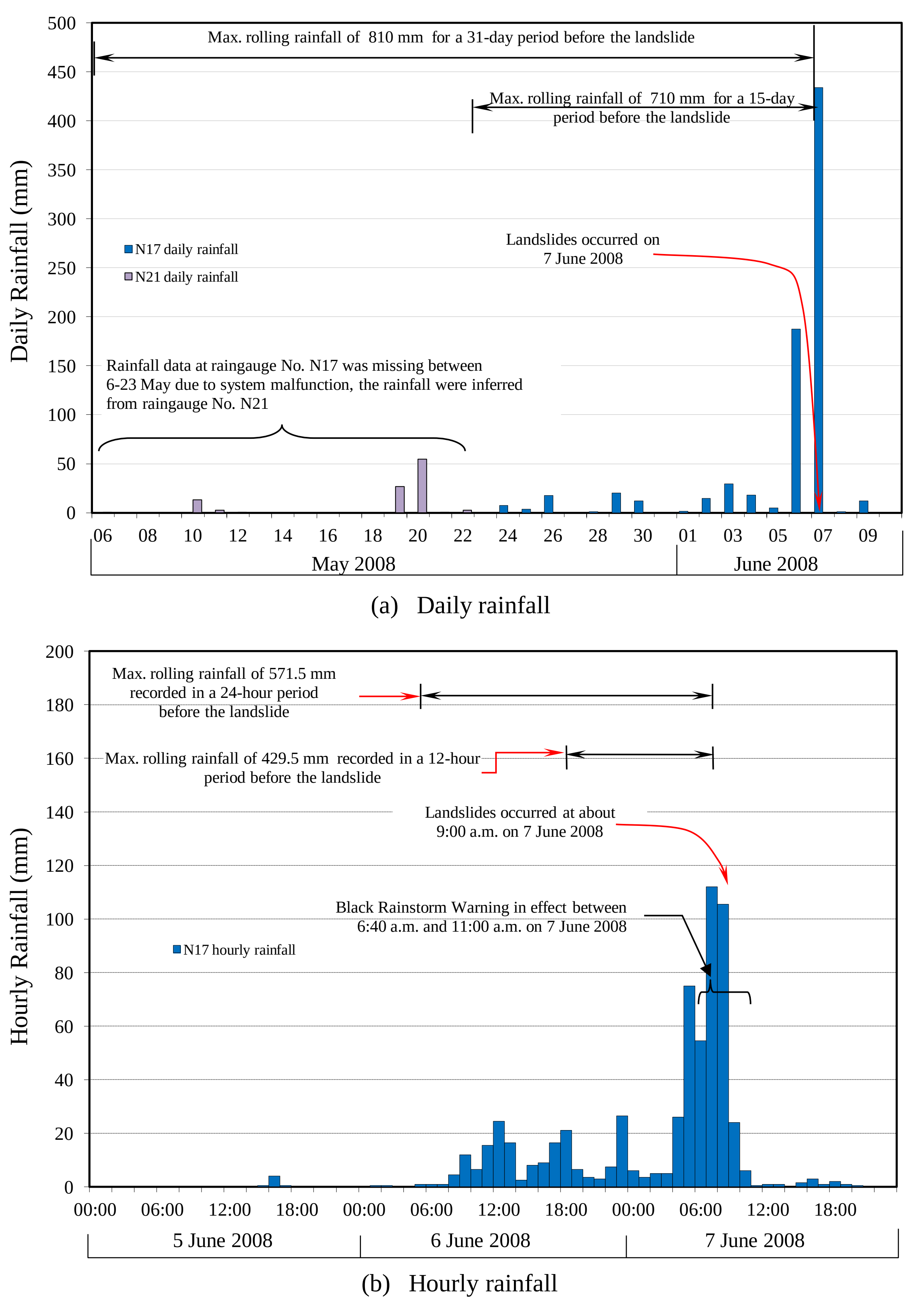


Figure 9 - Daily and Hourly Rainfall Records at GEO Raingauge No. N17

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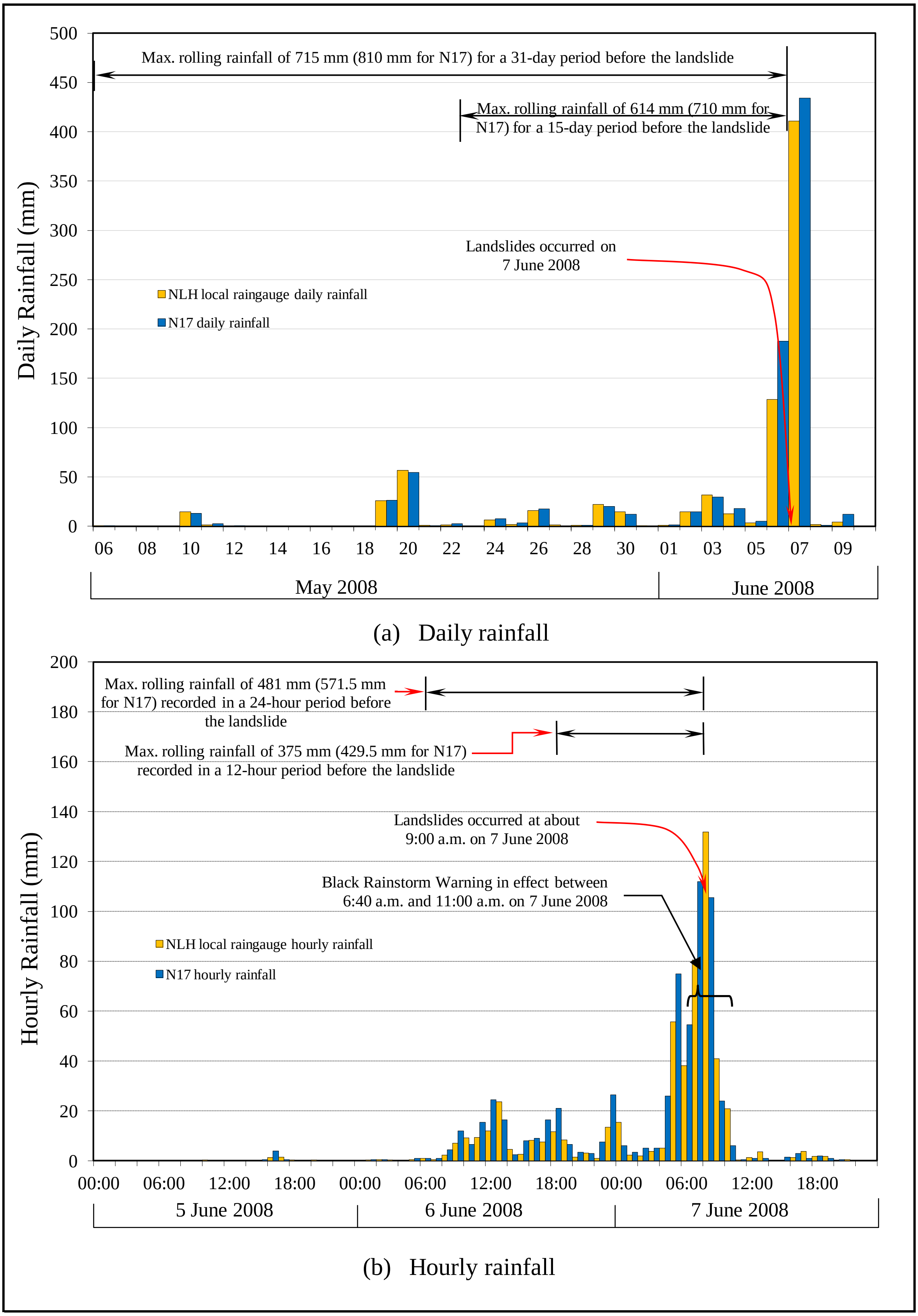


Figure 10 - Daily and Hourly Rainfall Records at NLH Local Raingauge and GEO Raingauge No. N17

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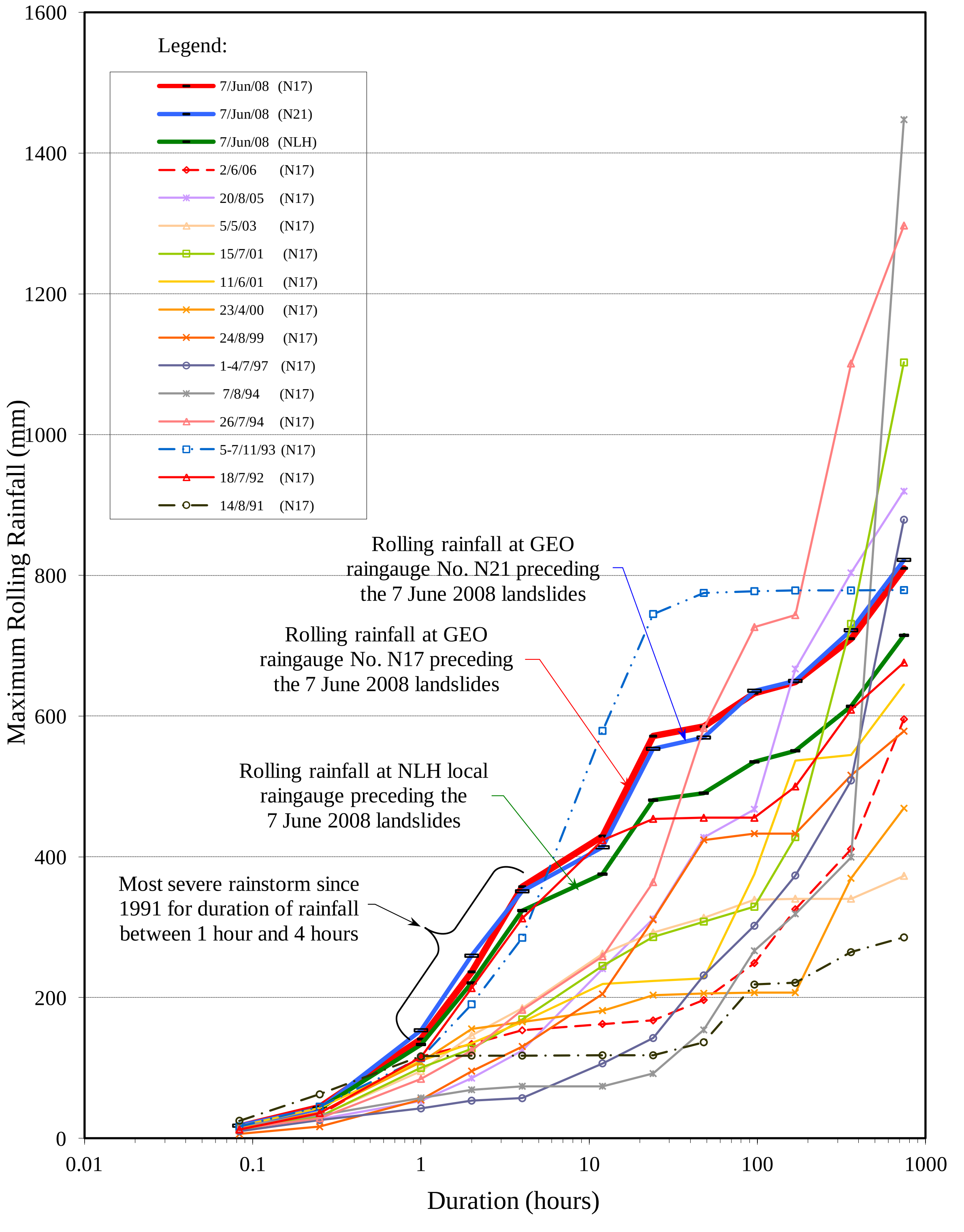


Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauges Nos. N17 (about 1.3 km to the west of the site) and N21 (about 2.4 km to the southwest).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N17 since April 1991 when the raingauges became operational.

Figure 11 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. N17

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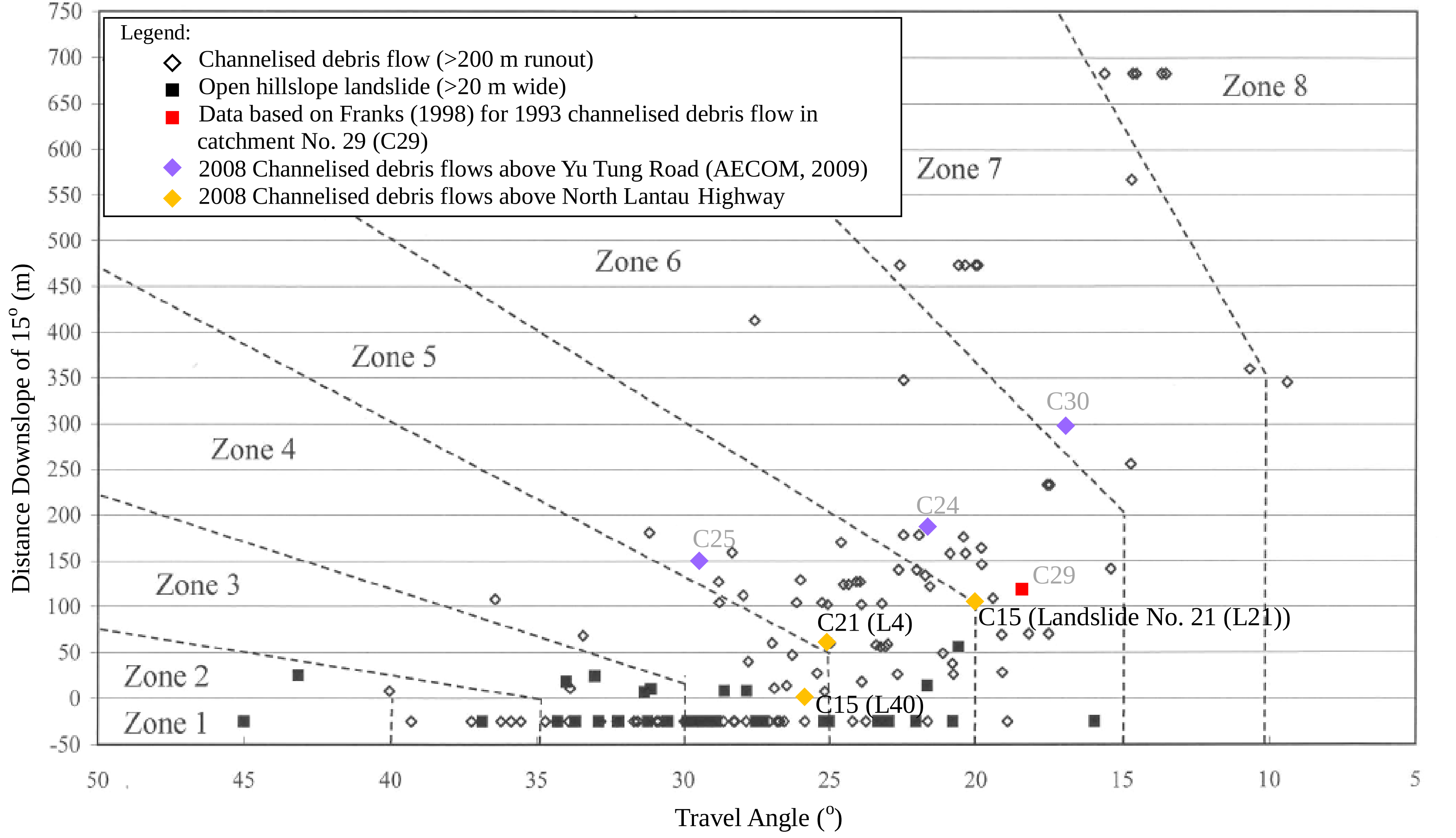


Note: Original Chart extracted from Wong et al (2006).

Figure 12 - Proximity Zones and Debris Runout Data from the 2008 Landslides



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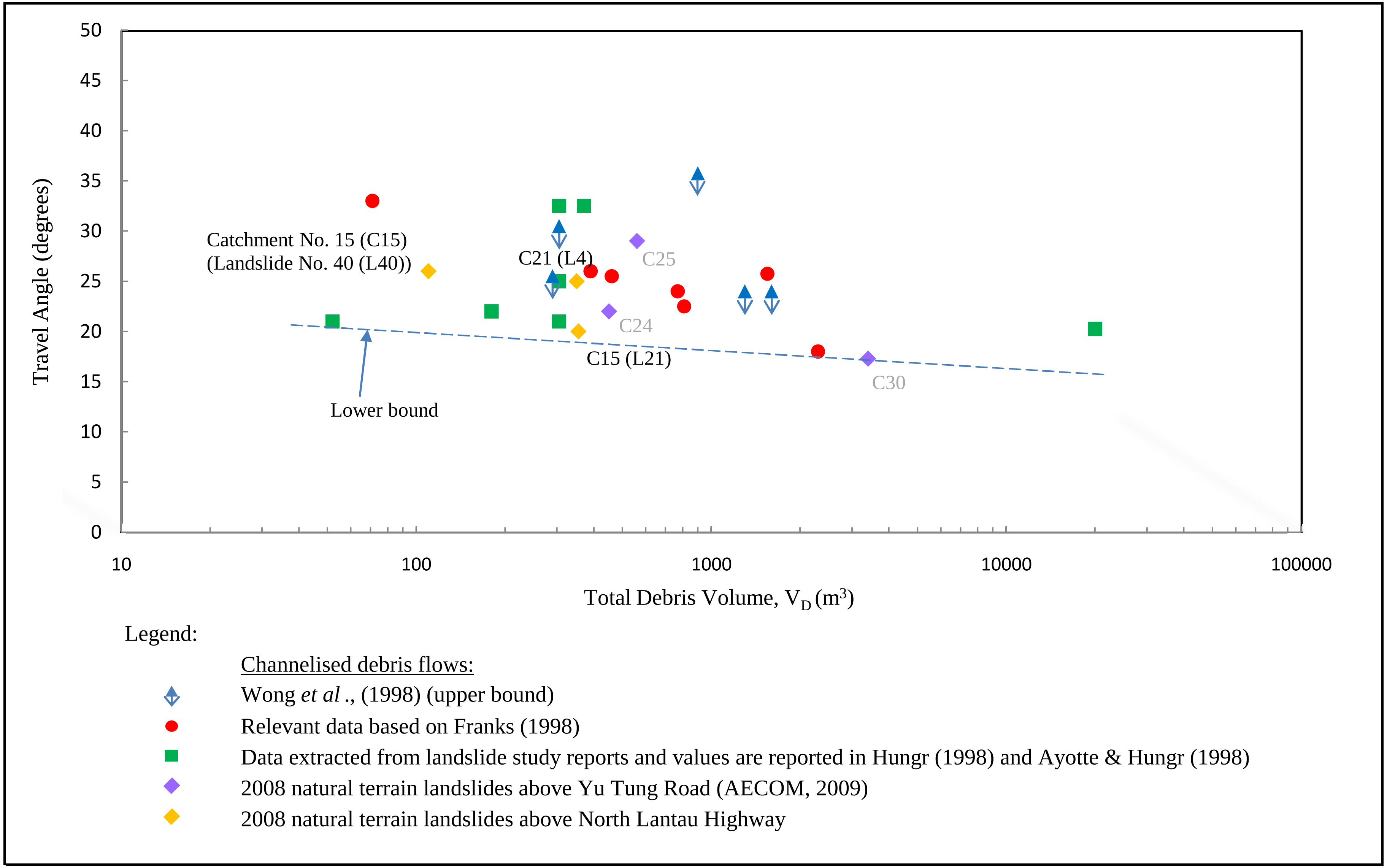


Figure 13 - Data on Debris Mobility for Channelised Debris Flows of Different Scale in Hong Kong



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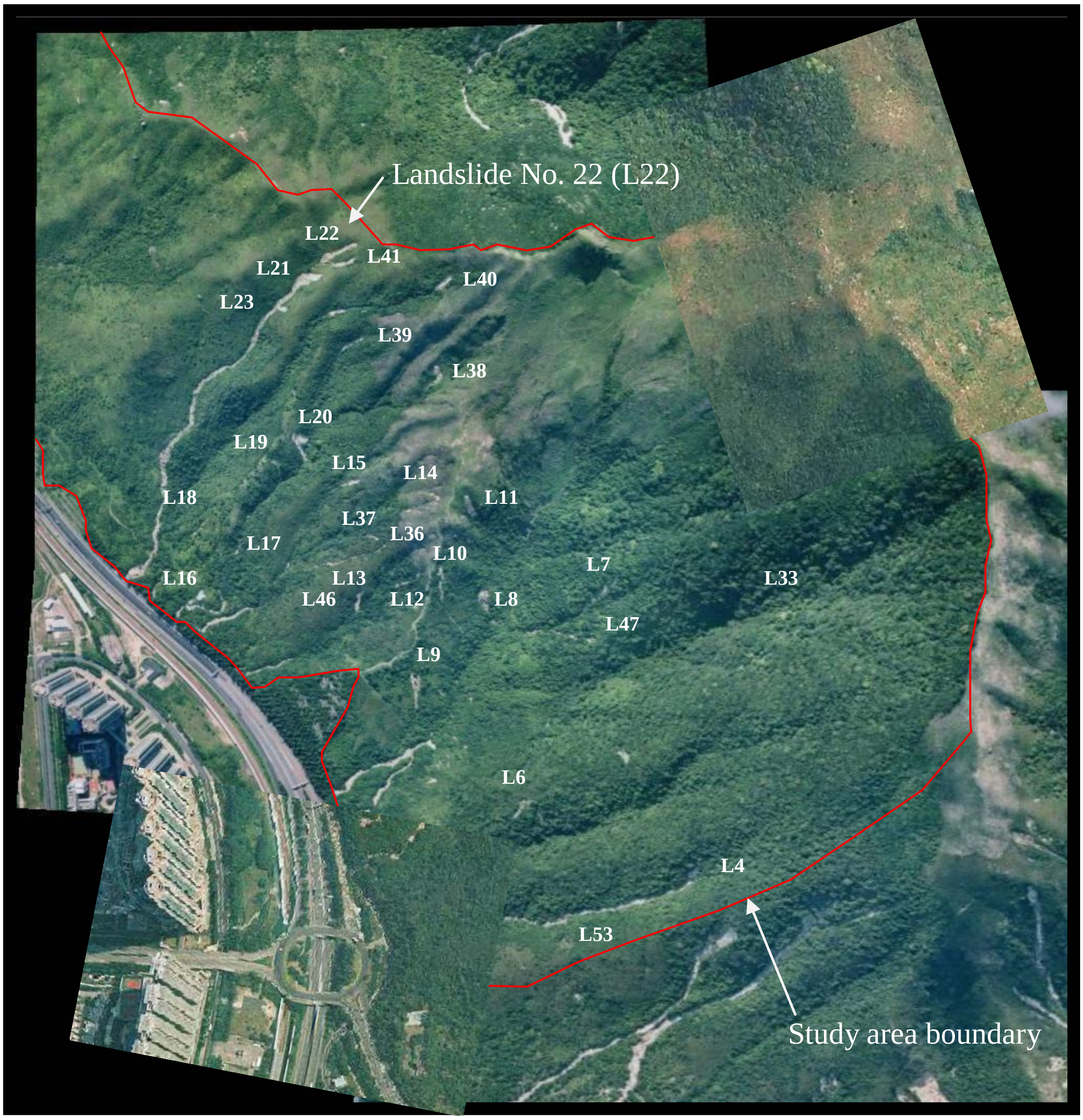


Photograph Nos. CS31599-600, CS13673-5, 6000 ft)

Plate 1 - 2008 Aerial Photograph of the Study Area (Photograph taken on 25 July 2008)

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Plate 2 - Flooding of North Lantau Highway (Photograph taken at 9:30 am on 7 June 2008)



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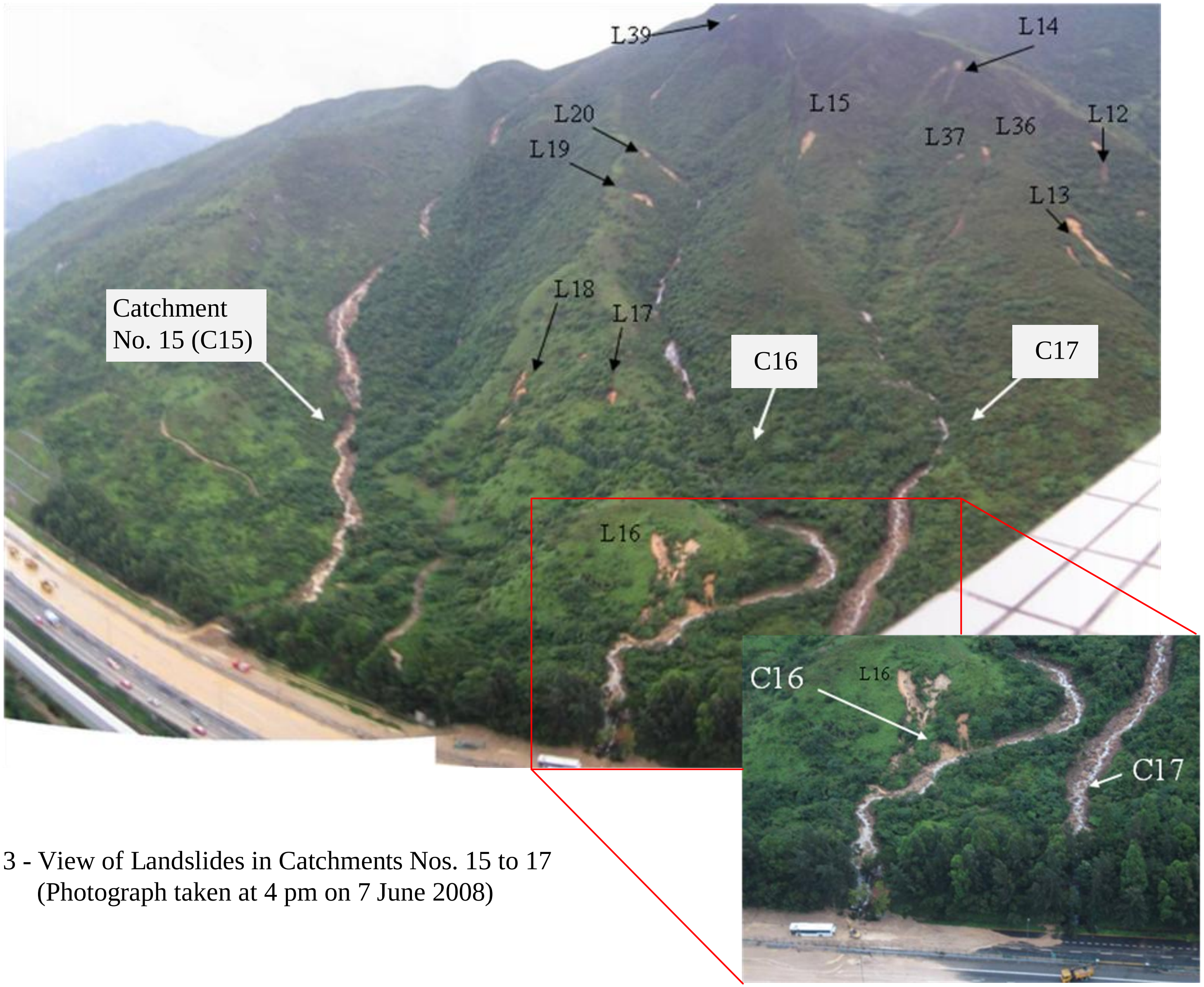


Plate 3 - View of Landslides in Catchments Nos. 15 to 17
(Photograph taken at 4 pm on 7 June 2008)



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Plate 4 - Fines Observed on North Lantau Highway (Photograph taken at 2 pm on 7 June 2008)

Plate 5 - Erosion at the Side of Drainage Channel at the Toe of Catchment No. 16 (Photograph taken at 2-3 pm on 7 June 2008)

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Plate 7 - Outwash Debris on Cheung Tung Road from Catchment No. 16 (Photograph taken at 2 pm on 7 June 2008)

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Plate 8 - Oblique Aerial View of Landslides Sources at Head of Catchment No. 15
(Photograph taken on 16 June 2008)

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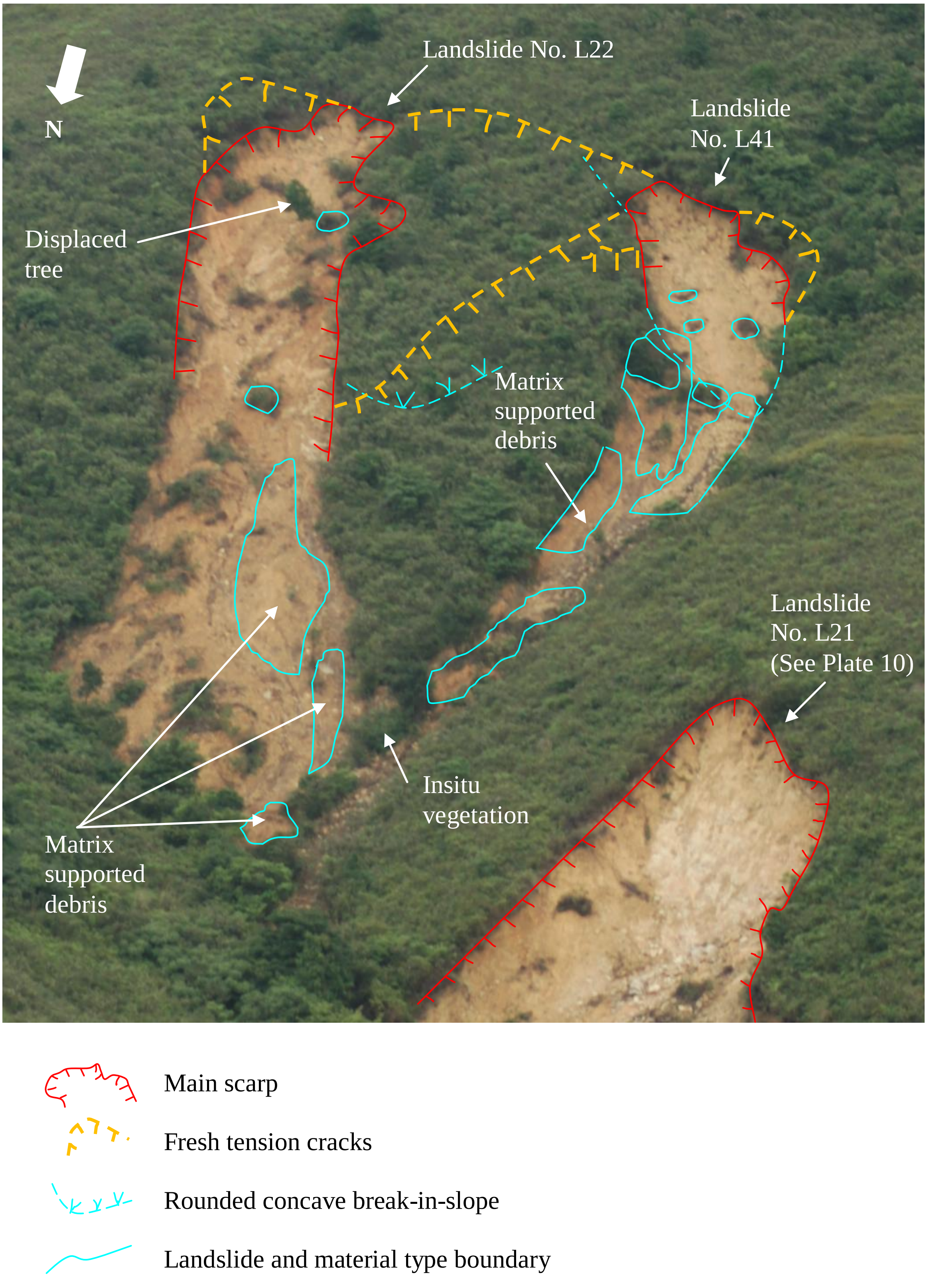


Plate 9 - Oblique Aerial Photograph of Landslides Nos. L22 and L41 Showing Tension Cracks and Distressed Hillside (Photograph taken on 16 June 2008)

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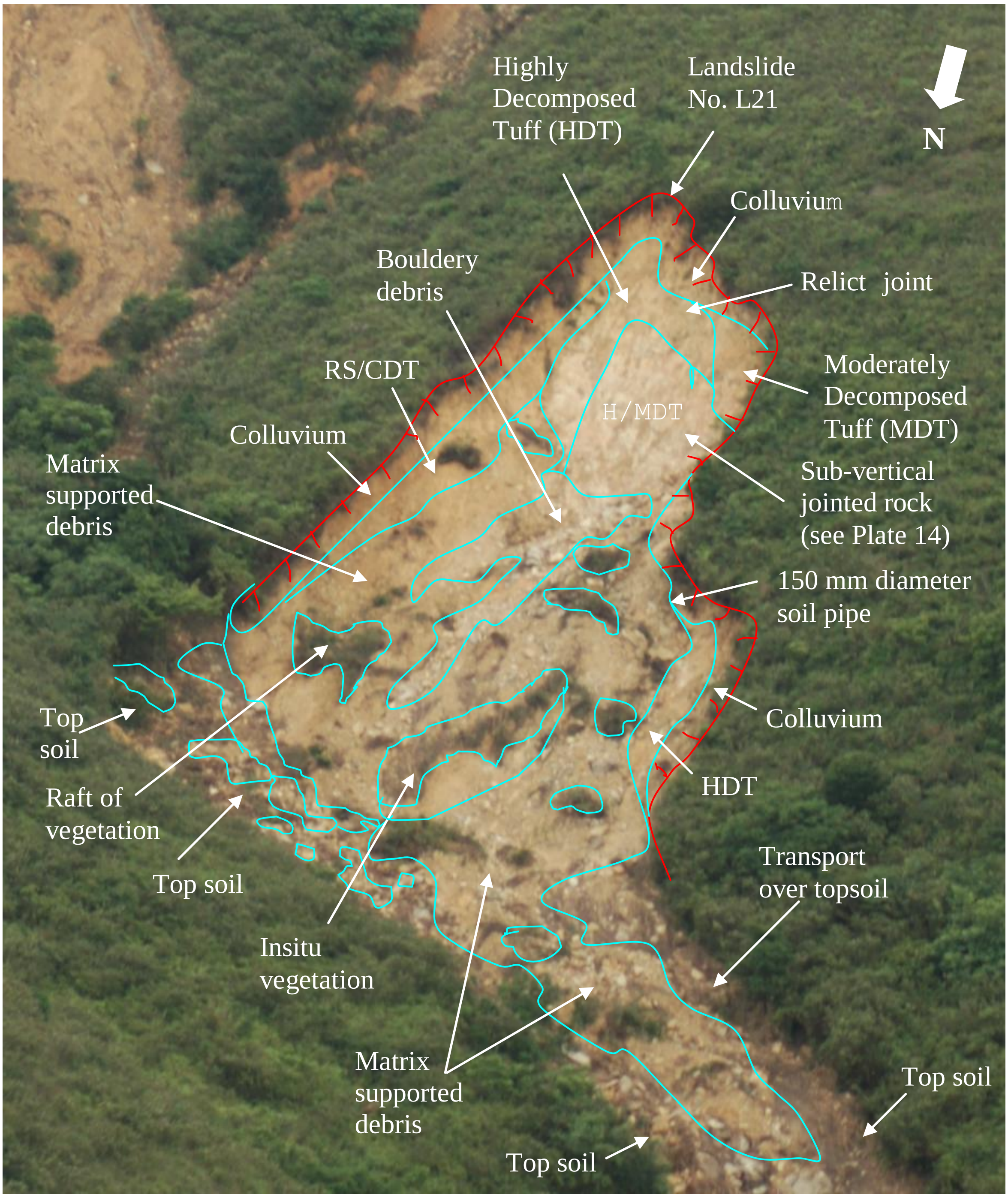


Main Scarp

Landslide and material type boundary

Plate 10 - Oblique Aerial Photograph of Landslide No. L21 (Photograph taken on 16 June 2008)

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Plate 11 - View of Tension Crack between Landslides Nos. L22 and L41 (Photograph taken on 10 October 2008)

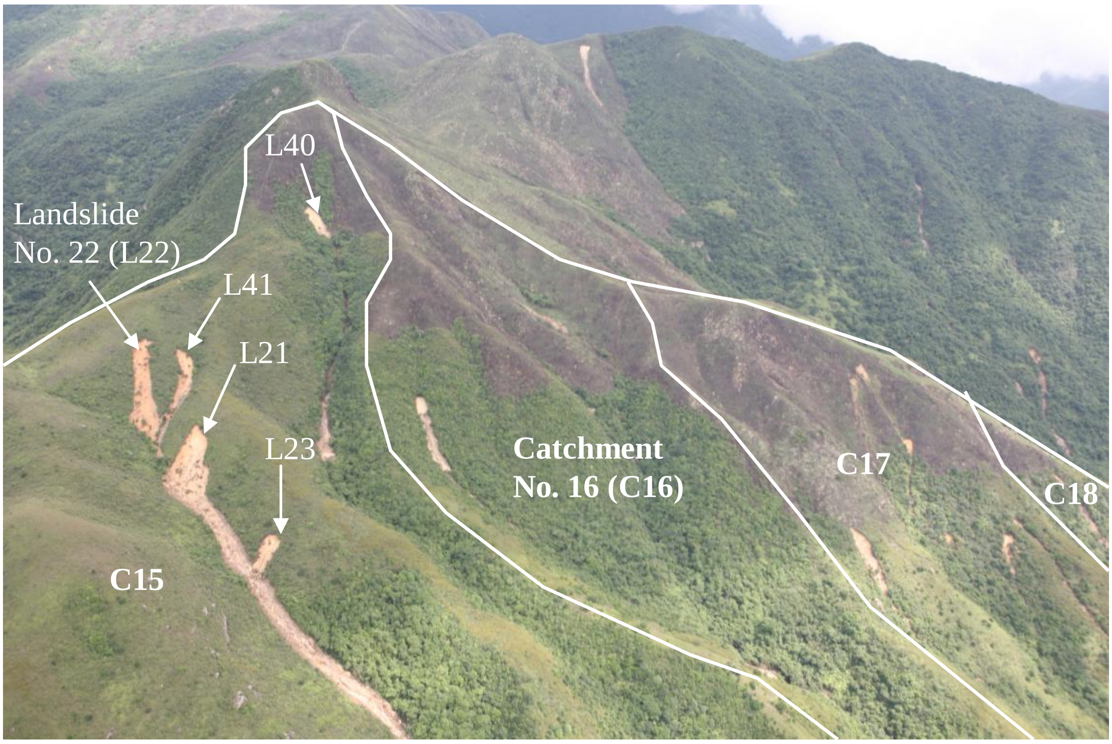


Plate 12 - Oblique Aerial Photograph Showing the Main Landslide Source Areas in the Upper Part of Catchment No. 15 (Photograph taken on 12 June 2008)

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Plate 13 - Oblique Aerial View of Landslide No. L4 in Catchment No. 21
(Photograph taken on 16 June 2008)

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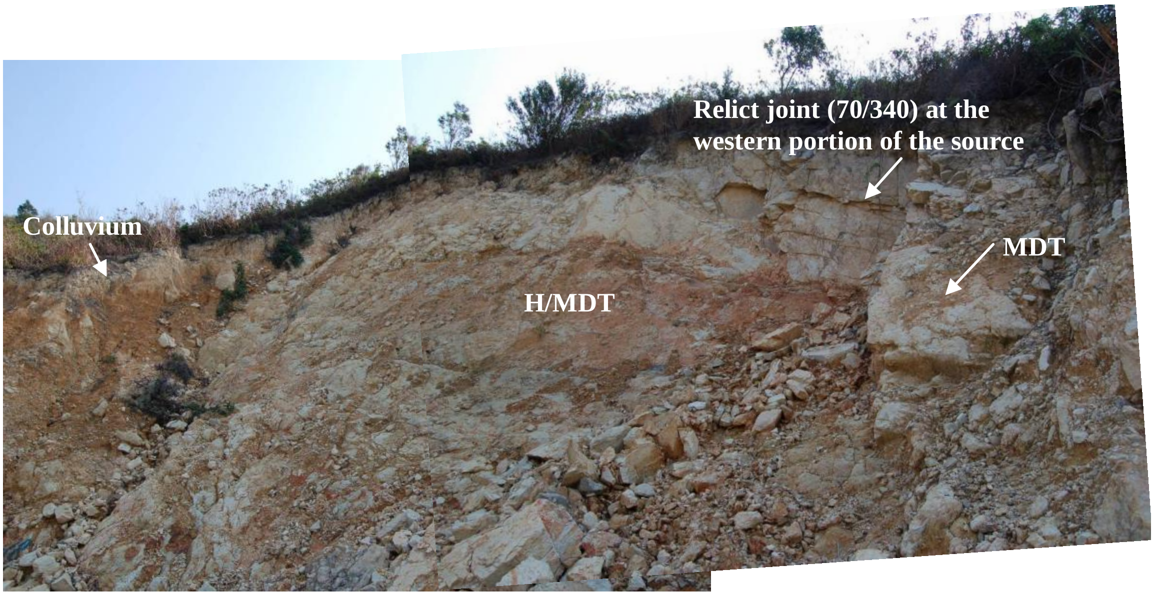


Plate 14 - Source of Landslide No. L21 in Catchment No. 15
(Photograph taken on 26 November 2008)

Plate 15 - Debris Avalanche for Landslide No. L21 in Catchment No. 15 at about CH30
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(Photograph taken on 26 November 2008)


Plate 17 - View at CH140 (Looking Down) in the Northern Drainage Line in Catchment No. 15 Exposing Rock and Partially Lithified Old Colluvium
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Plate 18 - View at CH340 (Looking Up) Revealing Transport over Topsoil and Rocky Streambed along the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)


Plate 19 - View at CH460 (Looking Up) Revealing Deposition of Super-elevated Debris at about CH440 in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)

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Plate 20 - View at CH310 Showing 8 m High Rock Step in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)

Plate 21 - View at CH590 (Looking Down) in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)

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Plate 22 - View at CH520 (Looking Up) Revealing Smooth Rocky Streambed in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)

Plate 23 - View at CH640 (Looking Up) in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)

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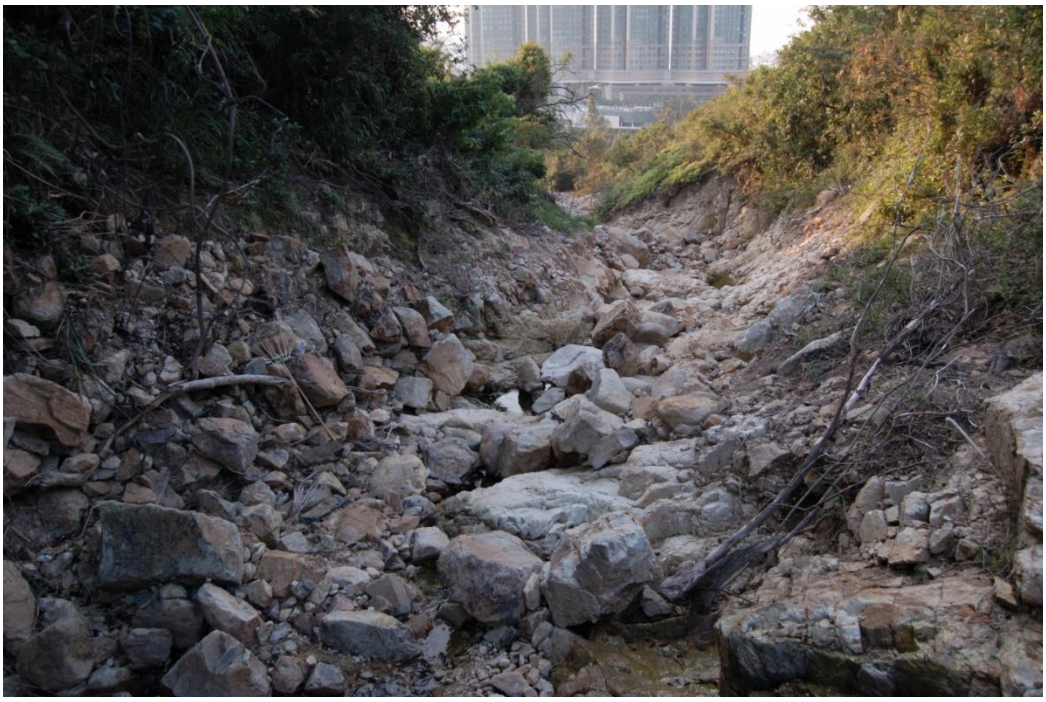

Plate 24 - View at CH670 (Looking Down) in the Northern Drainage Line in Catchment No. 15 (Photograph taken on 27 November 2008)


Plate 25 - About 300 $m^3$ of Matrix-Supported Bouldery Debris Observed at CH735, along the Northern Drainage Channel with a Gradient of 5° to 10° in Catchment No. 15 (Photograph taken at about 1 pm on 7 June 2008)

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Plate 26 - View of Debris Beyond CH735 in Catchment No. 15
(Photograph taken on 8 June 2008)


Plate 27 - Drainage Inlet Blocked with Clast-Supported Bouldery Debris at CH850
(Photograph taken at 11:30 am on 7 June 2008)

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Plate 28 - Drainage Inlet in Catchment No. 15 (Photograph taken at 11:30 am on 7 June 2008)

Plate 29 - No Impact Marks on the Concrete Head Wall Connected to the Drainage Inlet in Catchment No. 15 (Photograph taken on 8 June 2008)

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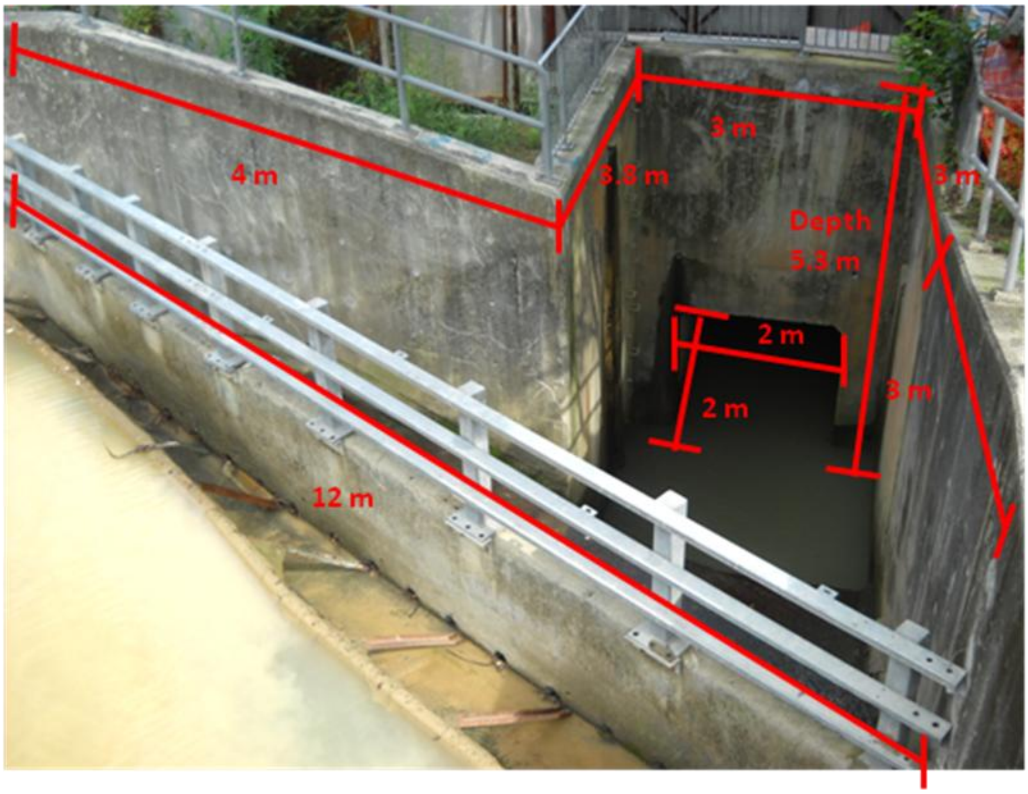


Plate 30 - Drainage Inlet at the Toe of Catchment No. 15 with Measured Dimensions

Plate 31 - The Blocked 2 m x 2 m Culvert Connected to the Drainage Inlet at the Toe of Catchment No. 15

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# APPENDIX A

## AERIAL PHOTOGRAPH INTERPRETATION

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## A1. INTRODUCTION

An Aerial Photograph Interpretation (API) has been carried out as part of the study to establish the geological, geomorphological and hydrogeological settings of the site. Site history has also been constructed by the API. Available aerial photographs between 1945 and 2008 have been reviewed and a list of the photographs is given in Table A1. Relevant observations relating to the morphology and hydrology of the site, as well as site history are shown on Figures A1 and A2. Pertinent observations from the 1945 and 1963 aerial photographs are highlighted in Figures A3 to A7.

## A2. SUMMARY

All available aerial photographs have been reviewed in detail, with an aim to identify the geological, geomorphological and hydrogeological settings of the concerned landslide locations, which might be relevant in contributing to the occurrence of the 7 June 2008 landslides.

Thirty-eight landslides occurred in catchments Nos. 15 to 21 on 7 June 2008. The catchments are located at the northwest flank of Por Kai Shan, and at the north flank of Pok To Yan, in the form of pre-existing topographical depressions (Figures A1 and A2). These depressions, which consist of relatively steep terrain, have been shaped by mass wasting processes. The steep terrain, which allows concentration of surface runoff or formation of drainage lines, has been further shaped and reworked by fluvial action and/or reactivated landslide activity with varying amounts of colluvial and fluvially re-worked debris within them. Some drainage lines are relatively incised with sharp convex breaks-in-slope located at the heads and flanks of some of the drainage lines, and many landslides sources areas are located in close proximity to these geomorphological features.

Exposed rock outcrops are encountered in the vicinity of some landslides source areas, which indicate the likelihood of relatively thin regolith cover. The regolith generally consists of colluvium which probably derived from previous mass wasting originated from landslide debris including bouldery material.

## A3. MORPHOLOGY, HYDROLOGY AND SUPERFICIAL MATERIALS

The study area is located on generally northwest-facing natural terrain, including catchments Nos. 1 to 21. Predominant rock exposures are observed at the upslope area of some catchments. Some apparent boulders are scattered across the upslope and mid-slope area of the hillside. The general morphology and hydrology of the area is shown on Figures A1 and A2.

There are ten main drainage lines (S1 to S10) descending generally towards northwest within the study catchments (Figure A1), and two photogeological lineaments (Figure A1). Photogeological lineament P1S is a strong feature and aligns with the main branch of the drainage line S3, while P2W is relatively ill-defined and aligns with drainage line S7 and sub-parallel to P1S. Both P1S and P2W correspond to drainage lines trending northwest and west-northwest respectively.

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In general, the upper catchments of the study area are delineated by well-defined ridgelines and spurlines. The terrain immediately downslope from the ridgeline is typically steep (approximately 37°, locally 57° in the vicinity of rock outcrop). The general steepness of the terrain may be associated with the presence of shallow rockhead. The midslope terrain comprises relatively shallow gradient terrain (approximately 30°), and the lower slopes comprise colluvial toe slope terrain (approximately 18°).

Several colluvial fans can be identified at the toe of catchment Nos. 9, 10, 16, 17, 19, 20 and 21 (Figures A1 to A4) in the pre-development 1963 air photographs. The largest fan is at the toe of catchments Nos. 19 to 21 and is approximately 450 m wide with extensive cultivation apparent (Figure A3). Most of the material forming the fan would have come from catchment No. 19 (the largest catchment), and to a lesser extent catchment No. 20, whose drainage lines form the centre of the fan. Another large fan is observed at the toe of catchments Nos. 16 and 17. It is about 220 m wide and may have partly blocked or dammed the drainage line within catchment No. 16, diverting the streamcourse. A smaller fan abuts against this fan to the east and from the morphology and principles of superposition, the smaller fan is considered to be relatively younger than the larger fan and appears to have formed at the outlet of the diverted streamcourse. Minor fans/lobes of colluvial/alluvial material are observed at the toe of catchments Nos. 9 and 10.

## A4. DETAILED OBSERVATIONS

Detailed observations from an examination of the aerial photographs for the period between 1945 and 2008 are presented below. Key observations are shown in Figures A1 to A6. A list of the aerial photographs examined is presented in Table A1.

| **YEAR** | **OBSERVATIONS** |
|---|---|
| 1945 | High flight, moderate resolution aerial photographs.<br><br>The study catchments are dominantly northwest-facing natural terrain which extend downhill from a relatively well-defined ridgeline and gradually becomes less steep as the hillside extends to the sea at the toe. Catchments Nos. 15-21 are differentiated by individual spurlines that generally run towards northwest.<br><br>Catchments Nos. 20 and 21 are linear with relatively confined central drainage lines. A poorly-defined convex break-in-slope differentiates the steep and gentle slope near the crest of the two catchments. The hillside near the toe becomes less steep and the change might be related to the presence of a photogeological lineament that cuts across the spurlines between these catchments (Figure 3).<br><br>Catchment No. 19 is the largest catchment in the study area, and consists of southwest-facing hillside. On the northern flank of catchment No. 19, a major west-northwest-trending drainage line which consists of a prominent valley/river basin with asymmetrical hillsides at both flanks, is present. The catchment can be further subdivided by several northwest-trending drainage lines. Some |

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**YEAR** **OBSERVATIONS**

convex break-in-slopes extend from catchment No. 19 to catchment No. 20 (Figures A1 and A2) and two depressions are evident to the immediate northeast of the breaks-in-slope which may correlate to previous relict landslides. The upper catchment is generally steep, although the southwestern boundary of the catchment, which forms the main ridgeline at the crest, is slightly steeper.

Footpaths (FP1 & FP2, Figures A1 and A2) are evident along the toe of the study catchments.

The materials eroded from catchments Nos. 19 and 20 were likely transported along the drainage lines and deposited along the toe slope area of catchment Nos. 18 to 21 to form a large debris fan which at the time of the photograph was the location of cultivated terraces (T1) which are shown in Figure A4. The drainage lines at the toe of catchments Nos. 18 and 21 may have contributed relatively minor amounts of debris at the periphery of the fan.

Catchments Nos. 16 to 18 consist of northeast-facing hillsides. On the northern flank of the catchments, northeast-trending drainage lines are present immediately downslope of northeast-trending spurlines. The drainage lines within these three catchments generally appear to be confined, especially catchment No. 16. A large and a small colluvial fan can be seen at the toe of catchments Nos. 17 and 16 respectively.

At the head of catchment No. 15, a well defined northwest-trending drainage line is located immediately downslope of the ridge crest. A few relatively shallow topographical depressions are observed that connect to the drainage line and may correspond to relict landslides exploited by fluvial erosion.

1962 High flight poor-resolution aerial photographs covering catchments Nos. 1 to 18 (without stereopair from catchments Nos. 15 to 18).

A recent open hillslide (LS1, Figure A1) is observed at the midslope of catchment No. 16. Some dwellings (M1, Figure A1) are evident near the crest of the terraces (T1, Figure A1) in catchments Nos. 16, 17 and 18.

Three graves (G1, G2 and G3, Figure A2) are observed adjacent to the footpath (FP1, Figure A2), near the toeslope area of catchments Nos. 4 and 5.

More cultivated terraces (T2, Figure A2) are visible near the toeslope area of catchment No. 9.

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| **YEAR** | **OBSERVATIONS** |
|---|---|
| 1963 | Low flight, good resolution aerial photographs. |

Catchment No. C19 consists of southwest-facing hillslopes which is located on the northern flank of the catchment. The middle slopes are characterized by an extensive stretch of intermittent rock outcrops, which strikes roughly in a northwest-southeast direction, generally following the alignment of the drainage lines. The upper portion of catchment No. C19 consists of relatively steep, rugged terrain with planar to convex profile. The area, which is covered with sparse to moderately dense vegetation, is dominated by many relict landslide scars and erosion gullies that form sharp topographical depressions on the hillsides, with convex break-in-slopes encircling their crests. These topographical depressions form surface channels for water flow. Few trails traversing the hillsides of catchment No. C19 are visible. Sheet erosion is also observed on the upper hillslopes and boulders are found scattered on the general hillsides.

A depression is evident on the eastern flank of the drainage line in catchment No. 18 which may correspond to the location of relict landslide scar. Rock outcrops are evident on the northwestern flank of the drainage line in catchment No. 17.

Two well-defined convex break-in-slopes are observed on the southwestern flank of catchment No. 16. Discrete rock outcrops located on the northeastern flank of the catchment may indicate shallow rockhead.

Catchments Nos. 1 to 14, are within terrain that generally has a gentler slope gradient than the other catchments in the study area. The hillside is dipping towards the northeast except in catchment No. 8. Catchment No. 8 contains a central drainage line and shows sheet erosion on the eastern flank near the crest and discrete rock outcrops within the catchment. Sheet erosion can also be identified near the toe of catchments Nos. 1 to 7 and upper hillside of catchments Nos. 6 and 7. Discrete rock outcrop is evident among these catchments. A depression probably corresponding to a relict landslide is evident near the toe area of catchments Nos. 1-2. A convex-break-in-slope is identified on the midslope of catchments Nos. 2-3.

An access road (M2) is visible to the south of the footpath (FP1 and FP2).

A bigger, relatively older colluvial fan is observed at the outlet of the drainage line S5 in catchments Nos. 16 and 17. A smaller and relatively younger debris lobe is observed emerging in front of the outlet of the drainage line at the eastern toe area of catchment No. 16. (Figure A1 and A4). A minor fans/lobe of colluvial/alluvial material is apparent at the toe area of catchments Nos. 9 and 10.

| | |
|---|---|
| 1964 | High flight, good resolution aerial photographs with full coverage of study area. |

An open hillside landslide (LS2, Figure A1) is observed at the west flank of catchment No. 21.

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| **YEAR** | **OBSERVATIONS** |
|---|---|
| 1973 | Low flight, good resolution aerial photographs.<br><br>Some area with decreased density of vegetation in catchments Nos. 5 to 7, suggesting caused by hillfire (HF1, Figure A2).<br><br>Fifteen landslides are observed within the study catchments. Two recent natural terrain landslides **(**LS3 and LS4, Figure A1) are visible at the eastern flank of catchment No. 21. Five recent natural terrain landslides (LS5 to LS9, Figure A1) are visible in catchment No. 19. Another seven recent natural terrain landslides (LS10 to LS16, Figure A1) are observed at the western flank of catchment No. 18 and one landslide (LS17, Figure A1) is observed at the eastern flank. |
| 1974 | High flight, good resolution with full coverage for study catchments.<br><br>Formerly hillfire affected area (HF1, Figure A2) is apparently re-vegetated. |
| 1975 | No changes of significance are observed except electricity cable poles (M1, Figure A1) are visible across catchments Nos. 1 to 14. |
| 1976 | No changes of significance are observed. There are no signs of distress or instability evident within the concerned catchments. |
| 1978 | Single, high flight, good resolution aerial photograph.<br><br>No changes of significance are observed. |
| 1979 | High flight, good resolution with full coverage for study catchments.<br><br>Two recent landslides (LS18 & LS19, Figure A1) are observed at the southern flank of catchment No. 19.<br><br>In catchment No. 18, further erosion is visible at the location of landslide No. LS3 (Figure A1). Another erosion area (E1, Figure A1) is visible at southern flank of the catchment which is next to the landslide No. LS14 (Figure A1). A recent landslide (LS20, Figure A1) is apparent at the northern flank of the catchment.<br><br>Recent landslide (LS21, Figure A1) is observed at the northern flank of catchment No. 16. |

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| **YEAR** | **OBSERVATIONS** |
| --- | --- |
| 1980 | Single, high flight, good resolution aerial photograph covered most of the study catchment except upslope area of catchment No. 19.<br><br>No changes of significance are observed. |
| 1981 | High flight, good resolution with full coverage for study catchment.<br><br>No changes of significance are observed except the density of vegetation relatively decreased. |
| 1982 | Single, high flight, good resolution aerial photograph precluded detail interpretation.<br><br>Two minor recent landslides (LS22 and LS23, Figure A1) are observed in catchment No. 19. Another landslide (LS24, Figure A1) is visible to the east of LS19 (Figure A1). A possible minor erosion area is observed to the source of LS10 (Figure A1).<br><br>Some small patches of highly reflective areas are visible at the toe of catchments Nos. 18 and 19, suggesting possible excavation works. |
| 1983 | High flight, good resolution aerial photographs without stereopair.<br><br>Landslide (LS24, Figure A1) is in evidence in catchment No. 19. Another landslide LS25 (Figure A1) is visible to the south of the landslide (LS1, Figure A1) in the 1962 aerial photograph. |
| 1984 | Single, low flight, good resolution aerial photograph precluded detail interpretation.<br><br>No significant changes are observed. The source of LS23 (Figure A1) appears bare without vegetation. |
| 1986 | Low flight, good resolution aerial photographs stereopair covered catchments Nos. 1 to 15, while single aerial photograph covered catchments Nos. 16 to 21.<br><br>No significant changes are observed. |
| 1987 | Single, high flight, good resolution, aerial photograph. No changes of significance are observed. |

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| **YEAR** | **OBSERVATIONS** |
|---|---|
| 1988 | No significant changes to the study area are observed. |
| 1989 | Single, high flight, good resolution aerial photograph precluded detail interpretation.<br><br>No changes of significance are observed. |
| 1990 | Low flight, good resolution, aerial photographs with full coverage of study catchment.<br><br>There is a general increase in density of vegetation in catchments Nos. 20 and 21. In catchment No. 16, vegetation clearance is visible at the terrace (M1, Figure A1) near the downslope and the area near the dwelling (M1) at the toeslope area of catchment No. 16. |
| 1991 | Low flight, good resolution, aerial photograph was reviewed.<br><br>No changes of significance are observed except some vegetation clearance and excavation works (M3, Figure A1) is visible near the cultivated terraces (T1, Figure A1), at the toe of catchment No. 19. |
| 1992 | Excavation works and reclamation works are apparent along the toeslope area of the study catchments. |
| 1993 | Construction of North Lantau Expressway and Yu Tung Road commenced. Reclamation works are apparent along the shoreline of catchments Nos. 8 to 11.<br><br>There are 13 recent landslides (LS25 to LS37, Figure A1) visible at the northern flank of the terrain in catchment No. 19. Most of the landslides are located at the midslope or downslope areas except LS26 which is observed at the upslope of catchment No. 19 with some of the corresponding debris collected by drainage line S3. Another seven landslides (LS38 to LS44) are visible along the flanks of drainage line S4 in catchment No. 18. Two landslides (LS45, LS46) are observed at the toeslope area of catchment No. 19. Four landslides (LS47 to LS50) are visible within catchment No. 17.<br><br>Ten landslides (LS51 to LS60) are found in catchment No. 15. Six landslides (LS61 to LS66) are located in catchment No. 21. |

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| **YEAR** | **OBSERVATIONS** |
|---|---|
| 1994 | No changes of significance are observed except tree planting is apparent in the vicinity of study catchments Nos. 23 to 31. Many man-made slopes are formed along Yu Tung Road. |
| 1995 | No changes of significance are observed except slopes Nos. 9SE-B/C26, 9SE-B/C27 have been formed along the Yu Tung Road. |
| 1997 | No changes of significance are observed. |
| 1998 | No changes of significance are observed. |
| 1999 | One channelised debris flow (LS67) is observed near drainage line S10 in catchment No. 4, with a runout distance of about 85 m.<br><br>Four recent landslides (LS68 to LS71) are observed near the toeslope area of catchment No. 16 while another recent landslide (LS72) is observed at the midslope area of catchment No. 16.<br><br>A landslide (LS73) is visible at the southern flank of catchment No. 18 and another landslide (LS74) is visible at the northern flank of catchment No. 19. |
| 2000 | No changes of significance are observed. |
| 2001 | A recent landslide (LS75) is observed at the northern flank of catchment No. 16. |
| 2002 | No changes of significance are observed. |
| 2003 | No changes of significances are observed. |
| 2005 | No changes of significances are observed. |
| 2006 | Three recent landslides are observed. LS76 coincides with LS10 at the southern flank of the terrain in catchment No. 18. LS77 (52 $m^3$) is located above LS57 at the upslope area of catchment No. 17 and landslide LS78 (103 $m^3$) is located above LS69 in catchment No. 17. Another minor landslide is identified in catchment No. 17 with source volume of about 20 $m^3$. |

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| **YEAR** | **OBSERVATIONS** |
|---|---|
| 2008 | Low flight, good resolution, aerial photographs<br><br>Thirty eight recent landslide scars are evident on the study catchment (Figures A1 and A2). |

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Table A1 - List of Aerial Photographs Examined

| Date taken | Altitude (ft) | Photograph Number |
|---|---|---|
| 11 November 1945 | 20000 | Y00404-7 |
| 11 November 1945 | 20000 | Y00446-8 |
| 11 November 1945 | 20000 | Y00499-501 |
| 22 January 1962 | 30000 | Y05690-1 |
| 24 January 1963 | 3900 | Y6280-2 |
| 25 January 1963 | 3900 | Y6358-64 |
| 14 December 1964 | 12500 | Y12876-7 |
| 4 April 1973 | 6000 | 3913-4 |
| 4 April 1973 | 6000 | 3917-8 |
| 20 November 1974 | 12500 | 9557-8 |
| 19 December 1975 | 12500 | 11692-3 |
| 24 November 1976 | 12500 | 16595-6 |
| 10 January 1978 | 12500 | 20781 |
| 28 November 1979 | 10000 | 27993-4 |
| 28 November 1980 | 10000 | 33450 |
| 27 October 1981 | 10000 | 39119-21 |
| 10 October 1982 | 10000 | 44484-5 |
| 30 November 1983 | 10000 | 51364-5 |
| 22 November 1984 | 6000 | 57263 |
| 7 July 1985 | 10000 | A01742 |
| 19 December 1986 | 3500 | A07864,6-7 |
| 5 January 1987<br>14 January 1987 | 20000<br>4000 | A08415<br>A08717 |
| 16 January 1988 | 10000 | A12230-1 |
| 20 November 1989 | 10000 | A19312-3 |
| 20 November 1989 | 10000 | A19268 |
| 20 May 1990 | 4000 | CN2309-10 |
| 6 December 1990 | 4000 | A24929-31 |
| 30 October 1991 | 5000 | A28953-5 |
| 8 December 1992<br>14 September 1992<br>9 January 1992 | 3100 ,<br>6000<br>5000, | A33355-6<br>CN3332-3<br>CN2763-5 |
| 4 February 1993<br>5 December 1993 | 5500<br>6000 | A33910<br>CN5206-7 |
| 28 March 1994<br>20 December 1994 | 6000<br>5000 | CN6260-62<br>CN8933 |

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| Date taken | Altitude (ft) | Photograph Number |
|---|---|---|
| 31 October 1995 | 5000 | CN11629-31 |
| 29 October 1996 | 3500 | A43560-2 |
| 11 November 1996<br>29 October 1997 | 5000<br>6000 | A43928<br>CN18105-6 |
| 27 July 1998<br>10 November 1998 | 4000<br>8000 | CN20050-2<br>CN22032-3 |
| 3 November 1999<br>3 November 1999<br>9 December 1999 | 5500<br>5500<br>8000 | CN24160<br>CN24192-4<br>CN25678 |
| 19 April 2000 | 5000 | CN26273-5 |
| 20 November 2001 | 8000 | CW35952-3 |
| 19 September 2002<br>7 October 2002 | 4000<br>4000 | CW43572<br>RW01044-7 |
| 19 October 2003<br>30 October 2003 | 8000<br>4000 | CW50931-2<br>CW51557 |
| 27 September 2004 | 4000 | CW59369 |
| 5 March 2005 | 5000 | RW05141-2 |
| 26 September 2006<br>17 December 2006 | 4000<br>8000 | CW72987-8<br>CW75747-8 |
| 25 July 2008<br>25 July 2008 | 6000<br>6000 | CS13599-600<br>CS13673-5 |

Note: All aerial photographs are in black and white apart from those with prefix CN and CW. RW refers to infrared.

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## LIST OF FIGURES

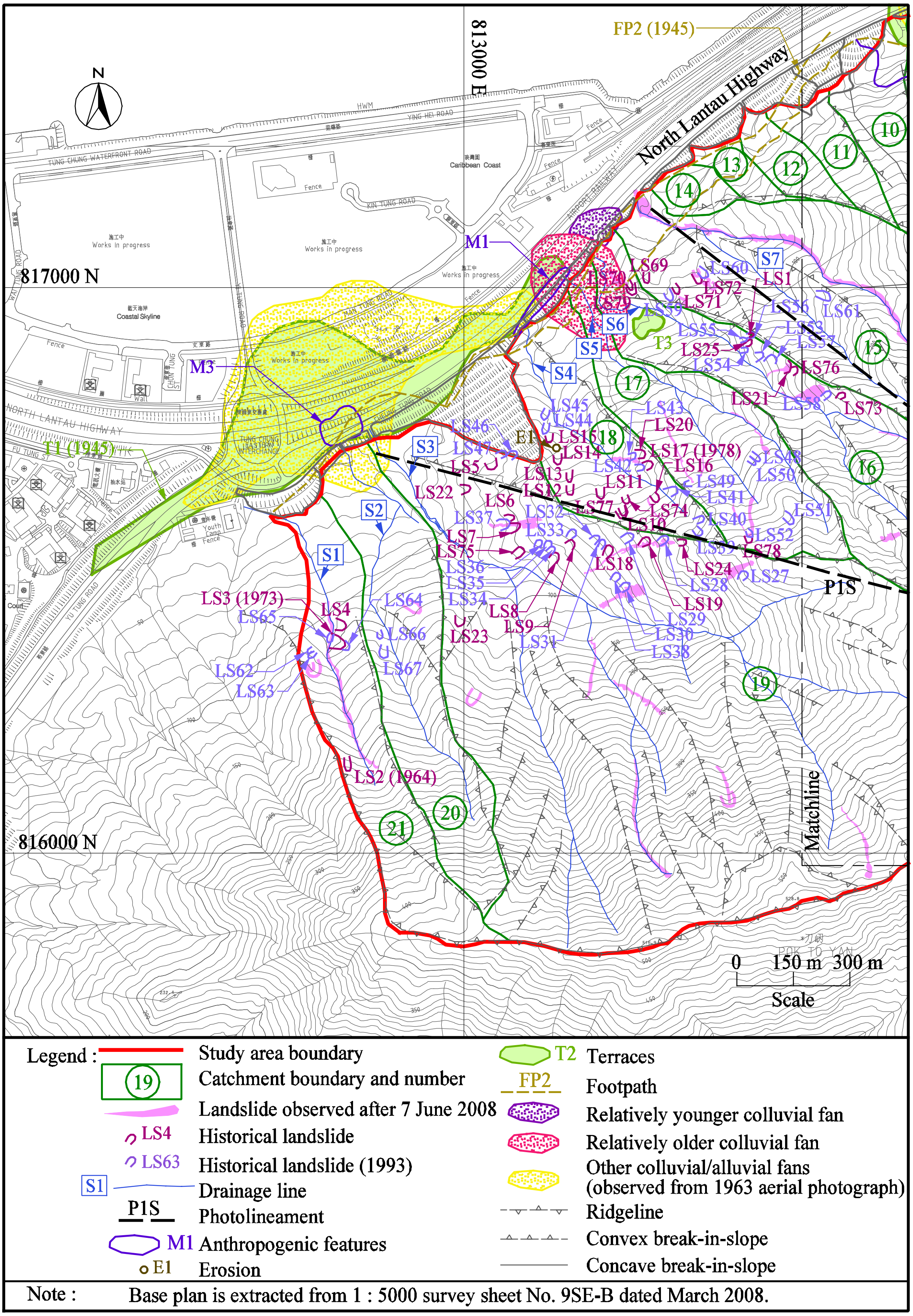


Figure A1 - Detailed Site History and Geomorphological Plan (Western Study Area)

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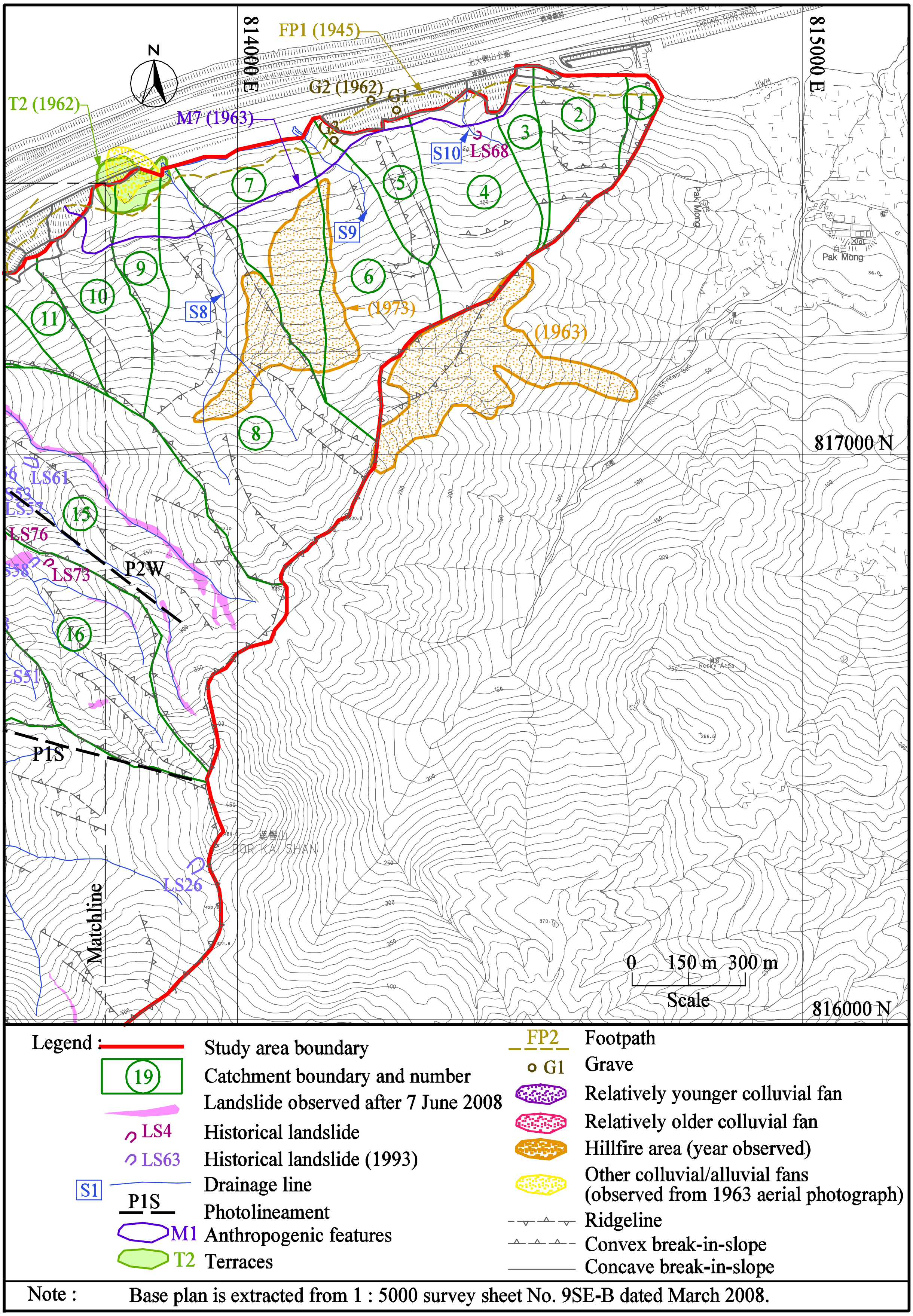


Figure A2 - Detailed Site History and Geomorphological Plan (Eastern Study Area)

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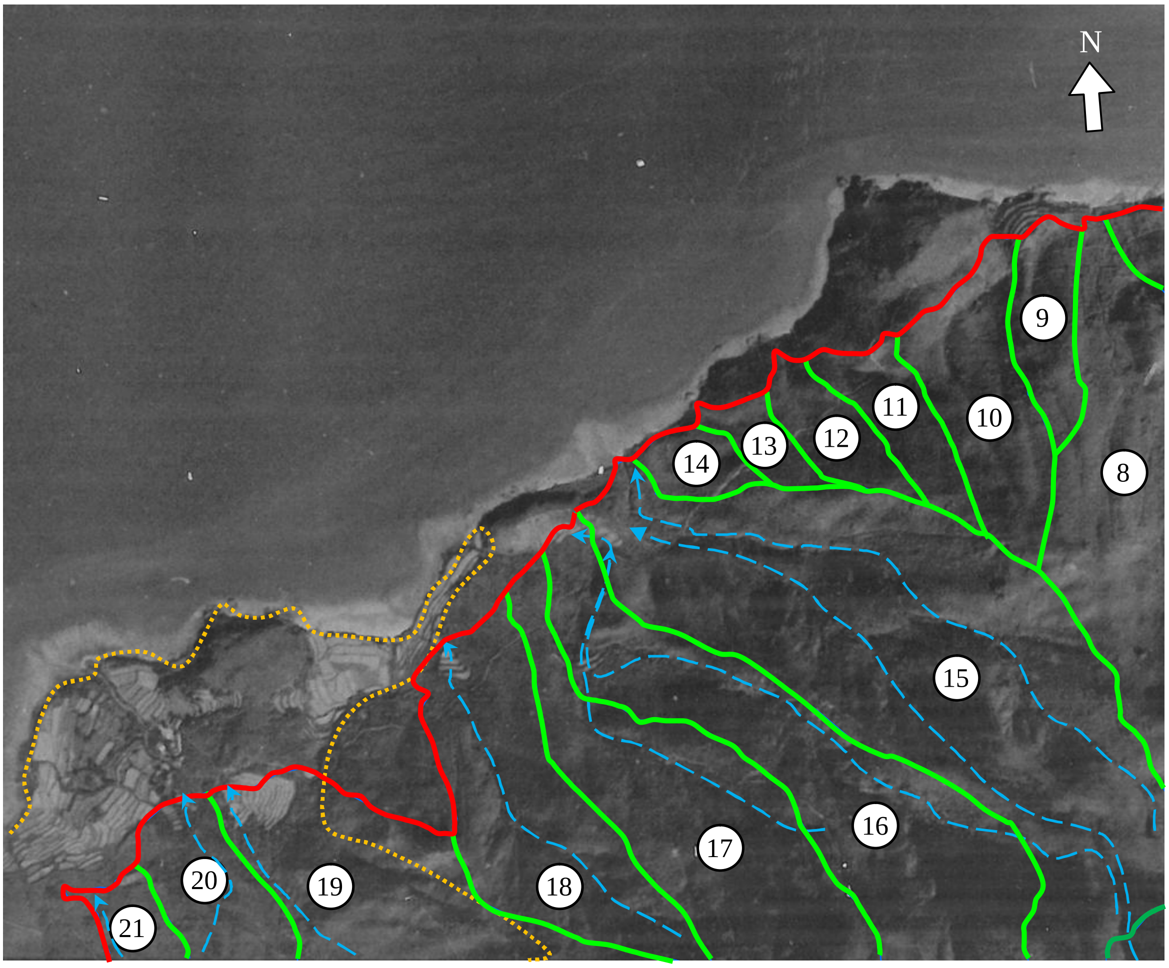


(Photograph Y00500 (20,000ft) taken on 11 November 1945)

Legend:

Study Area Boundary

Debris flow deposits

21 Catchment No.

Catchment Boundary

Drainage line

Figure A3 - Interpretation of 1945 Aerial Photograph Showing Colluvial/Alluvial Fans below Catchments Nos. 19, 20 and 21

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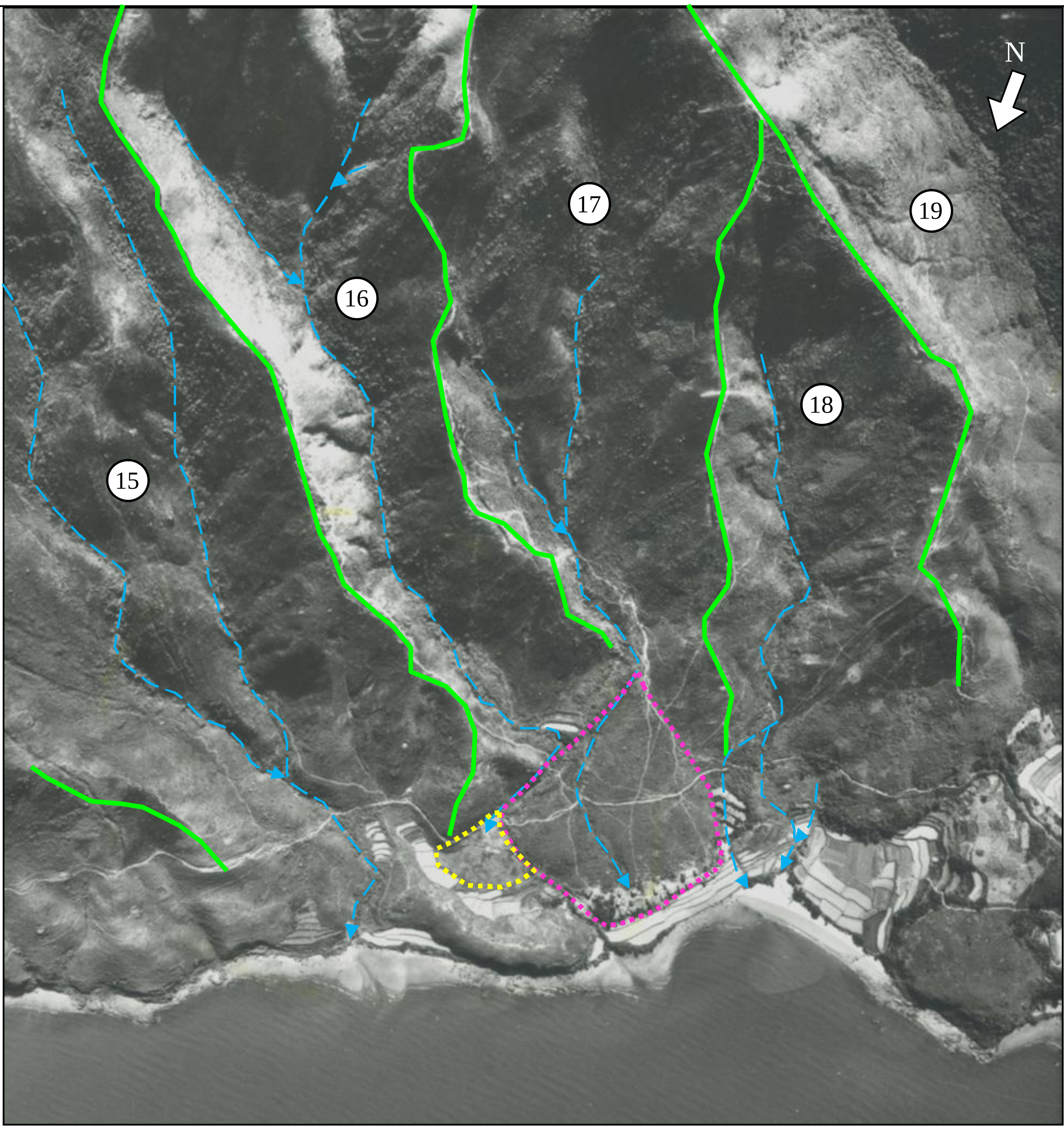


(Photograph Y06362 (3,900ft) taken on 25 January 1963)

Legend:

| | |
|---|---|
| Catchment Boundary | Relatively older colluvial fan |
| 16 Catchment No. | Relatively younger colluvial fan |
| Drainage line | |

Figure A4 - Extract from 1963 Aerial Photograph Showing Colluvial Debris Fans below Catchments Nos. 16 and 17

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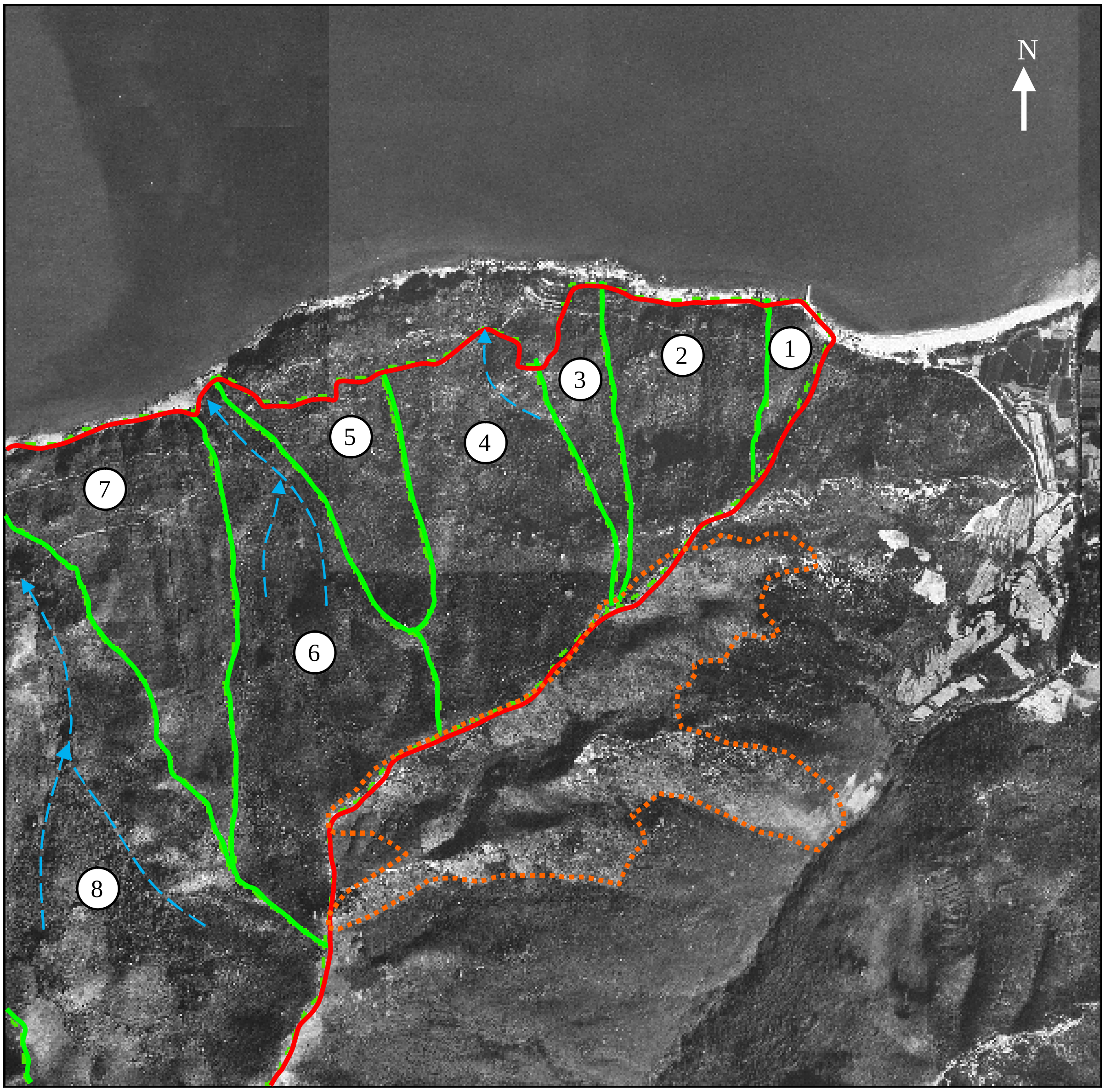


(Orthorectified 1963 photograph)

Legend:

Study Area Boundary

Catchment Boundary

Recent hillfire area

1 Catchment No.

Drainage line

Figure A5 - Interpretation of 1963 Aerial Photograph

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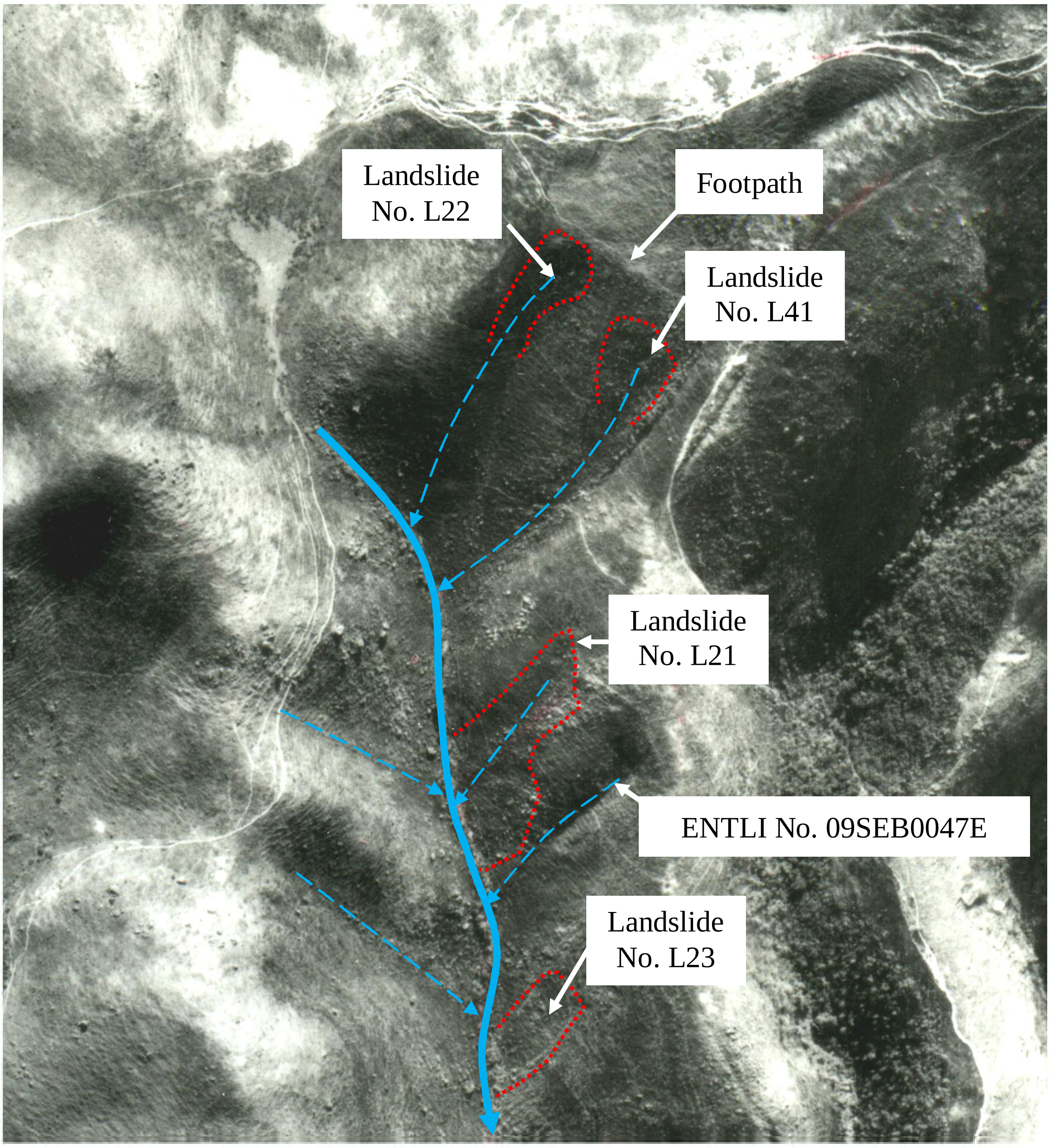


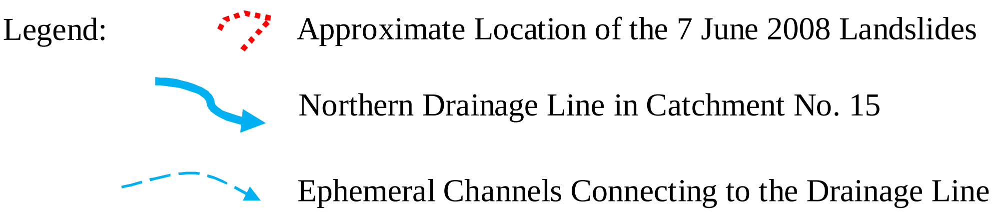


Figure A6 - Part Scan of 1963 Aerial Photograph Showing Topographical Depressions at Possible Previous Failures at Head of Catchment No. 15

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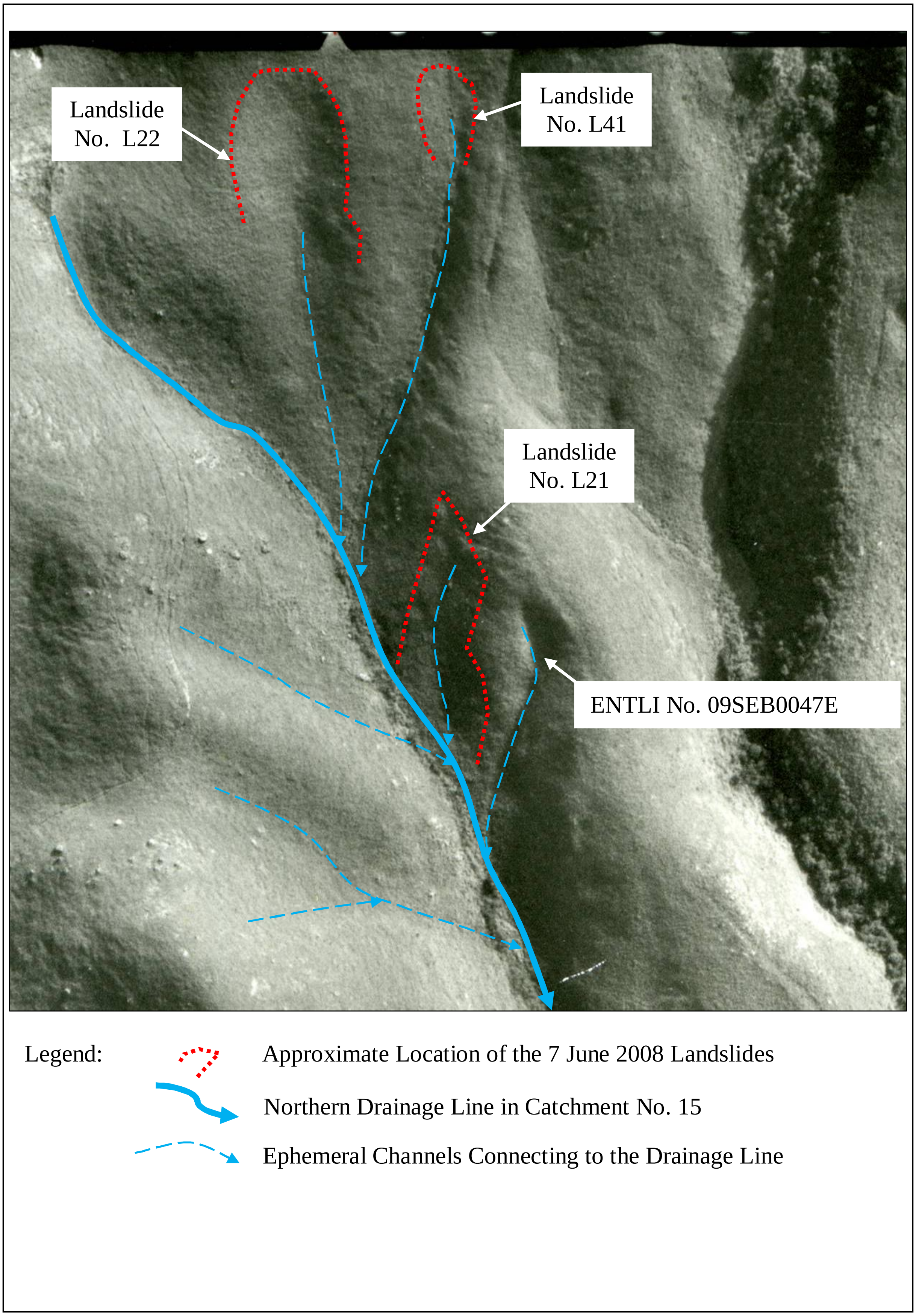


Figure A7 - Part Scan of 1968 Aerial Photograph Showing Possible Previous Failure at the Location of Landslide No. L21 in Catchment No. 15

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APPENDIX B

SALIENT OBSERVATIONS FROM DETAILED FIELD MAPPING
FOR LANDSLIDES NO. L40 AND L4

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## B1. INTRODUCTION

Detailed mapping was carried out for the CDFs in catchments Nos. 15 and 21 (Table 1). Detailed mapping of the CDF in catchment No. 19 could not be carried out due to site access problems. The rest of the landslides not selected for detailed mapping were inspected by a walkover survey where accessible. Details are given in file ref. No.: GCLI/2/A2/54-9. Salient observations from the detailed mapping for the longest CDF (i.e. landslide No. L21 in catchment No. 15) are given in Section 5.2 of the report, and those for the other two CDFs (i.e. landslide No. L40 in catchment No. 15 and landslide No. L4 in catchment No. 21) are given below.

## B2. CATCHMENT NO. 15

### B2.1 GENERAL

Catchment No. 15 comprised two prominent drainage lines, one on the northern part of the catchment and another on the south.

The 7 June 2008 rainstorm triggered nine landslides in catchment No. 15 (Figure 1).

Of the nine landslides, four (landslides Nos. L21, L22, L41 and L23) occurred near the flank or head of the northern drainage line. Landslide No. L21 (Plate 10) occurred at the flank of the northern drainage line and developed into a CDF with a runout distance over 750 m. Three other landslides Nos. L22, L41 and L23 occurred in the vicinity at the flank or head of the same drainage line (Plates 8 and 12). However, the debris was largely deposited at the base of the landslide source areas, and the amount that contributed to the CDF was relatively minor.

The remaining five landslides comprised landslides Nos. L40, L17, L18a, L18b and L18c. Landslide No. L40 occurred at the head of the southern drainage line, and developed into a CDF with a runout distance of 200 m (Plate 12). The other four landslides (i.e. Nos. L17, L18a, L18b and L18c) involved open hillslope failures and occurred at the lower part of the terrain (Figure 1).

Further details of landslide No. L40 that developed a CDF with runout distance of about 200 m are presented below.

### B2.2 LANDSLIDE NO. L40

Failure source area

Landslide No. L40 (Plate 12) occurred at 374 mPD in catchment No. 15, with a failure volume of 115 $m^3$. The landslide was located near the head of the southern drainage line in the catchment. The failure source area measured about 22 m long, 10 m wide and up to 1.5 m deep (Plate B1). The rupture surface appeared to be mostly along colluvium/saprolite interface, and partly through the top of the in-situ highly decomposed tuff, exposing some back release joints (325/77). A footpath was observed traversing the source area near CH15, and some minor soil pipes were noted at the main scarp area (Plates B1 and B2).

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Debris Trail

The debris travelled downhill as debris avalanche and entered the southern perennial drainage line some 20 m away at CH22 and developed into a CDF. The runout distance was 200 m and the active volume was about 110 $m^3$, which occurred at CH55.

Between CH22 and CH230 was the transport zone, where the channel bed was mostly on exposed rock with limited erosion and entrainment (Plates B3 and B4). The channel was relatively steep and confined, with an average gradient of about $39^o$ and a CR of around 3. The channel came to a 10 m high, near-vertical step at CH220 over a rock outcrop (Plate B5) before the channel bends sharply from near-north to northwest direction. About 90 $m^3$ of debris were deposited between CH230 and CH262 (Plate B5) as a result, and the channel also becomes broader and less steep, with a CR over 6 and a gradient of about 25° from CH230 onwards. The deposited debris comprised cobbles and a few boulders of about 0.3 m by 0.3 m in size (Plate B6) in a matrix of sandy silt. The proportion of fines in the debris is significantly low, suggesting a large amount of fine material had probably been removed by post-event erosion.

## B3. CATCHMENT NO. 21

### B3.1 GENERAL

The 7 June 2008 rainstorm triggered two landslides (Nos. L4 and L53) in catchment No. 21. Landslide No. L53 was an open hillslope failure and was located some 70 m away from the drainage line (Figure 1). Landslide No. L4 occurred at an elevation of 230 mPD at the eastern flank of a north-flowing drainage line (Plate 13).

### B3.2 LANDSLIDE NO. L4

Landslide No. L4 measured 9 m wide, 18.5 m long and up to 2.5 m deep and the failure volume was 94 $m^3$ (Plate B7). The landslide was close to the drainage line and about 85 $m^3$ of the debris entered the drainage line at CH27 and developed into a CDF. The runout distance of this CDF was 320 m.

The middle portion of the drainage line in catchment No. 21 (where the landslide debris entered into from landslide No. L4), has a gradient of about $30^o$, and is relatively incised with a CR of around 5 to 6 (Plate B8). Rock was exposed along most parts of the channel bed with limited depletion into the channel bed or side slopes. Isolated pockets of debris deposits were observed between CH27 and CH260 below areas of steep (near-vertical) steps (Plates B9 and B10). The channel gradient reduces to about $15^o$ at CH260, at which a large debris lobe extending to about CH320 was observed. Volume of debris in this debris lobe was estimated to be 350 $m^3$, and the debris comprised matrix- and clast-supported rhyolitic tuff cobbles and boulders up to 2 m in diameter (Plate B11). A significant amount of "entrainable" material was probably pre-existing along the drainage line and was entrained by the 7 June 2008 CDF, resulting in the increase in active volume of the CDF from its initial of 85 $m^3$ to 350 $m^3$ at the distal end. Post-landslide API (Section 4.4) also indicated possible pre-existing colluvial (entrainable) material within the drainage line prior to the June 2008 event.

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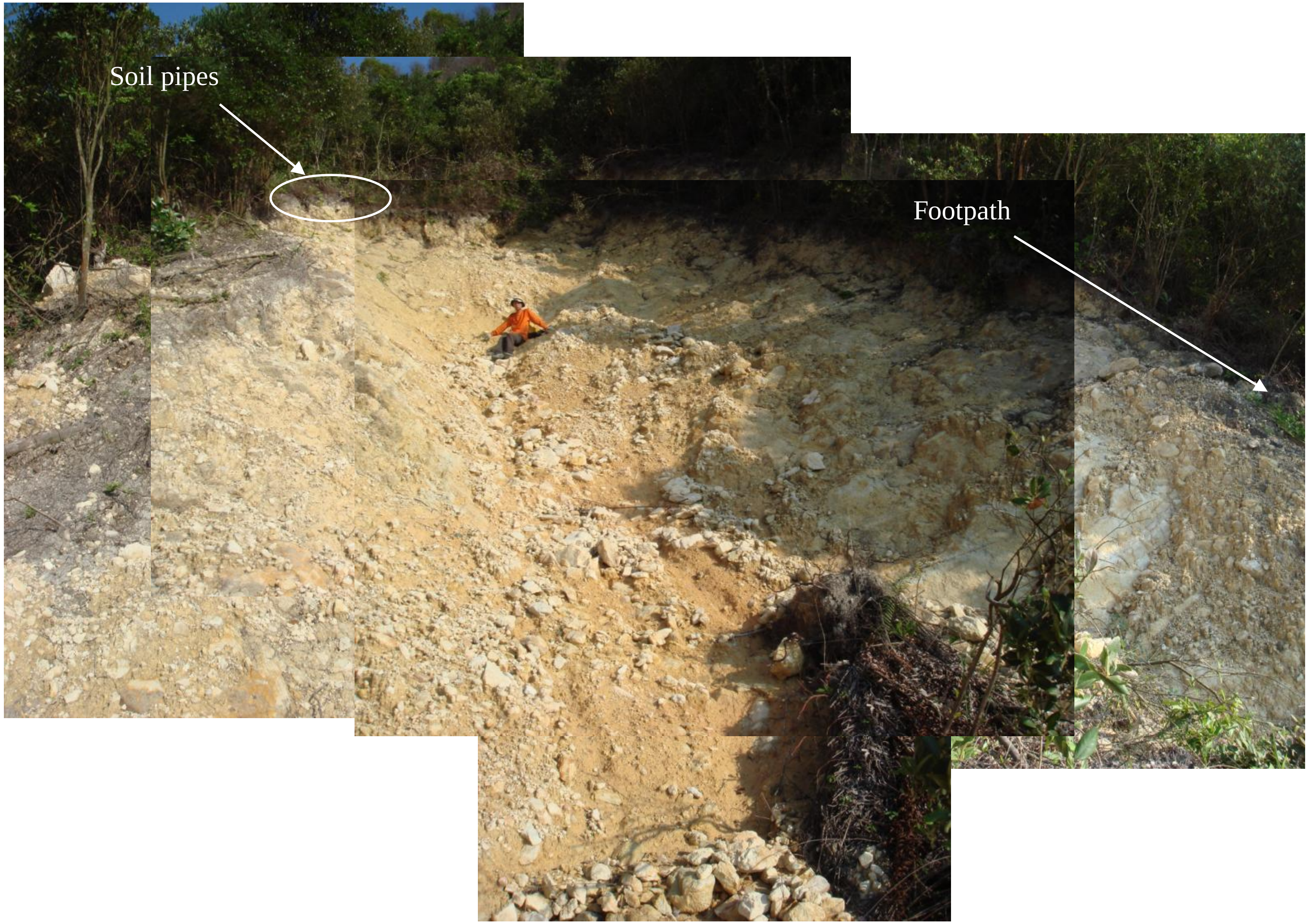


Plate B1 - Source Area of Landslide No. L40 in Catchment No. 15 (Photograph taken on 14 August 2008)



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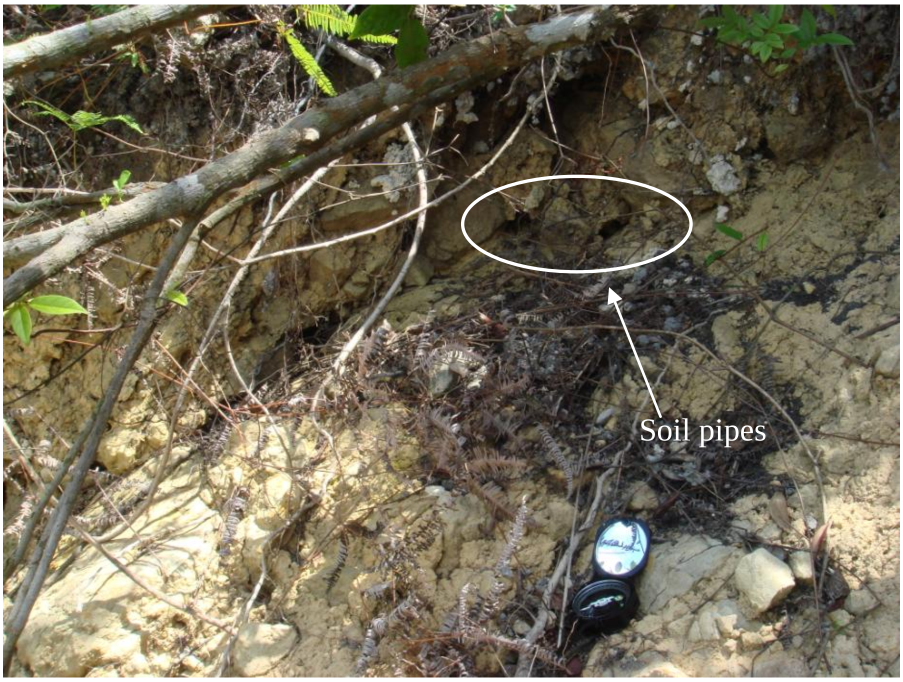


Plate B2 - Observed Soil Pipes at Source Area of Landslide No. L40 in Catchment No. 15 (Photograph taken on 18 August 2008)

Plate B3 - View at CH100 (Looking Down) in the Southern Drainage Line in Catchment No. 15 Showing the Transport Zone with Limited Amount of Erosion (Photograph taken on 18 August 2008)

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Plate B4 - View at CH150 (Looking Down) Showing Smooth Rocky Streambed in the Southern Drainage Line in Catchment No. 15 (Photograph taken on 18 August 2008)

Plate B5 - 10 m High Vertical Step on a Rock Outcrop at CH220 in the Southern Drainage Line in Catchment No. 15 (Photograph taken on 18 August 2008)

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Plate B6 - Main Body of Deposit at CH230 in the Southern Drainage Line in Catchment No. 15
(Photograph taken on 18 August 2008)




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Plate B7 - View of Landslide Source Area of Landslide No. L4 in Catchment No. 21
(Photograph taken on 11 August 2008)



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Plate B8 - View of Drainage Line at CH115 in Catchment No. 21 (Photograph taken on 14 August 2008)



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Plate B9 - Debris Deposited below a Steep Rock Step at CH170 in Catchment No. 21 (Photograph taken on 14 August 2008)




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Plate B10 - Debris Deposited below a Rock Outcrop at CH250 in Catchment No. 21 (Photograph taken on 14 August 2008)



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Plate B11 - View of Landslide Distal Toe at CH320 of Catchment No. 21 (Photograph taken on 14 August 2008)

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# APPENDIX C

## SUMMARY OF PREVIOUS GROUND INVESTIGATION IN THE VICINITY OF THE STUDY AREA

LIST OF TABLES

Table C1 - Summary of Previous GI in the Vicinity of North Lantau Highway Study Area (Sheet 1 of 5)

| Reference / Project<br>[Contractor] | Works Involved<br>[Duration] | Brief Description of Materials |
|---|---|---|
| Public Work Development<br>Hong Kong<br>Contract No. 682/77<br>[Gammon (Hong Kong) Ltd.] | 8 drillholes<br>[October to<br>December 1978] | D115: 0.5 m saprolite (Sap) over Rock (feldspar prophyry);<br>D116: 5.7 m colluviums (Coll) over 5.3 m Sap over Granite;<br>D117: 2 m Coll over 40.9 m Sap over Granite;<br>D120: 2 m Coll over 15.8 m Sap over Rock (quartz porphyry);<br>D121: 9 m Coll over 1.1 m Sap over Rock (quartz porphyry);<br>D122: 16 m Coll over Sap;<br>D123: 8 m Coll over 10.7 m Sap over Rock (porphyry);<br>D125A: 6.3 m Coll over 9.4 m Sap over Rock (porphyry). |
| Trunk Road to Replacement<br>Airport at Chek Lap Kok Phase I<br>[Bachy Soletanche Group] | 19 drillholes<br>[March to April<br>1982] | TRL125: 3 m Coll over 4.7 m Sap over Rock (banded lava);<br>TRL127: 6.3 m Coll over Sap;<br>TRL128: 1.5 m Coll over 16.3 m Sap over Rock (banded lava);<br>TRL129: 13.9 m Sap over Rock (banded lava);<br>TRL130: 3 m Coll over 4.9 m Sap over Rock (banded lava and granite porphyry);<br>TRL131: 7.1 m Sap over Granite;<br>TRL132: 2.5 m Coll over 17 m Sap over Rock (banded lava);<br>TRL134: 7 m Coll over 7 m Sap over Granite;<br>TRL146: 14.1 m Sap over Granite;<br>TRL148: 6.8 m Sap over Granite;<br>TRL150: 5 m Coll over 1 m Sap over Granite;<br>TRL151 and TRL 152: 1.8 m Coll over Granite;<br>TRL153: 7.6 m Sap over Granite;<br>TRL154: 30.3 m Granite;<br>TRL300: 9.7 m Coll over Sap;<br>TRL302: 4 m Coll over 10 m Sap over Granite;<br>TRM149: 4.1 m Sap over Rock (dolerite). |



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Table C1 - Summary of Previous GI in the Vicinity of North Lantau Highway Study Area (Sheet 2 of 5)

| Reference / Project [Contractor] | Works Involved [Duration] | Brief Description of Materials |
|---|---|---|
| North Lantau Development Site Investigation - Study Stage Contract No. IS 11/90 [Enpack (Hong Kong) Limited] | 2 drillholes and 4 trial pits [January to February 1991] | NL19: 12 m Coll over 16.4 m Sap over Feldsparphyric Rhyolite;<br>NL20: 1 m Coll over 3.5 m Sap over Feldsparphyric Rhyolite;<br>TPNT14: 0.7 m Coll over Sap; TPNT15: 0.5 m Coll over Sap;<br>TPNT16: 1.7 m Coll; TPNT17: 1.5 m Coll over Sap |
| North Lantau Expressway Site Investigation - Phase I Contract No. HY/90/23 [Geotechnics & Concrete Engineering (H.K.) Ltd.] | 5 drillholes [February to March 1991] | EL-70: 1.7 m Sap over Tuff;<br>EL-72: 1 m Coll over 10.8 m Sap over Feldsparphyric Rhyolite;<br>EL-73: 2 m Coll over 6.7 m Sap over Feldsparphyric Rhyolite;<br>EL-74: 1.4 m Sap over Feldsparphyric Rhyolite;<br>EL-79: 2 m Coll over 11.5 m Sap over Feldsparphyric Rhyolite. |
| Natural Terrain Hazard and Risk Studies - Tung Chung East Contract No.GE/97/15 [Enpack (Hong Kong) Limited] | 2 drillholes, 3 trial trenches, 21 trial tits [April to May 1999] | DHTCE1: 5 m Coll over Sap; DHTCE2: 5.3 m Coll over Sap;<br>TTTCE1: 2.8 m Coll; TTTCE2 and TTTCE3: 3.3 m Coll;<br>TPTCE1: 0.5 m Coll; TPTCE2: 0.7 m Coll over Sap;<br>TPTCE3: 0.8 m Coll over Sap; TPTCE3A: 0.6 m Coll over Sap;<br>TPTCE4: 2.8 m Coll; TPTCE5: 0.9 m Coll over Sap;<br>TPTCE6: 1.3 m Coll over Sap (possible tension cracks observed);<br>TPTCE7 and TPTCE8: 0.4 m Coll over Sap;<br>TPTCE9: 1.2 m Coll; TPTCE11: 2.7 m Coll over Sap;<br>TPTCE12: 1.7 m Coll; TPTCE13: 0.5 m Coll;<br>TPTCE14: 0.8 m Coll over Sap; TPTCE15: 1.6 m Coll over Sap;<br>TPTCE16: 1.7 m Coll; TPTCE17: 1.4 m Coll;<br>TPTCE18: 0.6 m Coll over Sap; TPTCE19: 1.1 m Coll over Sap;<br>TPTCE20: 1.3 m Sap; TPTCE21: 0.6 m Colls over 2.1 m Sap. |



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Table C1 - Summary of Previous GI in the Vicinity of North Lantau Highway Study Area (Sheet 3 of 5)

| Reference / Project [Contractor] | Works Involved [Duration] | Brief Description of Materials |
|---|---|---|
| Natural Terrain Landslide Studies Tung Chung East Study Area Ground Investigation Contract No.GE99/07 [Vibro (H.K.) Ltd.] | 10 drillholes [April to May 2000] | A1: 1 m Coll; A2: 1.9 m Coll over Sap;<br>A3: 2.2 m Coll over Sap; A4: 1.7 m Coll over Sap;<br>A5 and A6: 2.8 m Coll over Sap; A7: 0.6 m Coll over Sap;<br>G1P: 1.4 m Coll over Sap; G2P and G3P: 2.8 m Coll over Sap. |
| Landslip Investigation Consultancy Landslide Age-dating for Landslide on Natural Hillside above Tung Chung East, Ground Investigation Contract No. GE/2001/14 [Geotechnics & Concrete Engineering (H.K.) Ltd.] | 2 trial pits [July to August 2002] | TP1: 2.4 m Coll;<br>TP2: 2.2 m Coll |
| Natural Terrain Hazard Studies at North Lantau Expressway and Luk Keng Village – Feasibility Study (North Lantau Study Area) Contract No. GE/2001/14 [Geotechnics & Concrete Engineering (H.K.) Ltd.] | 2 drillholes, 20 trial pits [September to December 2003] | BH2: 2.8 m Coll over Rhyolite Lava;<br>BH3: 3.3 m Coll over Sap [standpipe installed with response zone at 0.5 m to 3.3 m b.g., depth of water ranged from 2.8 m to 3.0 m b.g. between 27 Oct and 3 Nov 2003];<br>TP1: 0.2 m over Sap; TP2: 1.6 m Coll over Rock (granite);<br>TP3: 2.1 m Coll over Sap [standpipe installed with response zone at 0.5 m to 2.4 m b.g., dry from 2 to 9 Dec 2003];<br>TP4: 1.9 m Coll over Sap; TP5 and TP6: 0.8 m Coll over Sap;<br>TP7: 0.7 m Coll over Sap; TP8: 3.3 m Coll over Sap;<br>TP9: 1.8 m Coll over Sap; TP10: 2.6 m Coll;<br>TP12: 0.8 m Coll; TP13: 2.4 m Coll over Sap;<br>TP15: 0.4 m Coll over Sap; TP16: 1.2 m Coll;<br>TP19: 1.2 m Coll; |



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Table C1 - Summary of Previous GI in the Vicinity of North Lantau Highway Study Area (Sheet 4 of 5)

| Reference / Project [Contractor] | Works Involved [Duration] | Brief Description of Materials |
|---|---|---|
| | | TP23: 0.9 m Coll over Sap [standpipe installed with response zone at 0 m to 1 m b.g., dry from 12 to 19 Dec 2003];<br>TP24: 3.4 m Coll over Sap [standpipe installed with response zone at 0.5 m to 3 m b.g., dry from 8 to 15 Dec 2003];<br>TP25: 1.1 m Coll over Sap [standpipe installed with response zone at 0.5 m to 3 m b.g., dry from 8 to 15 Dec 2003];<br>TP28: 2.2 m Coll over Sap [standpipe installed with response zone at 0.5 m to 3 m b.g., dry from 13 to 20 Dec 2003];<br>TP29: 1.4 m Coll over Sap [standpipe installed with response zone at 0.5 m to 2.4 m b.g., dry from 19 to 29 Dec 2003]. |
| Tension Cracks, Tung Chung<br>Contract No. GE/2004/06<br>[Vibro (H.K.) Ltd.] | 3 drillholes,<br>2 trial pits<br>[September to October 2004] | P1: Piezometer installed with response zone at 1 m to 1.5 m b.g., dry from 30 Sept to 8 Oct 2004;<br>P2: Piezometer installed with response zone at 1 m to 1.5 m b.g., dry from 30 Sept to 8 Oct 2004;<br>P3: Piezometer installed with response zone at 2 m to 2.5 m b.g., dry from 30 Sept to 8 Oct 2004 ;<br>TT1: 0.1 m top soil over 2.3 m Coll over 0.9 m Sap;<br>TT2: 2.4 m Coll over Sap. |
| HZMB Investigation - Addition Ground Investigation for Option KTK(T)<br>Contract No. GE/2004/06<br>[Vibro (H.K.) Ltd.] | 3 drillholes<br>[July 2005] | ABH04: 4 m Coll over 9.7 m Sap over Rock (decomposed tuff);<br>ABH05: 6.2 m Coll over Rock (decomposed tuff);<br>ABH06: 4.6 m Coll over Rock (decomposed tuff). |



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Table C1 - Summary of Previous GI in the Vicinity of North Lantau Highway Study Area (Sheet 5 of 5)

| Reference / Project [Contractor] | Works Involved [Duration] | Brief Description of Materials |
|---|---|---|
| Landslide Assessment and Monitoring Work at Four Selected Sites - Feasibility Study, Hillside above Tung Chung, Lantau<br>Contract No. GE/2004/06<br>[Vibro (H.K.) Ltd.] | 7 drillholes, 12 trial pits [October to November 2005] | BH1: 1 m Coll over Tuff; BH3: 2.2 m Coll over Sap;<br>BH8: 1.4 m Coll over Sap; BH5: 1.7 m Coll over Tuff;<br>BH6: 1.6 m Coll over 10.9 m Sap over Tuff;<br>BH7: 1.6 m Coll over Tuff; BH9: 0.7 m Coll over 1.4 m Sap over Tuff;<br>TP1: 1.2 m Coll over Tuff; TP2: 1.6 m Coll over Tuff;<br>TP3: 1.4 m Coll over Sap; TP4: 1 m Coll over Sap;<br>TP5: 3.1 m Coll over Sap; TP6: 2.7 m Coll over Sap;<br>TP7: 0.9 m Coll over Tuff; TT1: 1.5 m Coll over Sap;<br>TT2: 1 m Coll over Sap; TT3: 2 m Coll over Sap;<br>TT4: 1.5 m Coll over Sap; TT5: 0.6 m Coll 3.1 m Sap. |
| Natural Terrain Hazard Mitigation Works at North Lantau Expressway and Yu Tung Road Near Tung Chung Eastern Interchange Design and Construction<br>Contract No. GE/2006/02<br>[Gammon (Hong Kong) Ltd.] | 11 drillholes, 5 trial pits [February to April 2008] | DH1: 1.3 m Coll over Tuff;<br>DH2: 3.6 m Coll over 14.2 m Sap over Tuff;<br>DH3: 4.7 m Coll over 1.1 m Sap over Tuff;<br>DH4: 3 m Coll over 2.7 m Sap over Tuff;<br>DH5: 6.3 m Coll over Tuff;<br>DH6: 4.2 m Coll over 12.4 m Sap over Tuff;<br>DH7: 5 m Coll over 3.3 m Sap over Tuff;<br>DH8: 5.8 m Coll over 2.2 m Sap over Tuff;<br>DH9: 4 m Coll over 5.5 m Sap over Tuff;<br>DH10: 2.7 m Coll over Tuff; DH11: 2.56 m Coll over Tuff;<br>TP1: 0.8 m Coll; TP2: 1 m Coll;<br>TP3: 1.6 m Coll over Sap; TP4: 1 m Coll;<br>TP5: 0.9 m Coll. |
| GIU Ref. No.: R34812 | 10 drillholes | Logs cannot be located. |
| GIU Ref. No.: 7211 | 1 drillhole | Logs for inclined drillhole No. H-2 cannot be located. |



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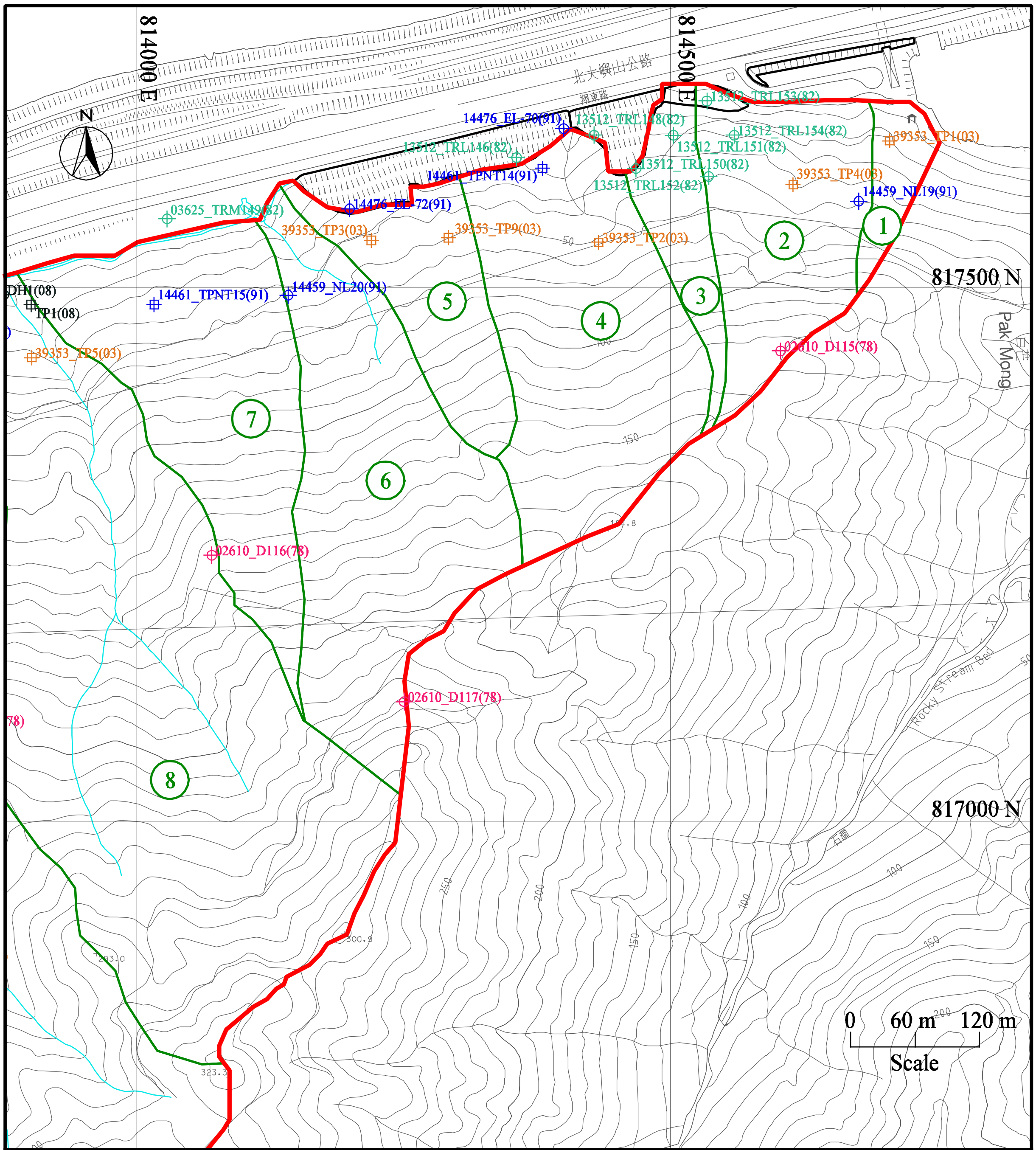


Legend :

| | |
|---|---|
| (red line) | Study area boundary |
| 19 | Catchment boundary and number |
| | 1978 PWD Contract No. 682/77 |
| | 1982 Trunk Road to Replacement Airport |
| | GIU No. 7211 |
| | 1991 (IS 11/90), 1991 (HY 90/23) |
| | 1999 NTHR (GE 97/15) |
| | 2000 NTLS (GE 99/07) |
| | 2002 Age-dating (CE 72/2000) |
| | 2003 NTHS (CE 89/2002) |
| | 2004 (GE 2004/06) |
| | 2005 HZMB (CE 26/2003) |
| | 2005 (CE 4/2005) |
| | 2008 (CE 9/2007) |
| | GIU No. R34812 |

Note : Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.

Figure C1 - Previous Ground Investigation (Sheet 1 of 4)

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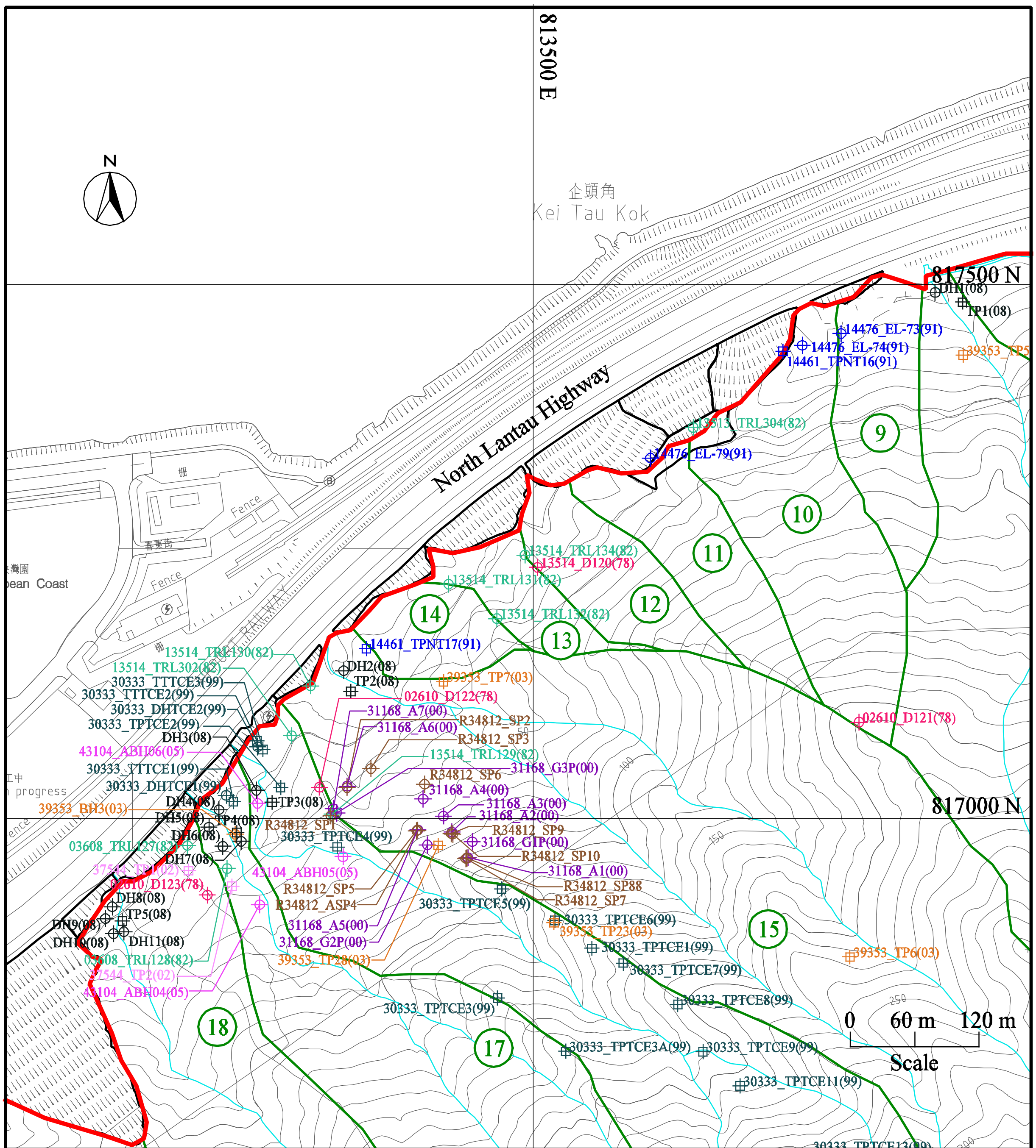


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- 1978 PWD Contract No. 682/77
- 1982 Trunk Road to Replacement Airport
- GIU No. 7211
- 1991 (IS 11/90), 1991 (HY 90/23)
- 1999 NTHR (GE 97/15)
- 2000 NTLS (GE 99/07)
- 2002 Age-dating (CE 72/2000)
- 2003 NTHS (CE 89/2002)
- 2004 (GE 2004/06)
- 2005 HZMB (CE 26/2003)
- 2005 (CE 4/2005)
- 2008 (CE 9/2007)
- GIU No. R34812

Note : Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.

Figure C1 - Previous Ground Investigation (Sheet 2 of 4)

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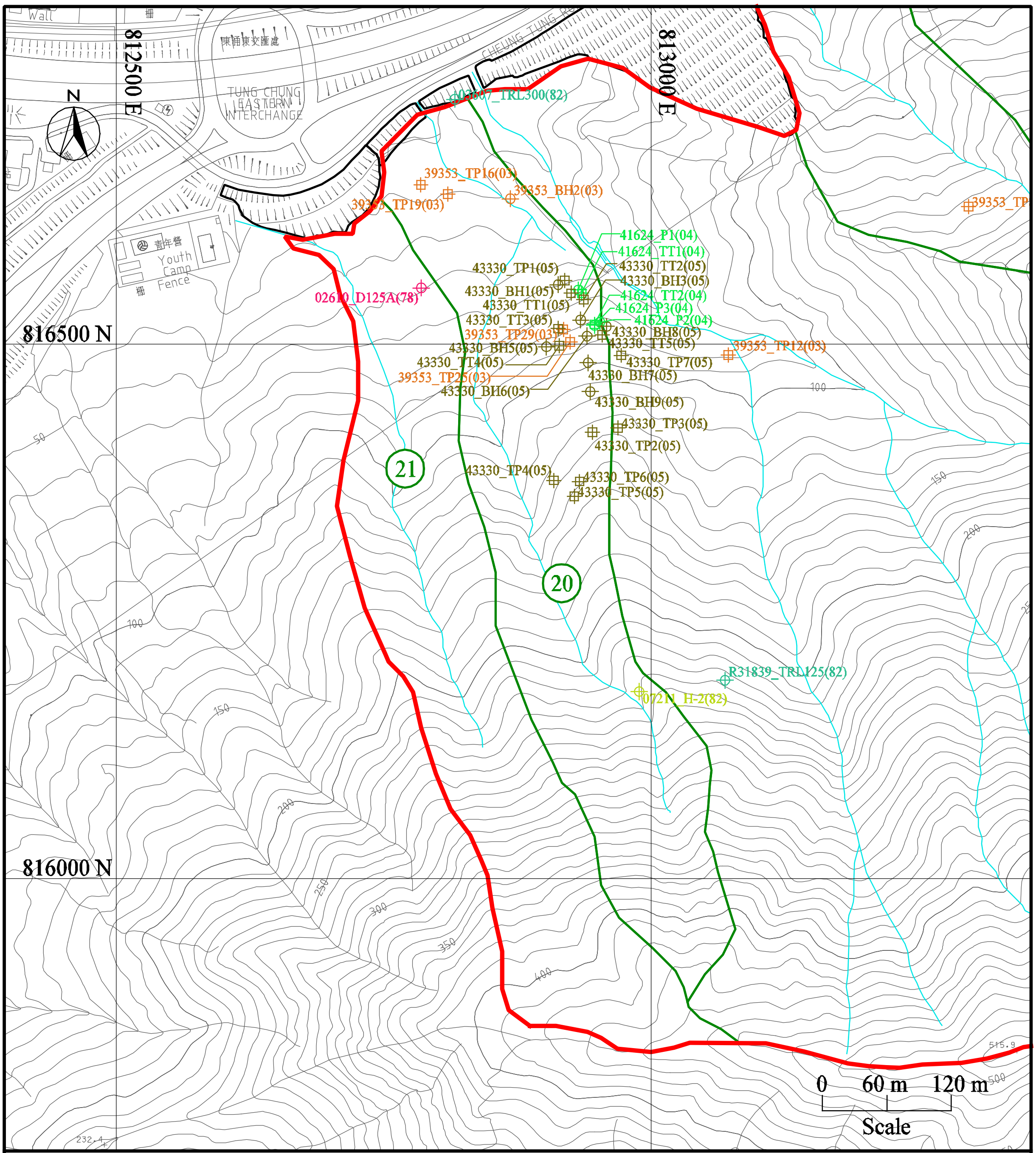


Legend :

Study area boundary

19 Catchment boundary and number

1978 PWD Contract No. 682/77

1982 Trunk Road to Replacement Airport

GIU No. 7211

1991 (IS 11/90), 1991 (HY 90/23)

1999 NTHR (GE 97/15)

2000 NTLS (GE 99/07)

2002 Age-dating (CE 72/2000)

2003 NTHS (CE 89/2002)

2004 (GE 2004/06)

2005 HZMB (CE 26/2003)

2005 (CE 4/2005)

2008 (CE 9/2007)

GIU No. R34812

Note : Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.

Figure C1 - Previous Ground Investigation (Sheet 3 of 4)

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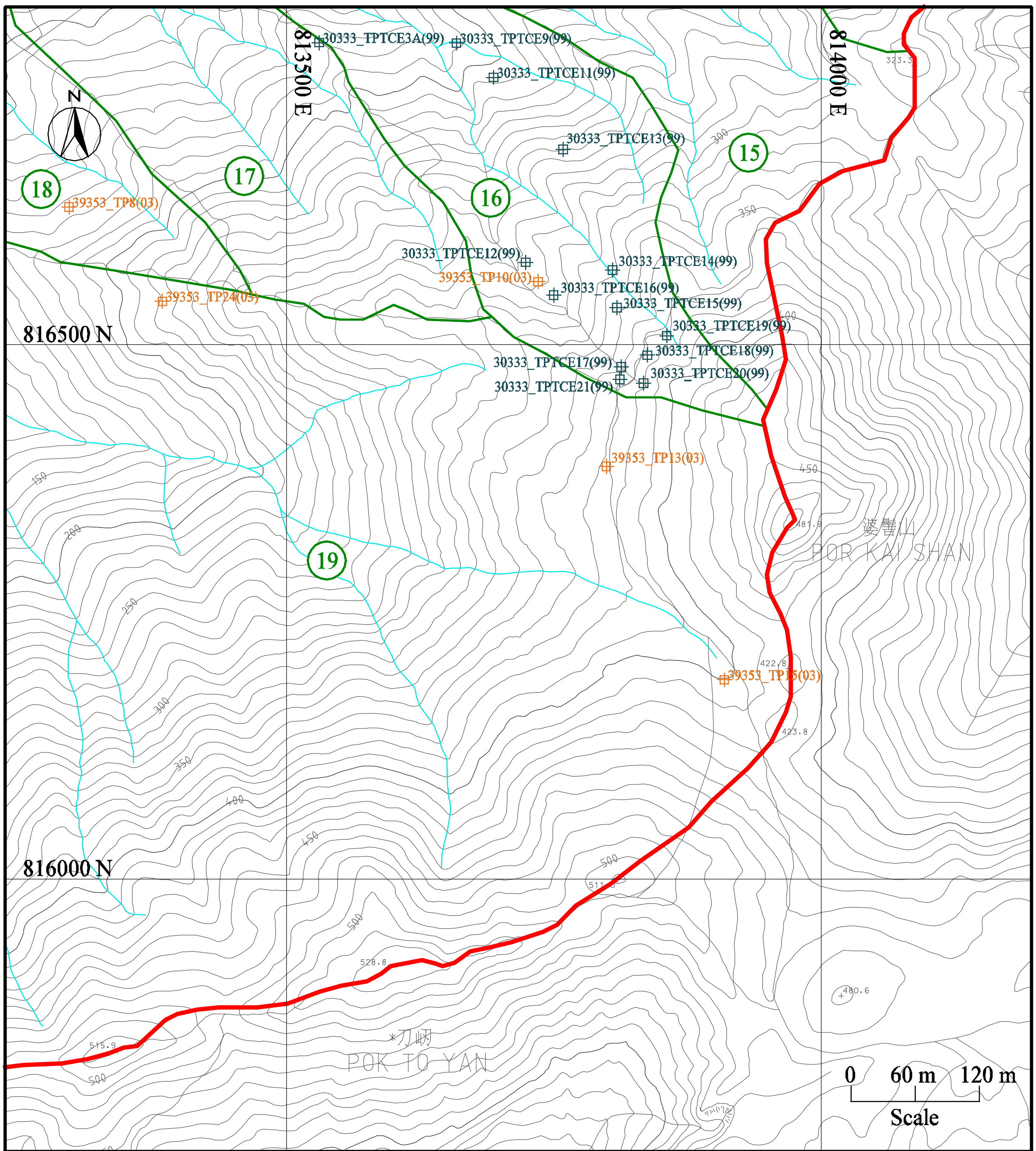


Legend :

- Study area boundary
- 19 Catchment boundary and number
- 1978 PWD Contract No. 682/77
- 1982 Trunk Road to Replacement Airport
- GIU No. 7211
- 1991 (IS 11/90), 1991 (HY 90/23)
- 1999 NTHR (GE 97/15)
- 2000 NTLS (GE 99/07)
- 2002 Age-dating (CE 72/2000)
- 2003 NTHS (CE 89/2002)
- 2004 (GE 2004/06)
- 2005 HZMB (CE 26/2003)
- 2005 (CE 4/2005)
- 2008 (CE 9/2007)
- GIU No. R34812

Note : Base plan is extracted from 1 : 5000 survey sheet No. 9SE-B dated March 2008.

Figure C1 - Previous Ground Investigation (Sheet 4 of 4)

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# 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.

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

## GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

## GEOGUIDES

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

## GEOSPECS

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

## GEO PUBLICATIONS

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

## GEOLOGICAL PUBLICATIONS

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

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

## TECHNICAL GUIDANCE NOTES

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| TGN 1 | Technical Guidance Documents |

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