REVIEW OF THE 22 AUGUST 2005 LANDSLIDE ON THE NATURAL HILLSIDE ABOVE SLOPE NO. 7SW-D/C2 AT LION ROCK TUNNEL ROAD, SHA TIN

GEO REPORT No. 241

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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This report is largely based on GEO Landslide Study Report No. LSR 7/2007 produced in August 2007

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

R.K.S. Chan
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March 2009

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FOREWORD

This report presents the findings of a review of a landslide (Incident No. 2005/08/0428) that occurred on a natural hillside above slope No. 7SW-D/C2 along Lion Rock Tunnel Road, Sha Tin. The landslide was reported on the afternoon of 22 August 2005 following heavy rainfall on 19 and 20 August 2005.

The landslide involved a failure volume of about 400 m^3. Much of the debris was deposited within 40 m of the source, with a small proportion of the debris travelling a total distance of about 80 m downslope from the source. Outwash from the landslide debris travelled to the crest of slope No. 7SW-D/C2 and spilled over onto Lion Rock Tunnel Road. One lane of the southbound carriageway of Lion Rock Tunnel Road was closed for three days as a result of the landslide.

The key objectives of this review were to document the facts about the landslide, including relevant background information and pertinent site observations made under this review. The scope of the review does not include any ground investigation or detailed diagnosis of the causes of the incident. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2006 Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2006, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 50/2005 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

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Agreement No. CE 50/2005 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2006 -
Feasibility Study

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CONTENTS

1. INTRODUCTION

In the late afternoon of 22 August 2005, following heavy rainfall on 19 and 20 August 2005, a landslide (Incident No. 2005/8/0428) occurred on the natural hillside above the southwest end of slope No. 7SW-D/C2. The landslide was identified following a report of constant heavy flow of muddy water from the hillside above slope No. 7SW-D/C2 onto the southbound carriageway of Lion Rock Tunnel Road (Figure 1 and Plates 1 and 2). No Rainstorm Warning or Landslip Warning was in effect when the landslide was reported.

The landslide involved a failure volume of about 400 m^3. The debris ran down the centre of the shallow topographical depression, in which the landslide occurred, and travelled a maximum distance of about 78 m with much of the debris deposited within 40 m of the source area. Outwash from the landslide travelled to the crest of the southwest end of slope No. 7SW-D/C2 and spilled over onto Lion Rock Tunnel Road. One southbound lane of Lion Rock Tunnel Road was closed for three days between 22 and 25 August 2005 as a result of the landslide. No casualties were reported.

Following the incident, Maunsell Geotechnical Services Limited (MGSL), the 2006 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a review of the incident for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 50/2005 (GE).

The key objectives of the study were to document the facts about the landslide, present relevant background information and the results of detailed geological mapping of the landslide source area and surrounding terrain. The scope of the review does not include any ground investigation (GI) or detailed diagnosis of the causes of the incident. Recommendations for follow-up actions are reported separately.

2. THE SITE

2.1 Site Description

The August 2005 landslide is located on a northwest facing hillside, about 100 m south of Lion Rock Tunnel Road, within a densely vegetated shallow rounded topographical depression. The depression is about 100 m wide by 120 m long (Figure 1). The source area of the landslide lies at an elevation of between 96 mPD and 104 mPD. The landslide occurred above a concave break-in-slope within a depression where the hillside is inclined at between 32° and 37° above the break-in-slope reducing to about 24° below (Figures 2 and 3).

A southwest to northeast trending ridgeline is located to the south of the head of the depression. On the southern side of the ridgeline is a perennial streamcourse (Plate 2), which drains towards Sha Tin Tau New Village (Figure 1). The upper streamcourse drains towards the north-northwest and changes direction of flow towards the northeast (Figure 1 and Plate 2) at a point near a saddle in the northeast trending ridgeline, approximately 50 m to the east-southeast of the August 2005 landslide scar (Figure 1). A disused concrete paved road passes through the saddle. Where the streamcourse begins to flow northeast, it widens and has a reduced gradient.

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The elevation of the streamcourse at the turning point is about 118 mPD and the elevation of the low point of the saddle is about 125 mPD.

2.2 Water-carrying Services

Based on the information provided by Water Supplies Department (WSD) and Drainage Services Department (DSD), there are no water-carrying services in the immediate vicinity of the landslide.

The Beacon Hill catchwater is located about 180 m south of the landslide source area, with the direction of flow within the catchwater from east to west. An overflow weir is located near the head of the streamcourse in the adjacent catchment, southeast of the August 2005 landslide.

2.3 Maintenance Responsibilities and Land Status

Based on the information obtained from Lands Department (Lands D), the August 2005 landslide occurred on unleased and unallocated government land.

Following the emergency repair works to the scar of the August 2005 landslide, the resulting feature has since been registered as cut slope No. 7SW-D/C986. According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands D, the slope is under the maintenance responsibility of Lands D.

2.4 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 7 (GCO, 1986) and The Pre-Quaternary Geology of Hong Kong (Sewell *et al.*, 2000), the landslide site is underlain by fine- to coarse-grained granite of the Needle Hill and Shui Chuen O Formations. Quartz monzonite from the Tei Tong Tsui Formation is shown to outcrop north of the landslide site at the lower part of the hillside above Lion Rock Tunnel Road (Figure 4). Further north the coarse-grained Sha Tin Granite is shown to outcrop. An inferred northwest–southeast trending fault is located about 300 m southwest of the August 2005 landslide, although no faults or photolineaments are shown at the August 2005 landslide site.

2.5 Geotechnical Area Studies Programme (GASP)

Geotechnical data relating to the study area were compiled as part of the Geotechnical Control Office's (GCO, renamed GEO in 1991) Geotechnical Area Studies Programme (GASP) Report No. II, Central New Territories (GCO, 1987). The data are shown on 1:20 000 scale maps, which are used for regional appraisal and strategic planning purposes. It should be noted that these maps are not intended for the assessment of local areas, such as the subject hillside, because of the limited resolution of the maps.

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The GASP Engineering Geology Map indicates that the hillside on which the August 2005 landslide occurred comprises granite with a quartz monzonite intrusion across the central portion of the hillside. The Geotechnical Land Use Map (GLUM) designates the terrain as GLUM Class II (i.e. with moderate geotechnical limitations) and the Physical Constraints Map does not indicate a constraint for the terrain affected by the August 2005 landslide.

3. SITE HISTORY AND PAST INSTABILITIES

3.1 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 5). Detailed observations from the aerial photograph interpretation (API) are summarised in Appendix A.

3.2 Site History

The earliest aerial photographs reviewed, which were taken in 1963, show that the landslide site is located on a densely vegetated northwest-facing natural hillside (Figure 5).

In 1963, anthropogenic activities were evident on the hillside below the landslide site, with an area of cultivation terraces and some isolated squatter structures at the approximate location of the present-day Kak Tin Village Nam Kau, downslope of the present-day Lion Rock Tunnel Road. On the southeast side of the ridgeline above the landslide site, squatter structures and cultivation terraces were present and a section of the streamcourse within the southeast catchment had been channelised. The catchwater, located about 180 m south of the landslide site, had already been constructed to its present-day alignment.

By 1973, Lion Rock Tunnel Road had been constructed together with roadside slopes Nos. 7SW-D/C2 and 7SW-D/C3. The slope surfaces appeared to be sparsely vegetated with localised areas possibly covered with a masonry facing. In 1974, an area along the ridge above the landslide site had been cleared of vegetation.

Between 1974 and 1977, a concrete paved road (subsequently confirmed through site inspection) had been constructed across the hillside and extended towards the upper portion of the catchment where the August 2005 landslide occurred. It crossed over the southwest-northeast trending ridgeline above the August 2005 landslide catchment and into the adjacent southeast catchment at a saddle in the ridgeline (Figure 5). By 1978, Lion Rock Tunnel Road had been widened to a two-lane dual carriageway and by 1985, the concrete-paved road crossing the hillside appeared to be no longer in use.

Apart from two small areas of the hillside above the crest at the southwest end of slope No. 7SW-D/C2 that appear to have been cultivated between 1985 and 1987, there has been little change to the hillside in the vicinity of the landslide site other than a general increase in the density of vegetation.

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In the 1994 aerial photographs, slope No. 7SW-D/C2 and the lower batter of slope No. 7SW-D/C3 were observed to be shotcreted.

According to the file records, slopes Nos. 7SW-D/C3, 7SW-D/C2 and 7SW-D/C229 were upgraded under the LPM Programme in 1993, 2001 and 2002 respectively (see Section 4).

3.3 Past instabilities

3.3.1 Natural Terrain Landslide Inventory (NTLI) and Large Landslide Database

In 1995, GEO compiled the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high-altitude aerial photographs dating from 1945 to 1994 (Evans *et al*, 1997; King, 1999). According to the NTLI database, there are no landslides in the immediate vicinity of the August 2005 landslide. Two NTLI landslides with tag Nos. 07SWD0087 and 07SWC0001 are indicated on the hillside above the catchwater, more than 200 m from the August 2005 landslide site (Figure 6).

In 2004, GEO commenced a project to update the NTLI using low-altitude (8,000 ft and below) aerial photographs and produced an Enhanced Natural Terrain Landslide Inventory (ENTLI). The ENTLI records four relict features near the August 2005 landslide as tag Nos. 07SWD0693E to 07SWD0696E (Figure 6). The degree of confidence with which a relict landslide has been interpreted under the ENTLI is indicated by assigning the identified relict feature to a class. The classes of each ENTLI feature identified near the August 2005 landslide are also shown on Figure 6, with a key to the landslide classes given in Table 1.

The landslides with tag Nos. 07SWD0693E and 07SWD0694E, located directly above the August 2005 landslide (Figure 6), have been assigned "Class A2", which relates to a "sharp scarp with no evidence of debris immediately downslope" and indicates a reasonable degree of confidence in the interpretation of the features as landslides. Landslides with tag Nos. 07SWD0695E and 07SWD0696E have been assigned "Class B1", which relates to a "minor depression" and a lesser degree of confidence in their interpretation as landslides.

The August 2005 landslide is not located within an Historical Landslide Catchment (HLC), (i.e. a catchment with an ENTLI record that is considered to present a potential hazard to an important facility downslope) as identified under the ENTLI project. However, two HLC's, Nos. 07SWD-O2 and 07SWD-C5, are indicated in adjacent catchments (Figure 6).

GEO's large landslide database (Scott Wilson, 1999) contains a record of a single large landslide with tag No. 7SWDL013 on the hillside within HLC No. 07SWD-O2, northeast of the topographical depression, where the August 2005 landslide occurred (Figure 6). The large landslide is coincident with ENTLI landslide tag No. 07SWD0701E, a relict landslide which has been assigned Class C2, i.e. a "depression [that] may have been formed by landslide-related activity".

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3.3.2 Aerial Photograph Interpretation

Based on the 1963 aerial photographs, the landslide site is located on the densely vegetated northwest-facing natural hillside within a shallow depression (defined by a rounded convex break-in-slope) between two rounded spurlines that trend northwest and north-northwest. A well-defined northeast-trending ridge delineates the upper limit of the catchment (Figure 5).

Four relict landslides can be identified in the 1963 aerial photographs along the head of the topographical depression where the August 2005 landslide occurred (Figure 5 and Plate A1 of Appendix A). The four landslides coincide with those identified under the ENTLI (section 3.3.1) with tag Nos. 07SWD0693E to 07SWD0696E. The landslides are identified as shallow depressions bounded by distinct convex breaks-in-slope. The landslide scars appear to be degraded and are covered with dense vegetation. No landslides appear to have affected the ridgeline since those identified in the 1963 aerial photographs.

In the northwest towards the downhill side of the shallow depression, there is an accumulation of colluvium, which appears to continue further downslope to a colluvial lobe upon which terrace cultivation has taken place at about the location of the present-day Kak Tin Village, Nam Kau.

3.3.3 GEO's Landslide Database

According to the GEO's Landslide Database, there are no past reported landslides located in the immediate vicinity of the August 2005 landslide. The nearest past landslide incident (Incident No. MW84/6/3) occurred in June 1984 at a registered cut slope (No. 7SW-D/C3), about 120 m northwest of the August 2005 landslide, alongside Lion Rock Tunnel Road (Figure 6). The volume of failure was recorded as 10 m^3 and the landslide resulted in the temporary closure of one southbound lane of Lion Rock Tunnel Road.

Three landslides (Incidents Nos. 2005/08/0496 to 2005/08/0498) occurred along the Beacon Hill Catchwater on 21 August 2005. Incident No. 2005/08/0496, with a failure volume of about 1,900 m^3, occurred on slope No. 7SW-D/CR412 and the natural hillside above. Incident No. 2005/08/0497, with a failure volume of about 310 m^3, occurred on slope No. 7SW-D/C561. These two incidents occurred on the upslope side of the catchwater located at about 460 m and 920 m southwest of the August 2005 landslide above Lion Rock Tunnel Road respectively and are on the downstream side of the overflow weir located near the head of the streamcourse. The catchwater was blocked and water overflowed at the weirs upstream of these two landslides. Another landslide (Incident No. 2005/08/0498) occurred on slope No. 7SW-D/C558 on the uphill side of the catchwater about 280 m southeast of the August 2005 landslide (Figure 6). The failure volume was about 110 m^3 and the catchwater was blocked by landslide debris.

On 25 April 2006 a landslide (Incident No. 2006/05/0605) occurred immediately below the August 2005 landslide scar (now registered as slope No. 7SW-D/C986). The incident involved soil erosion (from an area of about 2 m by 2 m) below the erosion control mat located in front of the chunam cover of slope No. 7SW-D/C986 (Figure 6).

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4. PREVIOUS ASSESSMENTS AND SLOPE WORKS

There have been no previous engineering works/studies carried out within and in the vicinity of the 22 August 2005 landslide. Relevant information on previous assessments of the man-made slopes along Lion Rock Tunnel Road is presented.

In August 1993, a Stage 3 Report (S3R 4/93) was prepared by the Design Division of the GEO for cut slopes Nos. 7SW-D/C2, 7SW-D/C3, 7SW-D/C4 and 7SW-D/C5 along the southern side of Lion Rock Tunnel Road, about 90 m below the location of the August 2005 landslide. The slopes had been included in the GEO's Landslip Preventive Measures (LPM) Programme "under the category of 'High Economic Risk'." The report concluded that slope No. 7SW-D/C2 was up to the required geotechnical standard and no works were recommended. Soil nailing was proposed for a portion of slope No. 7SW-D/C3, with the upper batter to be cut back to 45° and the lower batter shotcreted. Hydroseeding of the finished surface was proposed for the main portion of the slope. It was recommended that the upper batters of slope No. 7SW-D/C4 should be cut back to 45° and the lower slope batter shotcreted. Hydroseeding of the finished surfaces was proposed for the main portions of the slope. The slope works commenced in February 1993 and were completed in April 1994.

Slope No. 7SW-D/C2 was re-injected into the LPM Programme following the 3 August 1997 Ching Cheung Road landslide. In May 2001, Fugro (Hong Kong) Limited prepared a Stage 3 Report (S3R 136/2000) for slope No. 7SW-D/C2. The Stage 3 Report recommended the installation of soil nails to "upgrade the feature to meet the current government standards". Removal or trimming of boulders was also recommended, "depending on the nature of the surface materials'. The slope works commenced in December 2000 and were completed in August 2001. According to the as-built record drawings, a single row of nine 12 m long raking drains was installed at the lower batter of the slope during the slope works.

In February 2002, Babtie Asia Ltd. in association with ESA Consulting Engineers Ltd. and SMEC Asia Ltd. prepared a Stage 3 Report (S3R 194/2001) for slope No. 7SW-D/C229 and proposed the installation of soil nails. The slope works commenced in April 2003 and were completed in November 2003.

Following a design review by Fugro (Hong Kong) Limited under LPM Agreement No. CE 53/2002 (GE) in 2005, slope No. 7SW-D/C4 was re-injected into the LPM Programme. In June 2006, Fugro (Hong Kong) Ltd. prepared a Stage 3 Report (S3R 143/2006) for slope No. 7SW-D/C4, and recommended the installation of soil nails and raking drains to upgrade the slope to the current safety standards. The proposed works had not commenced at the time this landslide study report was prepared.

5. THE AUGUST 2005 LANDSLIDE AND POST-FAILURE OBSERVATIONS

5.1 General

According to the record notes of the incident prepared by the Highways Department (HyD), the incident occurred at about 2:30 p.m. on 22 August 2005, when muddy water was observed to flow over the crest of slope No. 7SW-D/C2. The notes record that "traffic police arrived [at the location of the debris on Lion Rock Tunnel Road] at 15:20 hrs" on

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22 August 2005. The incident resulted in the closure of one lane of the southbound carriageway of Lion Rock Tunnel Road between 3:30 p.m. on 22 August 2005 and 6:00 a.m. on 24 August 2005.

MGSL inspected the landslide site on the morning of 23 August 2005. Muddy water continued to discharge from the natural terrain uphill into the crest channel of slope No. 7SW-D/C2 and a heavy discharge of water from a raking drain on the slope face was observed below the location of the muddy water flow (Plates 3 and 4). Access to the landslide source area was difficult due to dense vegetation and its remote location from the road. The location of the source of the August 2005 landslide was therefore not confirmed until around 12:00 noon on 23 August 2005. Subsequent inspections of the landslide site were carried out on 25 August 2005, 29 August 2005 and 9 February 2006.

The flow of water from the hillside above slope No. 7SW-D/C2 into the crest channel had ceased by the time of the second MGSL site visit on 25 August 2005, although water continued to discharge from the raking drain installed in slope No. 7SW-D/C2 and was observed during all site visits. The rate of water discharge had diminished by 9 February 2006, but the flow remained moderate.

5.2 Landslide Source

The landslide source comprised two distinct portions, a main source and a secondary source (Figure 2). A plan of the landslide area and a longitudinal section through the landslide are shown in Figures 2 and 3 respectively. General views of the landslide are presented in Plates 5 to 8.

The main source of the August 2005 landslide had a maximum length of about 18 m, a maximum width of about 8 m, a maximum depth of 4.5 m and an average depth of about 2.75 m. The crown of the landslide is at an elevation of between 102 mPD and 104 mPD. The source is located immediately above a concave break-in-slope where the terrain gradient, based on the 1:1,000 topographical plan, changes from about 37° above the source to between 30° and 32° at the source, reducing to about 24° below the toe of the surface of rupture (Figure 2). The flanks of the main source (trending 160°-340° and 000°-180° on the eastern and western sides respectively) decreased in height from 4.5 m at the crown of the landslide scarp to existing ground level at the toe of surface of rupture. The eastern flank measured 11 m in length while the western flank was 13 m long. The main source width (at the original ground surface) ranged from about 8.5 m at the main scarp to about 7 m near the toe of rupture. The estimated volume of the main source of the landslide was about 265 m^3. Cross sections through the main source are shown on Figure 7.

The secondary source appears to be a retrogressive failure extending uphill of the southeast corner of the main source area. The relative timing of the retrogressive failure and the main event is not known, although it may be postulated that both the main and retrogressive failures occurred at about the same time. The secondary source is about 7 m long by about 5 m wide with an average depth of about 4 m and has an estimated volume of 130 m^3. The estimated total volume of the 22 August 2005 landslide is therefore about 400 m^3.

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Basic measurements of geological structure were taken at the landslide source area. The main scarp appears to be defined by a joint orientated at 79°/330°. The secondary source area has a clear wedge (intercepting joints 56°/248° and 46°/028°) and steep side-release joints 88°/070°, probably indicating structural control (Plates 9 and 10).

The lower portion of the eastern flank of the landslide is within completely decomposed granite. Distinct areas of kaolinisation, kaolin seams and manganese oxide staining were noted within the CDG (Plates 11 to 13). The main flow of surface water was observed along the base of the landslide scar near the eastern flank. The general planar nature of the upper part of this side-scarp suggested the influence of relict discontinuities. About 1 m of the upper portion of the eastern flank comprised bouldery colluvium with several boulders on the ground surface (Plate 7).

The main scarp of the landslide comprised a weathered rock mass of moderately decomposed fine-grained granite (MDG) blocks and showed clear evidence of joint dilation. Joint dilation varied between 20 mm and a maximum of about 100 mm, with most open joints infilled with silty coarse sand (Plates 14 to 17). Heavy water seepage was observed from the open joints (38°/040°) and from the base of the displaced blocks of MDG. Active subsurface seepage could still be observed at the landslide source area even one week after failure.

The material observed within the secondary source comprised MDG with considerable displacement and dilation between individual MDG blocks of up to 200 mm, in the lower part of the main scarp (Plates 9 and 10). Surface water flow was observed in the secondary source during the first inspection on 23 August 2005 but it had ceased by the second inspection on 25 August 2005.

The western flank of the landslide comprised a bouldery colluvium towards the toe of rupture and towards the ground surface. The colluvium comprised cobbles and boulders of MDG to CDG up to 1 m across in a sandy silt matrix. There was no evidence of in-situ structure (Plate 18).

The surface of rupture of the landslide was covered by debris, but based on site inspection it appeared to be inclined at an angle of about 20° (Figure 3). The surface of rupture appeared to be within colluvium at the western side of the landslide source and within completely decomposed granite at the eastern side, and may therefore have been partially structurally controlled.

Minor retrogressive toppling of the main scarp was indicated by an accumulation of about 24 m^3 of debris, mainly boulders with saturated slurry, in the centre of the landslide source. The debris was draped with a trail of vegetation from the southwest corner of the source which indicated a collapse from that area of the main scarp.

5.3 Debris Trail

The debris trail was covered with plastic sheeting by HyD contractors after the incident. Plates 19 to 26 show the debris trail in sections from the toe of rupture to Lion Rock Tunnel Road. To provide a reference for field mapping and fixing the position of features within the

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debris trail, a chainage reference was established along the centreline of the landslide. The crown of the landslide is designated chainage CH 0 and chainage CH 108 marks the distal end of the main outwash fan. A plan of the landslide and debris trail is shown in Figure 2.

Chainage Ch 0 - chainage CH 18: Source.

Chainage CH 18 - chainage CH 38: Debris trail width 9 m; hillside inclined at 24°; maximum depth of debris 0.8 m. A rock step (about 1 m high) was present at Chainage CH 38 (Plates 19 and 20).

Chainage CH 38 - chainage CH 58: Debris trail width 8 m; hillside inclined at 28°; maximum depth of debris 0.7 m (Plates 21 and 22).

Chainage CH 58 - chainage CH 78: Debris trail width 5 m; hillside inclined at 24°; maximum depth of debris 0.25 m. About 1 m high edge of cultivation terrace at chainage CH 66. The maximum travel distance of the debris noted at about chainage CH 78 (Plates 23 and 24).

Chainage CH 78 - chainage CH 98: Outwash fan width 9 m; hillside inclined at 20°; maximum depth of outwash 0.3 m. Cultivation terraces covered by deposition of washed debris (Plate 25).

Chainage CH 98 - chainage CH 108: Outwash fan width 19 m; hillside inclined at 20°; maximum depth of outwash 0.3 m (Plate 26).

Evidence from the displaced boulders along the debris trail indicated that avalanching processes occurred during the landslide. The main transportational process appears to have involved flow of saturated material, as indicated by the remoulded material along the debris trail. The distribution of material with distance from the landslide source indicated that the bulk of the initial debris was deposited within 40 m of the source with the maximum travel distance of the debris at about 78 m from the landslide source. The travel angle (Wong & Ho, 1996) of the debris was about 26°.

Subsequent outwash of sandy material led to the formation of a debris fan, about 0.3 m deep, with a distal end at about chainage CH 108, some 15 m from the crest of slope No. 7SW-D/C2, with further outwash from the debris fan spreading to the crest of slope No. 7SW-D/C2 and over the 52° slope face onto one southbound lane of Lion Rock Tunnel Road.

5.4 Hillside Surrounding the August 2005 Landslide Source

Based on the 1:1000 topographical survey plan (map sheet No. 7SW-20D) the hillside in the vicinity of the August 2005 landslide has a gradient of between 30° and 38° (Figure 2 and Plate 27).

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A number of minor steps in the terrain, generally less than 1 m high, is evident uphill of the August 2005 landslide (Figure 2). The largest step observed, about 1 m high, was located at an elevation of about 114 mPD (i.e. about 20 m below the ridge line). The steps may be highly degraded landslide scarps, and appear to coincide with relict landslides identified under the ENTLI (Section 3.3.1).

An area of hummocky terrain was observed about 20 m to the south of the August 2005 landslide. This area coincides with a depression indicated on the 1:1000 topographical survey sheet No. 7SW-25B and landslide scars identified from API (Figure 5 and Plate A1) and recorded under the ENTLI (tag No. 07SWD0693E on Figure 6). The scarp was about 1 m in height bounding the southern side of the hummocky ground (see Figure 2), and it appears to be an old landslide.

Three minor exposures were identified uphill of the August 2005 failure. Completely decomposed coarse-grained granite with substantial kaolinisation was observed at slope No. 7SW-D/C570 located about 30 m southeast of the August 2005 landslide (Figure 2). A minor failure from the slope face exposed the granite which also exhibited slickensides plunging down dip on a thick manganese-stained relict joint surface dipping 72°/170° (Plate 28).

Another exposure, approximately 10 m west of slope No. 7SW-D/C570, comprised moderately decomposed fine-grained granite with relatively widely spaced joints (about 1.5 m). A poorly-developed stress relief joint daylighted from the slope at this location (Plate 29). An exposure approximately 5 m to the west of the above exposure also comprised fine-grained granite with closely spaced joints. The joints were steeply dipping between 70° and 80° towards an orientation of 220° with the strike of the joints trending 340°-160°.

There was no evidence of concentrated surface runoff from the disused concrete paved road located in front of the toe of slope No. 7SW-D/C570 uphill of the landslide (Figure 2).

The natural streamcourse on the southern side of the ridgeline (Figure 2) was also inspected on 23 August 2005. Water discharge remained heavy despite two dry days since the rainstorm (Plate 30). Due to minor agricultural terracing, the streamcourse widens and has a flatter gradient at the section where it passes above the line of the scar (Plate 31). The water at this location continued to flow over flattened and ‘aligned’ grass almost two days after the rainstorm, indicating that the flow was particularly high. This was supported by witnesses account from a local village resident who indicated that water had not flowed over this location for many years.

6. GEOLOGY AND GEOMORPHOLOGY

6.1 General

The geology of the site was determined using information from desk study and through field mapping. The desk study comprised a review of all the available data and published geological information including Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 7 (GCO, 1986) and the Pre-Quaternary Geology of Hong Kong (Sewell *et al.*, 2000), and consultation with the HKGS regarding the

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updating of Geology Map Sheet No. 7 which indicated that there were no significant changes to the geology in the vicinity of the August 2005 landslide. Examination of field samples indicated that the rocks in the study area are consistent with the published geology (see Section 2.4).

6.2 Previous Ground Investigation

No GI was carried out as part of this study and therefore a review of the results from the previous GI in the vicinity of the August 2005 landslide was carried out. A summary of the previous GI carried out in the vicinity of the study area is shown in Table 2 and the locations of the GI stations are shown in Figure 8. A discussion of the relevant GI is provided below.

The earliest available records of GI near the study area include eight drillholes (Nos. DH1 to DH3 and DH5 to DH9) that were completed in 1978. Gammon (Hong Kong) Ltd. carried out the GI for the site formation interchange between Lion Rock Tunnel Road and Hung Mui Kok Road, located over 1 km southwest of the August 2005 landslide. The drillholes encountered colluvium overlying completely weathered granite.

In April 1988, Lam Geotechnics Ltd. completed three drillholes (Nos. DH1 to DH3) in Kak Tin Village. Drillholes Nos. DH1 and DH2 encountered 2 m to 3.5 m of colluvium overlying about 10 m of highly to completely decomposed granite with corestones. Slightly decomposed granite was encountered between 13.7 m and 16.7 m below ground surface. In drillhole No. DH3, 2 m of alluvium was encountered overlying 15 m of completely to highly decomposed granite. Slightly to moderately decomposed granite was found below a depth of 16.75 m.

Between 1990 and 1991, Enpack (Hong Kong) Ltd. completed five drillholes (Nos. BH2 to BH6) and two trial pits (Nos. TP3 and TP4) at slopes Nos. 7SW-D/C2, 7SW-D/C3, 7SW-D/C4 and 7SW-D/C5 along Lion Rock Tunnel Road. Drillhole Nos. BH2 and BH3 were sunk at the toe and crest of slope No. 7SW-D/C3 respectively. Drillholes Nos. BH4, BH5 and trial pit No. TP4 were sunk on the crest of slope No. 7SW-D/C2 (the northeast portion of slope No. 7SW-D/C2 was subsequently registered as slope No. 7SW-D/C229). Trial pit No. TP3 was excavated and drillhole No. BH6 sunk at the crest of slope No. 7SW-D/C4. Drillholes Nos. BH3 to BH6 encountered between 0.5 m and 2.5 m of colluvium overlying residual soil to completely decomposed granite with corestones. A slightly to moderately decomposed quartz monzonite was encountered at depths of between 10 m and 20 m below ground surface. In drillhole No. BH5, the contact between quartz monzonite and granite was recorded at 43.63 mPD. In drillhole No. BH2, an approximately 5.1 m thick layer of fill overlying a thin layer of colluvium with slightly to moderately decomposed granite being encountered at approximately 5.6 m below ground surface.

In October 2000 under contract No. GE/99/15, Gold Ram Engineering & Development Ltd. completed three trial pits as part of a Stage 3 study for slope No. 7SW-D/C2. The trial pits, J01-TP1 to J01-TP3, revealed a relatively consistent ground profile. A layer of topsoil and fill of between 0.1 m and 0.8 m thick was found to overlie colluvium. The colluvium was described predominantly as clayey silt with occasional cobbles and boulders.

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In July 2001, fifteen trial pits were excavated on slope No. 7SW-D/F271, which is adjacent to the Wilson Trail. The trial pits confirmed that the slope comprises fill with a maximum thickness of 2.8 m overlying residual soil or completely decomposed granite. Between April 2001 and July 2001, Enpack (Hong Kong) Ltd. completed three drillholes and three trial pits as part of a Stage 3 study for slope No. 7SW-D/C229, which was formerly the northeast portion of slope No. 7SW-D/C2. Drillholes Nos. DH07/1 to DH07/3, revealed a layer of topsoil/colluvium overlying completely decomposed granite with corestones.

Between November 2005 and January 2006, Driltech Ground Engineering Ltd. completed six drillholes and five trial pits to investigate slope No. 7SW-D/C4. Drillholes Nos. C4-DH1, C4-DH2 and C4-DH6 were sunk at the crest of the slope while drillholes Nos. C4-DH3, C4-DH4 and C4-DH5 were sunk at the mid-height of the slope. The ground conditions revealed by the recent GI were similar to those encountered by the Enpack (HK) Ltd. GI in 1991 with no apparent adverse geological materials encountered.

6.3 Superficial Deposits

The superficial deposits encountered at the site essentially included colluvium, typically comprising cobbles and boulders up to several metres across with a matrix of silty fine to coarse sand. Based on field measurements at the source of the August 2005 landslide, the colluvium is about 3 m thick. About 7 m of colluvium was encountered in drillhole No. DH07/1 at slope No. 7SW-D/C229, alongside Lion Rock Tunnel Road.

6.4 Solid Geology

Based on the published geology map (Figure 4), field inspection and the results of the previous GI, the solid geology in the vicinity of the 22 August 2005 landslide comprises completely decomposed to moderately decomposed fine- and coarse-grained granite, with quartz monzonite encountered in the exploratory holes along Lion Rock Tunnel Road.

6.5 Geological and Geomorphological Model

The August 2005 landslide is located on weathered granitic terrain at a concave break-in-slope towards the southern edge of a shallow topographical depression where there is an accumulation of colluvium (Figure 5). The landslide source area is also situated near the head of a poorly defined minor ephemeral drainage line that runs down the topographical depression in an approximately north-northwest direction (Figure 5). While the catchment above the landslide site is relatively small (plan area of approximately 2,000 m^2), the convergence of both surface and sub-surface water flows is likely to occur during heavy rainstorms.

From aerial photographs, the depression in which the August 2005 landslide occurred can be seen as a distinct feature on the northern flank of an east-northeast trending ridgeline between two rounded spurs that trend northwest and north-northwest (Plate A1). A number of relict landslides, identified as a series of distinct convex breaks-in-slope, can be seen along the crown of the depression (Figure 5), and a hummocky morphology, possibly indicative of ground movement, was observed within the scar of one of the relict landslides (Figure 2). Towards the mouth of the depression, the accumulation of colluvium appears to thicken, based on the GI at slope No. 7SW-D/C229 (Section 6.2), and continues downhill to a colluvial lobe, at about the location of the Kak Tin Village Nam Kau.

The geomorphological setting of the August 2005 landslide is a concave topographical depression at the head of an ephemeral drainage line, which appears to have influenced the failure through colluvial infilling of the topographical depression. The August 2005 landslide may have resulted from a 'ripening' of the depression, through the gradual accumulation of depression colluvium until the thickness of colluvium reached a critical level that was susceptible to failure (HCL, 2003; Crozier et al., 1990).

The August 2005 landslide may also have been influenced by the underlying geology of the landslide site, with joints within the granite appearing to have had a partial structural control on the eastern flank of the main source of the landslide and a greater control on the secondary source in which a possible wedge failure was observed. The dilated and infilled joints within the granite have influenced the groundwater flow at the landslide, which is likely to have been a significant contributing factor to the failure.

6.6 Landslide Susceptibility

Along the crown of the depression, four relict landslides are visible in the 1963 aerial photographs and in the ENTLI records (see Sections 3.3.1 and 3.3.2 respectively). No landslides appear to have affected the crown, or any other part, of the topographical depression since these relict landslides occurred. However, the accumulation of colluvium and a probable colluvial lobe downhill of the topographical depression indicate a history of past instability, though the scale and frequency of such failures cannot be determined.

7. HYDROGEOLOGY

7.1 General

The elevated groundwater and rapid and continued runoff at the landslide site appears to be a significant feature of the August 2005 landslide. Heavy seepage was observed from sandy infilled joints at the August 2005 landslide scar, and continued up to a week after the rainstorm (Section 5.2), and high water flow in the streamcourse located in the adjacent catchment to the southeast may indicate a degree of hydrogeological connection between the natural streamcourse uphill and the landslide source.

There is an apparent alignment of the August 2005 landslide, the saddle in the southwest-northeast ridgeline southeast of the landslide and the point where the streamcourse in the southeast adjacent catchment is observed to change direction of flow (Figure 5). This suggests that the development of the saddle and a possible hydrogeological connectivity between the streamcourse and the August 2005 landslide has a structural control. There was no obvious evidence of a fault at the landslide site either from site inspection or aerial photograph interpretation, although joints measured at slope No. 7SW-D/C570 had a strike trending approximately sub-parallel to the apparent alignment.

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7.2 Groundwater Conditions

As part of the previous GI carried out at the slopes alongside Lion Rock Tunnel Road (see Section 6.2), piezometers and standpipes were installed in some of the drillholes. A summary of installation details and groundwater monitoring at the boreholes is presented in Table 3.

In the five drillholes Nos. BH2 to BH6 sunk by Enpack in 1991, single piezometer tips were installed in drillholes Nos. BH2, BH3 and BH5, while double piezometers were installed in drillholes Nos. BH4 and BH6. Piezometer tips were located near the fill/colluvium, colluvium/CDG or soil/rock interfaces. Groundwater monitoring was carried out between June 1991 and May 1992, with the highest water levels recorded in drillhole Nos. BH2, a rise of 0.7 m above the fill/colluvium interface and in drillhole No. BH6 a rise of 0.39 m being recorded above the completely decomposed/highly decomposed quartz monzonite interface.

In the drillholes sunk as part of the Stage 3 study of slope No. 7SW-D/C229, a double piezometer was installed in drillhole No. DH07/1 while single piezometers were installed in drillholes Nos. DH07/2 and DH07/3. Groundwater monitoring was carried out manually on a weekly basis between June 2001 and January 2002, with the highest water levels recorded in drillholes Nos. DH07/1 and DH07/3 at 7.45 m and 15 m above soil/rock interface. The highest water levels were recorded 5 days after the major rainfall ceased. However, it should be noted that groundwater monitoring was carried out at weekly intervals and the delayed response may be apparent only. The maintenance manual for slope No. 7SW-D/C2, in which a raking drain with a constant heavy seepage was observed during and subsequent to the August 2005 landslide, did not indicate any records on unusual groundwater conditions during the slope upgrading works.

As part of the GI for slope No. 7SW-D/C4, double piezometers were installed in drillholes Nos. C4-DH1, C4-DH2, C4-DH3, C4-DH4, C4-DH5, while a single standpipe and a single piezometer were installed in drillhole No. C4-DH6. Groundwater monitoring was carried out between January 2006 and May 2006 after which the ground investigation report was finalised and the Stage 3 Report (Fugro, 2006) submitted to GEO in June 2006 and finalised in August 2006. The highest ground water level recorded in the drillholes about 0.5 m above the piezometer tips.

8. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. N42, which is located about 0.5 km to the north of the August 2005 landslide on the roof of Wing Wai House, Sun Tin Wai Estate, Sha Tin (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the GEO and the Hong Kong Observatory (HKO). The daily rainfall recorded by raingauge No. N42 over the month preceding the landslides, together with the hourly rainfall readings for the period between 19 and 22 August 2005, are presented in Figure 9. Records from another nearby GEO automatic raingauge No. N01, which is about 1.9 km to the west of the August 2005 landslides, were also examined. The pattern of rainfall recorded at this raingauge is broadly similar to those recorded at raingauge No. N42 but with a slightly higher intensity.

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The rainstorm preceding the landslides commenced around midnight on 19 August 2005 and continued until the evening of 20 August 2005. Amber Rainstorm Warnings were hoisted from 7:25 a.m. on 19 August 2005 to 12:55 a.m. on 20 August 2005, and from 8:35 a.m. to 9:10 p.m. on 20 August 2005. According to the incident records, the landslides occurred at approximately 2:30 p.m. on 22 August 2005. The maximum 12-hour and 24-hour rainfall before the landslides was 310.5 mm and 518.5 mm respectively. The maximum 1-hour rolling rainfall was recorded as 54 mm between 8:55 a.m. and 9:55 a.m. on 20 August 2005 (Table 4). The rainfall analysis also shows a period of delay (about 45 hours) between the end of the main rainstorm at 8:35 p.m. on the 20 August 2005 and the time of failure.

An analysis of the return periods for various durations of maximum rolling rainfall recorded at raingauge No. N42, with reference to historical rainfall data at the HKO at Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994), shows that a rainfall duration of 48 hours or more before the landslide was the most critical, with a corresponding return period of more than 100 years (Table 4).

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) from rainfall data recorded by local raingauge No. N01 between 1984 and 1997. The return period of the 7-day rainfall at raingauge No. N42 was the most critical with a return period of 68 years (Table 4), which is less than that estimated by the historical rainfall data at the Hong Kong Observatory.

The maximum rolling rainfall for the August 2005 rainstorm has been compared with the past significant rainstorms recorded by raingauges Nos. N01 and N42 between 1979 and 2004 (Figure 10). The August 2005 rainstorm is the most severe for rainfall durations between 24 hours and 15 days.

9. DISCUSSION

The relative timing of the 22 August 2005 landslide and the preceding heavy rainfall suggests that the landslide was probably triggered by rainfall. The severe antecedent rainfall probably played an important role in this failure. Although the landslide did not directly affect the very busy Lion Rock Tunnel Road, it is likely that outwash from the landslide reached the road only a short time after the landslide occurred and therefore only shortly before it was reported (HyD recorded a time of failure at 2:30 p.m.). However, the landslide was reported almost two days after the end of the intensive rainstorm on the 20 August 2005 (Section 8). The continued heavy seepage from dilated joints with a sandy infill indicates that subsurface water flow was probably a significant contributory factor to the landslide.

This case is notable in that it comprised a delayed hillside failure and that active subsurface seepage could still be seen at the landslide source area even one week after failure. Such cases of shallow hillside failures with a significant delay (up to 45 hours) between the end of the major rainstorm and the time of failure, together with the observation of strong and prolonged groundwater seepage following failure, are not common.

The likely mechanism of failure probably involved wetting up of the ground mass due to direct infiltration and subsurface seepage through the dilated joints leading to the transient development of perched groundwater pressure within the colluvium and possibly along joint

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surfaces within the decomposed granite.

The geomorphological setting of the August 2005 landslide (Section 6.5) appears to have influenced the location of the landslide, with likely convergent surface and subsurface water flow at the head of a drainage line into a colluvium-filled concave depression. It is also apparent that there has been a partial structural control to the eastern flank and possibly the main scarp of the main source of the August 2005 landslide, while the secondary source appears to have been predominantly structure controlled. There were no obvious signs of any incipient large-scale failure (e.g. tension cracks) identified at the landslide site.

The timing of the landslide in August 2005 and not at some earlier time, may have been influenced by the degree of deterioration of the underlying granite and by the 'ripening' of the topographical depression in which the thickness of the colluvium attained a level that was more susceptible to failure. Such a mechanism may explain the apparent absence of observed landslides at the site in the recent past (i.e. over the past 50 years), since following failure the progressive deterioration of the underlying granite and 'ripening' of the concave depression could take some time before reaching a level that is once more susceptible to failure if this postulation was correct.

The relationship between the ridgeline and the drainage pattern may indicate that the geology of the minor ridgeline is more resistant to weathering and erosion than the adjacent material. The location where the streamcourse is closest to the ridgeline may be a key area for the potential elevation of local groundwater pressures on the uphill side of the ridge, with the difference in elevation between the August 2005 landslide site and the uphill streamcourse at about 10 m, see Section 2.1.

According to the Geology Map Sheet No. 7 (GCO, 1986), faults are inferred in the granite and quartz monzonite in the area (Figure 4), that are sub-parallel to the apparent alignment of the turning point in the streamcourse in the southeast adjacent catchment, the saddle and the August 2005 landslide source (Figure 2) and may relate to a possible structural influence on hydrogeology. The above can only be conjectured in the absence of a detailed hydrogeological investigation. It is noteworthy that grain size variations in the granitic material observed in the vicinity of the landslide often result in differences in weathering and may also result in local variations in joint pattern and spacing, which could in turn influence the local hydrogeology which is likely to be complex.

10. CONCLUSIONS

The 22 August 2005 landslide was probably the result of progressive deterioration of a hillside with an adverse geomorphological and complex hydrogeological setting, triggered by a combination of infiltration and subsurface flow through open joints following a severe and prolonged rainstorm. The landslide was also influenced by the underlying geological structure.

The 22 August 2005 landslide is notable given that there was a significant delay (up to 45 hours) between the end of a major rainstorm and the time of failure, and that there was strong and prolonged groundwater seepage from the landslide source area up to one week following failure.

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Table 1 - Class Assigned to Relict Features Identified under the ENTLI

Class	Comment	Degree of Confidence
A1	- Sharp scarp with associated downslope debris. - Well-defined scarp with evidence of debris immediately downslope.	90%
A2	- Sharp scarp with no evidence of debris immediately downslope. - Sharp scarp with some evidence of downslope debris but indefinitely related.	90%
B1	- Minor depression (width ≦ 15 m). - Depression (15 m < width ≦ 20 m). - Wide depression probably formed by landslide-related activity (width > 20 m).	50%
B2	- Rock outcrop at rear of scarp may have controlled failure. No evidence of downslope debris. - Rock outcrop at rear of scarp may have controlled failure. Some evidence of downslope debris.	50%
C1	- Insufficiently defined - head of ephemeral streamcourse.	10%
C2	- Depression may have been formed by landslide-related activity (width ≦ 20 m). - Wide depression may have been formed by landslide-related activity (width > 20 m).	10%
S	- Coastal failure potentially caused due to undercutting.	-
Note: Classes developed for the ENTLI project under Agreement No. CE 15/2005 (GE).		

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Table 2 - Summary of Previous GI in the Vicinity of Lion Rock Tunnel Road (Page 1 of 3)

Project	Contractor	Date carried out	Types of works carried out	Remarks
P.W.D Contract 673/33 Lion Rock Tunnel Road (GIU No. 2503)	Gammon (Hong Kong) Ltd.	December 1978	8 drillholes (DH1 to DH3, DH5 to DH9)	The drillholes are located near Hung Mui Kok Road at 540 m southwest of August 2005 landslide. Up to 5 m of colluvium (mainly sandy silt with clay and gravels) overlying on CWG
Village Extension in Kak Tin (Area 24C) Natural Slope Adjacent to Kak Tin Village (GIU No. 10932) (GIU No. 38589)	Lam Geotechnics Ltd.	31 March 1988 to 11 April 1988	3 drillholes (DH1 to DH3)	DH1: 3.5 m colluvium (mainly sandy silt); 10.22 m CDG with corestones; 5.36 m S-MDG DH2: 2 m colluvium (sand with rock fragments); 9.78 m H-CDG with corestones: 5.29 m SDG DH3: 2 m alluvium (mainly silty sand); 14.75 m H-CDG with corestones; 2.98 m S-MDG
CESD Contract No. CE/89/06 Ground Investigation Slope No. 7SW-D/C2, C3, C4 & C5 Lion Rock Tunnel Road (GIU No. 15598)	Enpack (Hong Kong) Ltd.	20 November 1990 to 29 April 1991	5 Drillholes (BH 2 to BH6) 2 Trial Pits (TP3 to TP4)	BH2: 5.1 m Fill; 0.53 m colluvium (mainly boulder and cobbles); 4.37 m S-MDG* & 7 days GWL monitoring recorded below the tip level of piezo. BH3: 2.5 m colluvium (mainly sandy silt); 3 m residual soil; 9.95 m CDG with corestones; 6 m S-MDG* BH4: 2.5 m colluvium (mainly sandy silt); 7.95 m CDQM with corestone; 5 m S-MDQM; 2 piezo. installed but S3R 4/93 with 3 piezo. monitoring records. BH5: 0.5 m colluvium(silty sand); 17.60 m CDQM with corestones; 1.9 m S-MDQM BH6: 2.5 m colluvium; 6 m residual soil; 8 m CDG; 3.3 m HDG; 5.37 m S-MDQM * recorded as granodiorite but likely to be quartz monzonite

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Table 2 - Summary of Previous GI in the Vicinity of Lion Rock Tunnel Road (Page 2 of 3)

Project	Contractor	Date carried out	Types of works carried out	Remarks
CESD Contract No. CE/89/06 Ground Investigation Slope No. 7SW-D/C2, C3, C4 & C5 Lion Rock Tunnel Road (GIU No. 15598)	Enpack (Hong Kong) Ltd.	20 November 1990 to 29 April 1991	5 Drillholes (BH 2 to BH6) 2 Trial Pits (TP3 to TP4)	BH2: 5.1 m Fill; 0.53 m colluvium (mainly boulder and cobbles); 4.37 m S-MDG* & 7 days GWL monitoring recorded below the tip level of piezo. BH3: 2.5 m colluvium (mainly sandy silt); 3 m residual soil; 9.95 m CDG with corestones; 6 m S-MDG* BH4: 2.5 m colluvium (mainly sandy silt); 7.95 m CDQM with corestone; 5 m S-MDQM; 2 piezo. installed but S3R 4/93 with 3 piezo. monitoring records. BH5: 0.5 m colluvium(silty sand); 17.60 m CDQM with corestones; 1.9 m S-MDQM BH6: 2.5 m colluvium; 6 m residual soil; 8 m CDG; 3.3 m HDG; 5.37 m S-MDQM * recorded as granodiorite but likely to be quartz monzonite
Ground Investigation Works for Slopes in Sha Tin District 7SW-D/C2 (GIU No. 32602)	Gold Ram Engineering & Development Ltd.	11 October 2000 to 30 November 2000	3 Trial Pits (J01-TP1 to J01-TP3)	Up to 0.2 m top soil; locally with 0.7 m fill; 1.7 m colluvium (clayey silt with occasional boulder and cobbles)

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Table 2 - Summary of Previous GI in the Vicinity of Lion Rock Tunnel Road (Page 3 of 3)

Project	Contractor	Date carried out	Types of works carried out	Remarks
Contract No. GE/2000/20 Slope No. 7SW-D/F271 Wilson Trail (GIU No. 33426)	Enpack (Hong Kong) Ltd.	3 July 2001 to 31 July 2001	15 trial pits (TP30/1 to TP30/15)	(TP30/1 to TP30/4, TP30/6 to TP30/8, TP30/12): 0.3 m to 2.8 m fill; 0.2 m - 0.3 m former top soil; max 3.2 m RS/CDG (TP30/5, TP30/9, TP30/10, TP30/11, TP30/13-TP30/15): 0 m - 2.8 m Fill; 0.2 m former topsoil; 0.4 m - 1.4 m colluvium (mainly clay/silt occasional with gravel, cobbles and boulder); max 1.2 m C/HDG
Contract No. GE/2000/20 7SW-D/C229 At Roadside of Lion Rock Tunnel Road (GIU No. 33421)	Enpack (Hong Kong) Ltd.	27 April 2001 to 17 July 2001	3 Drillholes (DH07/1 to DH07/3) 3 trial pits (TP07/1, TP07/2, TP07/4)	DH07/1: 0.5 m top soil; 6.9 m colluvium (sandy clay with gravels, cobbles and boulders); 8.05 m CDG (major clayey silty coarse sand) with corestones DH07/2: 0.5 m top soil; 11.33 m CDG (major slightly clayey, slightly silty, very sandy gravel) with corestones DH07/3: 0.5 m top soil; 1.35 m colluvium (silty clayey sand with cobbles); 13.95 m CDG (major silty sand) with corestones
Contract No. GE/2003/19 Feature No. 7SW-D/C4 Lion Rock Tunnel Road (GIU No. 42845)	Driltech Ground Engineering Ltd.	14 Nov 2005 to 26 January 2006	6 drillholes (C4-DH1 to C4-DH6) and 5 trial pits (C4-TP1 to C4-TP5)	C4-DH2: 0.5 m fill; 2.1 m colluvium; 17.4 m CDQM with corestones; 5.08 m S-MDQM C4-DH1: wash boring. Installed 2 piezometer C4-DH3: wash boring; installed 2 piezometer C4-DH4: 2.89 m colluvium; 9.11 m CDQM with corestones; 1.9 m S-MDQM C4-DH5: 2.7 m Fill/RS; 7.64 m CDQM with corestones C4-DH6: 0.5 m fill; 1 m colluvium; 13.13 m CDQM with corestones; 4.94 m S-MDQM

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Table 3 - Summary of Groundwater Monitoring at Boreholes Adjacent to Lion Rock Tunnel Road (Page 1 of 2)

BH No.	Ground Level (mPD)	Period of Monitoring		Piezometer / Standpipe Tip location	Piezometer / Standpipe Tip level (mPD)	Highest Recorded Groundwater level (mPD)
		From	To			
DH07/1	56.92	14/05/2001	16/01/2002	CDG/Corestone	48.82	49.66
DH07/1	56.92	14/05/2001	16/01/2002	CDG	41.97	49.42*
DH07/2	60.94	02/05/2001	16/01/2002	CDG/SDG	48.94	51.55
DH07/3	54.99	07/05/2001	16/01/2002	C-HDG/MDG	39.49	54.49*
BH2	45.43	24/11/1990	31/05/1992	Fill/Col	40.3	41
BH3	84.23	22/04/1991	31/05/1992	CDQM/MDQM	67.23	67.5
BH4A	62.66	09/04/1991	31/05/1992	Col/CDQM	60.16	60.2
BH4B	62.66	09/04/1991	31/05/1992	CDQM/S-MDQM	52.21	52.2
BH4C	62.66	01/06/1991	31/05/1992	N/I	N/I	54.5**
BH5	61.13	29/03/1991	31/05/1992	CDQM/S-MDQM	45.36	45.5
BH6A	63.11	24/04/1991	31/05/1992	RS/CDQM	55.11	55.1
BH6B	63.11	24/04/1991	31/05/1992	CDQM/HDQM	47.11	47.5
C4-DH1(P)Upper	59.71	01/01/2006	31/05/2006	CDQM	53.71	54.21*
C4-DH1(P)Lower	59.71	01/01/2006	31/05/2006	CDQM/corestone	48.71	49.21*
C4-DH3(P)Upper	51.09	01/01/2006	31/05/2006	Col/CDQM	48.09	48.59*
C4-DH3(P)Lower	51.09	01/01/2006	31/05/2006	CDQM/corestone	45.09	45.59*
C4-DH4(P)Upper	51.04	01/01/2006	31/05/2006	CDQM	41.04	41.54*
C4-DH4(P)Lower	51.04	01/01/2006	31/05/2006	S-MDQM	37.64	38.04*
C4-DH5(P)Upper	49.76	01/01/2006	31/05/2006	CDMQ/Corestone	43.76	44.26*

Table 3 - Summary of Groundwater Monitoring at Boreholes Adjacent to Lion Rock Tunnel Road (Page 2 of 2)

BH No.	Ground Level (mPD)	Period of Monitoring		Piezometer / Standpipe Tip location	Piezometer / Standpipe Tip level (mPD)	Highest Recorded Groundwater level (mPD)
		From	To			
C4-DH5(P)Lower	49.76	01/01/2006	31/05/2006	CDMQ/Corestone	39.96	40.26*
C4-DH6(S)	51.28	01/01/2006	31/05/2006	RS/Corestone	47.08	47.28*
C4-DH6(P)	51.28	01/01/2006	31/05/2006	HDG/S-MDQM	36.58	36.78*
DH1	52.62	28/03/1988	08/04/1988	CDG/SDG	38.92	dry
DH2	36.71	08/04/1988	15/04/1988	MDG/SDG	22.46	dry
DH3	22.65	12/04/1988	19/04/1988	HDG/MDG	5.9	13.1

Notes:

*	Halcrow Bucket reading
**	In GIU No. 15598 report 2 piezo. Installed in BH4 but S3R 4/93 with 3 piezo monitoring records.
Fill	Fill
Col	Colluvium
RS	Residual Soil
CDG	Completed decomposed granite
H-CDG	Highly to completely decomposed granite
HDG	Highly decomposed granite
S-MDG	Slightly to moderately decomposed granite
CDQM	Completed decomposed Quartz Monzonite
MDQM	Moderately decomposed Quartz Monzonite
S-MDQM	Slightly to moderately decomposed Quartz Monzonite

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Table 4 - Maximum Rolling Rainfall at GEO Raingauge No. N42 for Selected Durations Preceding the 22 August 2005 Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)	
			By Lam & Leung (1994)	By Data of N01 from Evans & Yu (2001)
5 Minutes	7.5	10:55 a.m. on 20 August 2005	< 2	< 2
15 Minutes	20.5	11:00 a.m. on 20 August 2005	< 2	< 2
1 Hour	54.0	9:55 a.m. on 20 August 2005	< 2	< 2
2 Hours	100.5	11:00 a.m. on 20 August 2005	2	2
4 Hours	158.0	11:50 a.m. on 20 August 2005	5	3
12 Hours	310.5	6:45 p.m. on 20 August 2005	14	12
24 Hours	518.5	6:30 p.m. on 20 August 2005	57	34
48 Hours	703.0	9:30 p.m. on 20 August 2005	152	54
4 Days	833.0	6:10 a.m. on 21 August 2005	148	33
7 Days	953.0	9:05 p.m. on 21 August 2005	217	68
10 Days	1048.5	9:05 p.m. on 21 August 2005	158	32
12 Days	1128.5	6:00 p.m. on 21 August 2005	158	46
15 Days	1143.0	9:05 p.m. on 21 August 2005	175	28
31 Days	1416.5	4:05 p.m. on 21 August 2005	198	13

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and using data from Evans & Yu (2001) with interpolation of rainfall parameters for the 10 days and 12 days events.
(3) According to the incident records, the landslide occurred at about 2:30 p.m. on 22 August 2005.
(4) The nearest GEO automatic raingauge to the landslide site is raingauge No. N42 (which started operation in October 1999) located at about 0.5 km to the north of the landslide site. GEO automatic raingauge No. N01 (which started operation in September 1978) is located about 1.9 km to the west of the landslide site.

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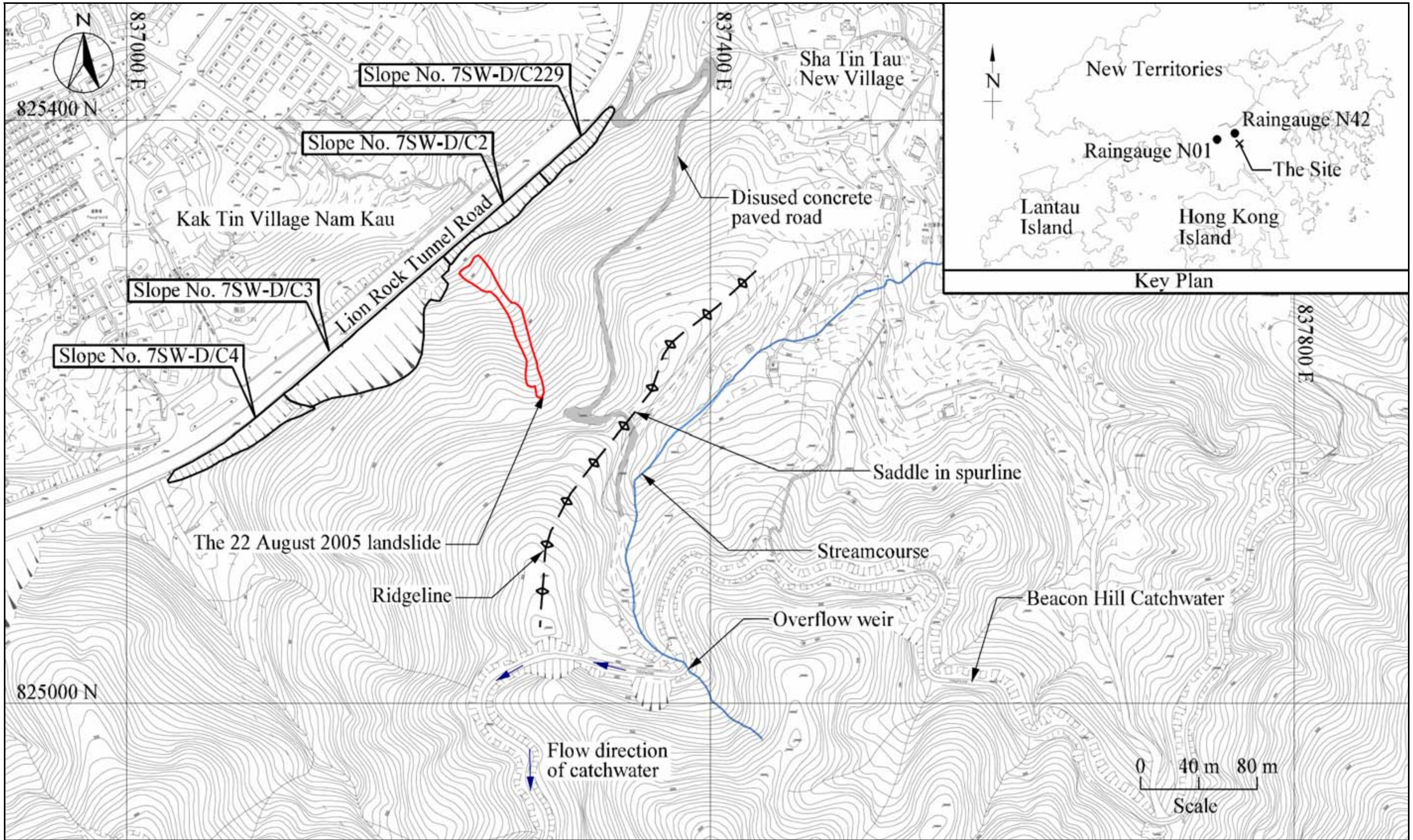

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE-16C, 7SE-21A, 7SW-20D and 7SW-25B dated March 2004.

Figure 1 - Location Plan

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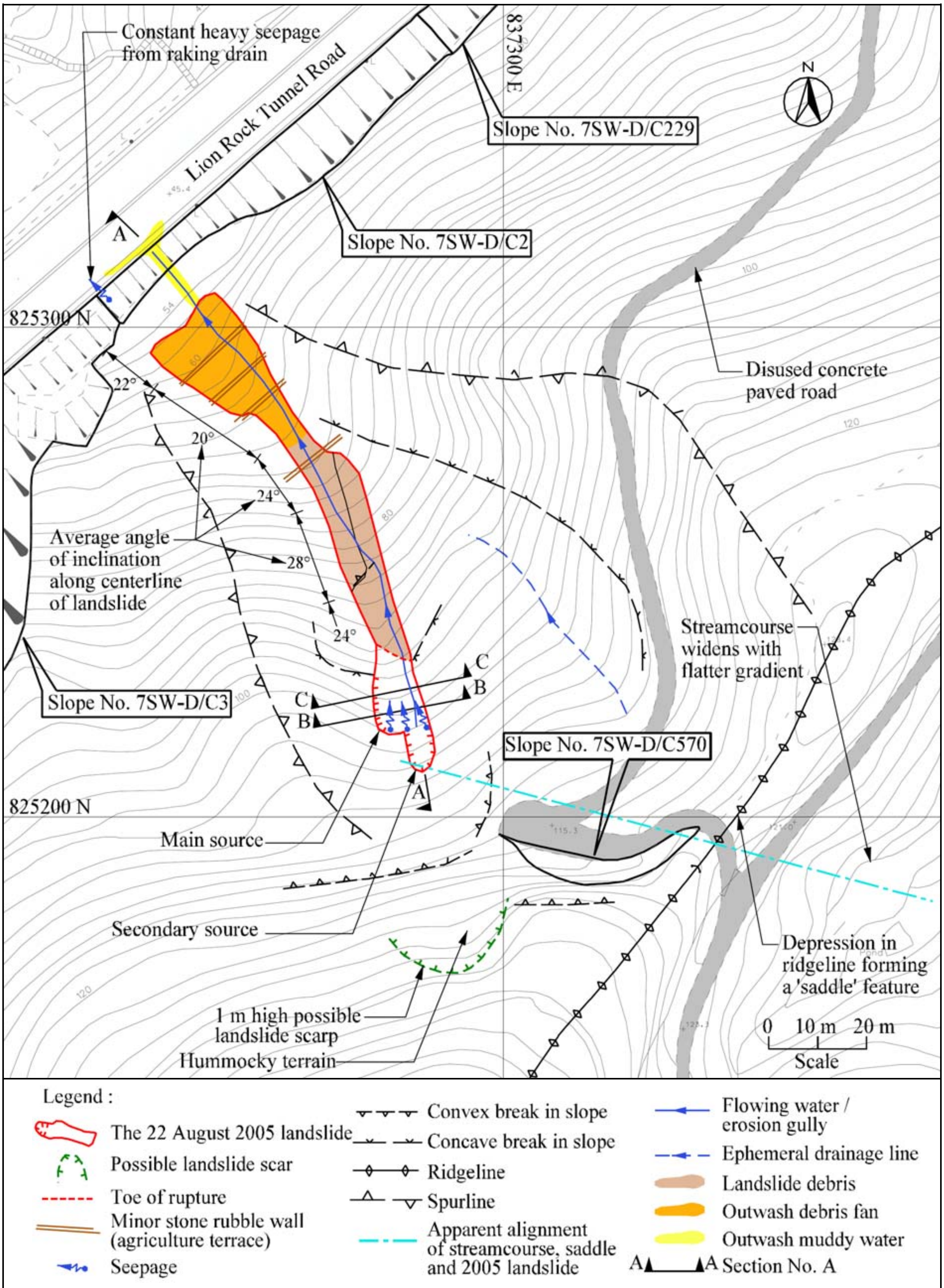

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 7SW-20D and 7SW-25B dated March 2004.

(2) See Figure 3 for Section A-A and Figure 7 for Sections B-B and C-C.

Figure 2 - Site Layout Plan

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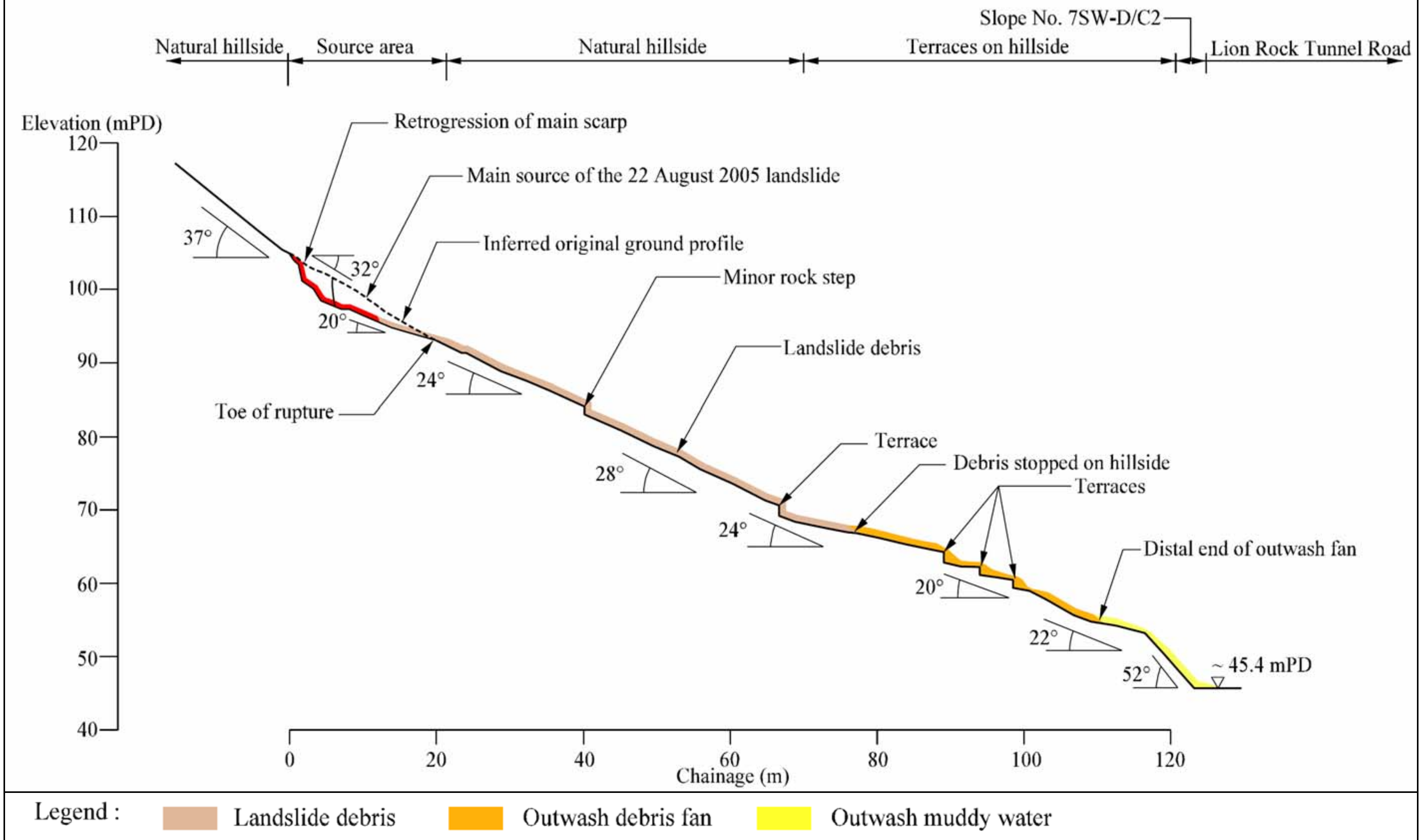

Note: See Figure 2 for location of cross-section.

Figure 3 - Section A-A through the 22 August 2005 Landslide

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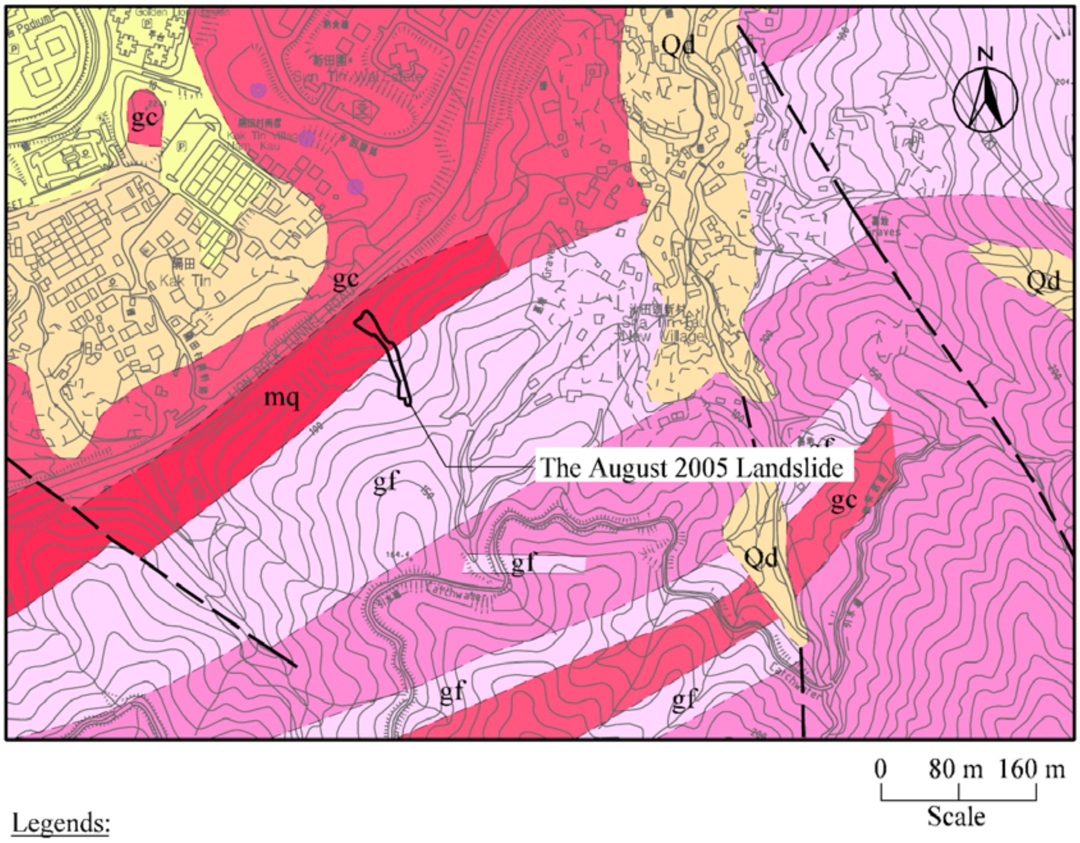

Legends:

Superficial deposits

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

Solid geology

gf	Fine-grained granite, < 2mm
gm	Medium-grained granite, 2 - 6mm
gc	Coarse-grained granite, > 6mm
mq	Quartz monzonite

Geological lines

——— ——	Fault
-------	Geological boundary, superficial deposits

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

Figure 4 - Regional Geology

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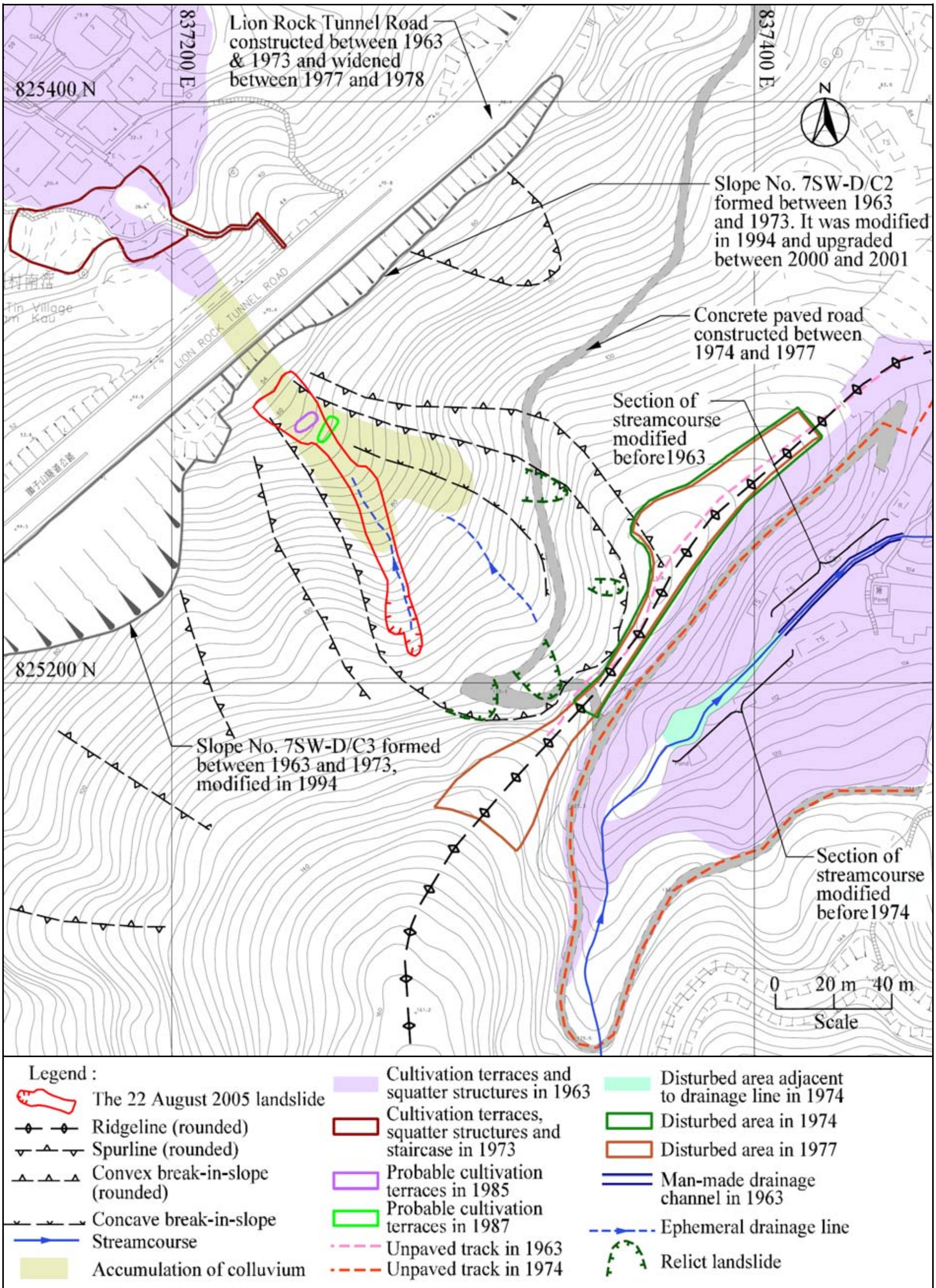

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SW-20D and 7SW-25B dated March 2004.

Figure 5 - Site History and Geomorphology

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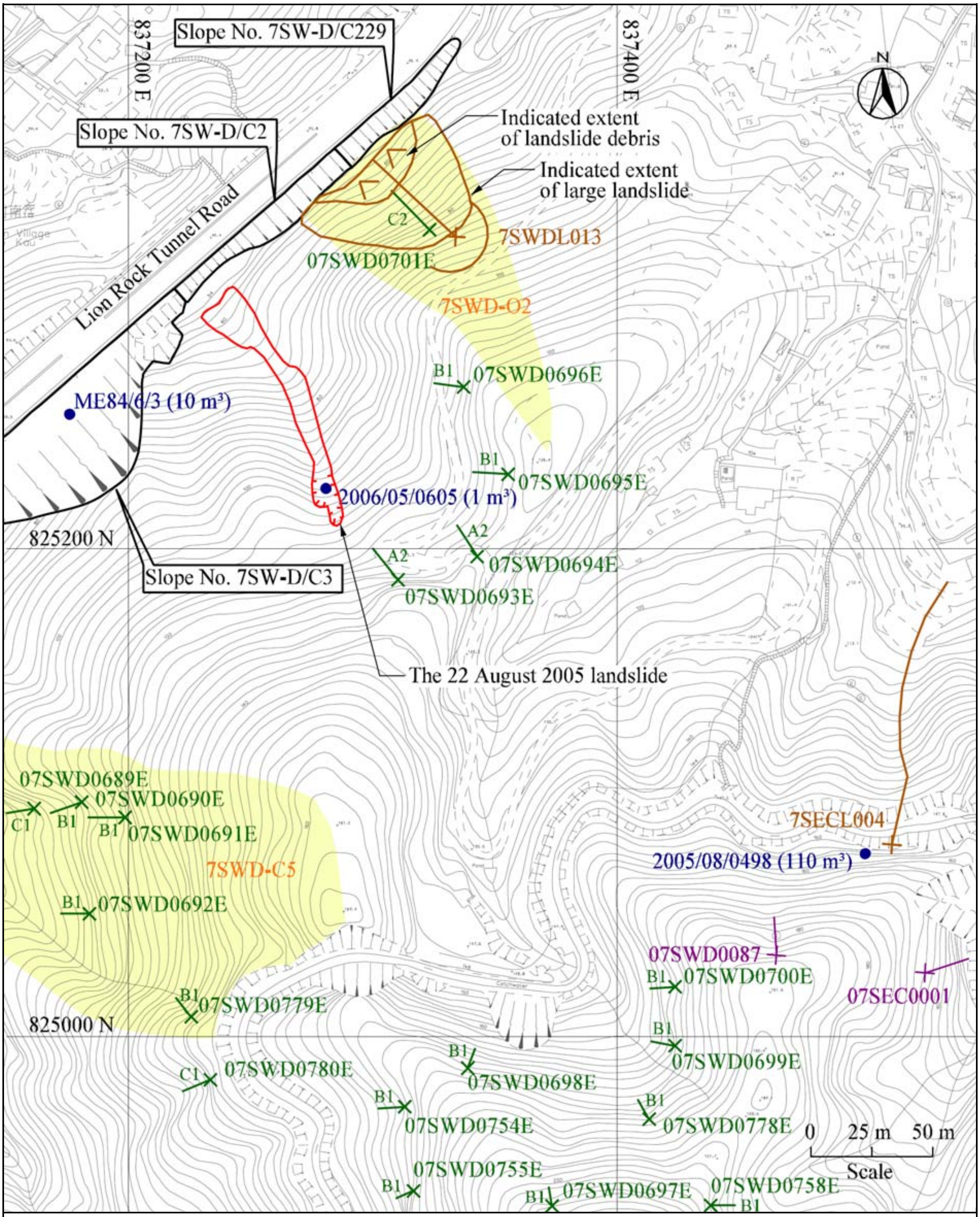

Legend : ME84/6/3 (10 m³)	Landslide Incident No. ME84/6/3 with failure volume	07SWD0087	NTLI Landslide with Reference No.
7SWDL013	Large Landslide with Reference No.	07SWD0700E B1	ENTLI Landslide with Reference No. and comment (see Table 1 for details)
7SWD-C5	Historical landslide catchment with Reference No.		

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE-16C, 7SE-21A, 7SW-20D and 7SW-25B dated March 2004.

Figure 6 - Past Instabilities

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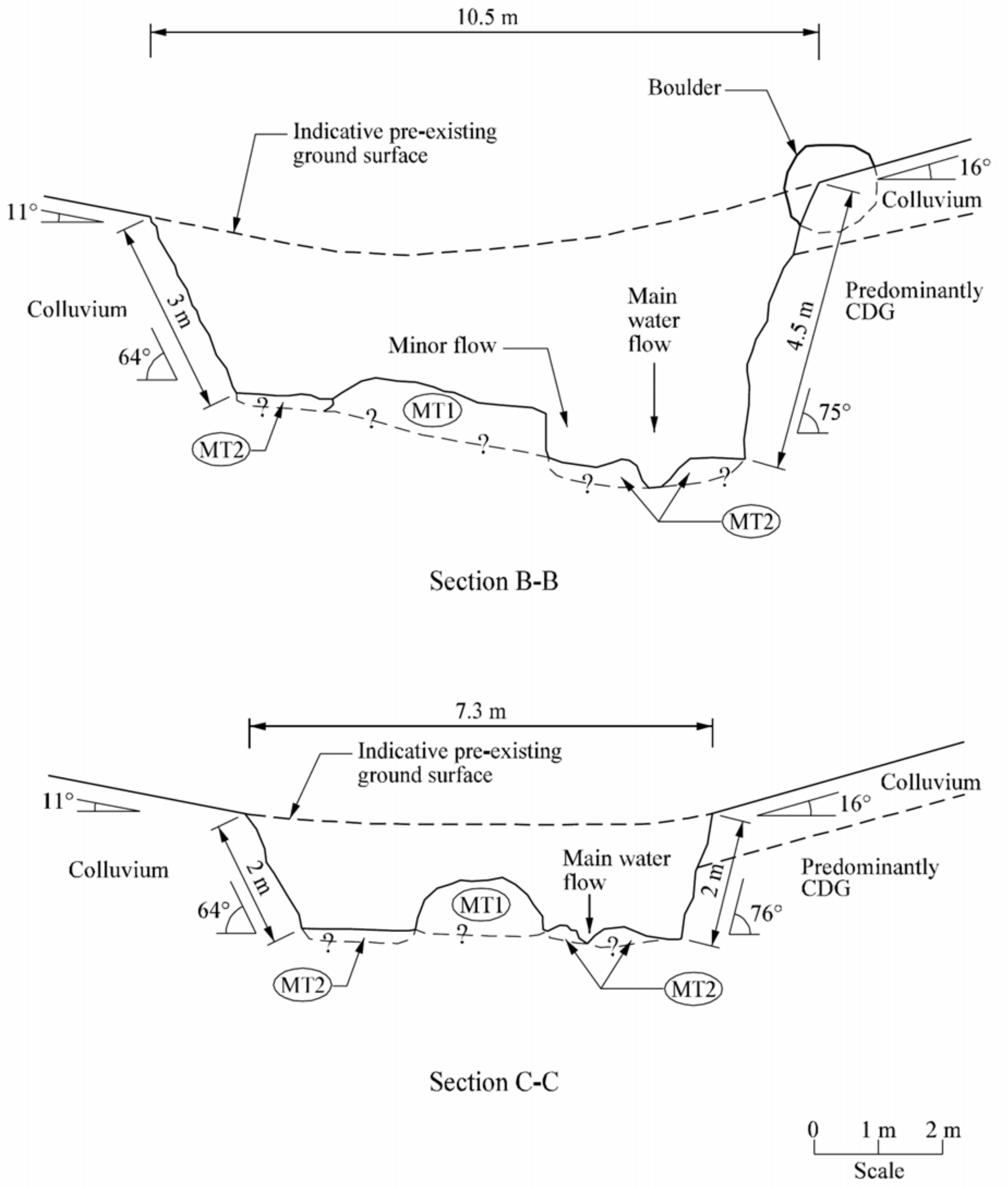

Legend:	MT1	Collasped material - Boulders with much wet silty sandy material
	MT2	Loose, slightly clayey, silty fine to coarse sand with some to many cobbles of highly and moderately decomposed fine-grained granite
Note:	See Figure 2 for location of cross-sections.	

Figure 7 - Sections B-B and C-C through the 22 August 2005 Landslide

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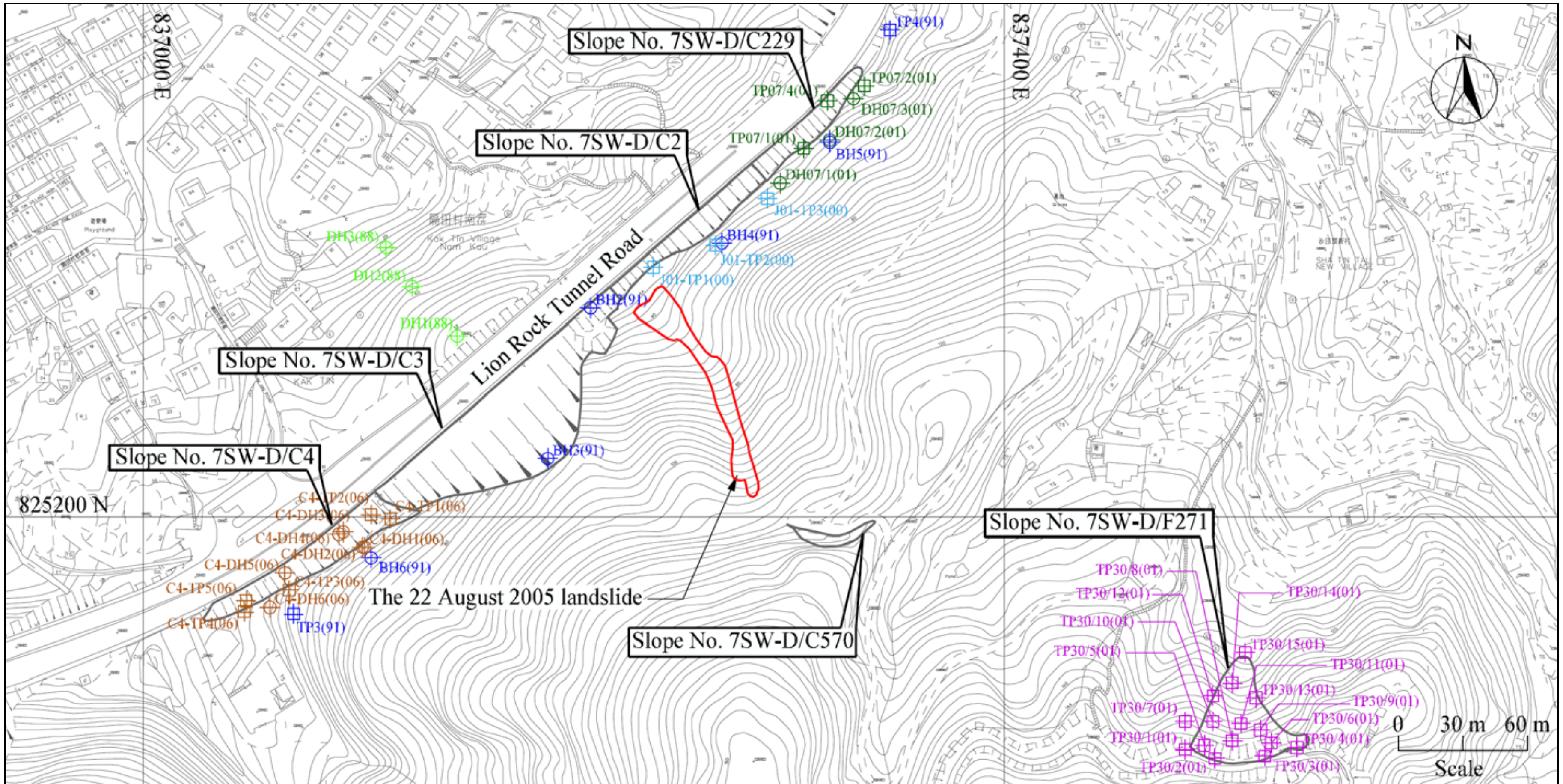

Legend : The 22 August 2005 landslide

DH3(88)	Drillhole for village extension of Kak Tin in 1988	J01-TP1(00)	Trial pit for LPM Stage 3 Study of Slope No. 7SW-D/C2 in 2000	TP30/12(01)	Trial pit for LPM Stage 3 Study of Slope No. 7SW-D/F271 in 2001
BH3(91)	Drillhole for LPM Stage 3 Study in 1991	DH07/1(01)	Drillhole for LPM Stage 3 Study of Slope No. 7SW-D/C229 in 2001	C4-DH5(06)	Drillhole for LPM Stage 3 Study of Slope No. 7SW-D/C4 in 2006
		TP07/2(01)	Trial pit for LPM Stage 3 Study of Slope No. 7SW-D/C229 in 2001	C4-TP2(06)	Trial pit for LPM Stage 3 Study of Slope No. 7SW-D/C4 in 2006

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SE-16C, 7SE-21A, 7SW-20D and 7SW-25B dated March 2004.

Figure 8 - Previous Ground Investigation

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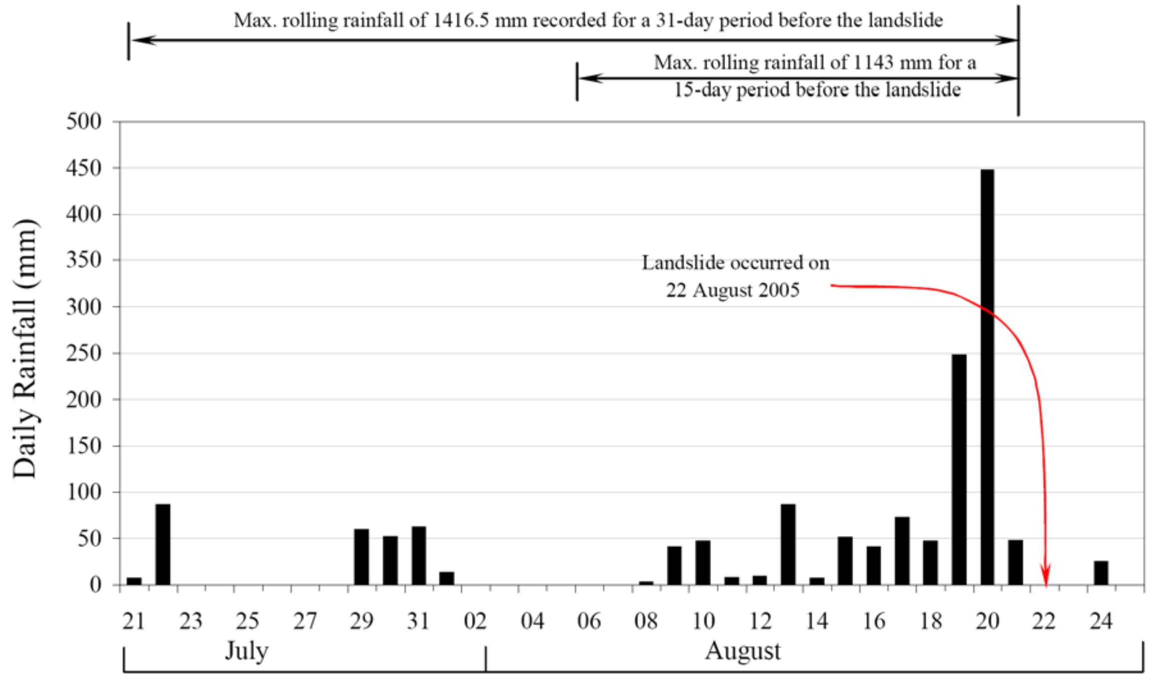
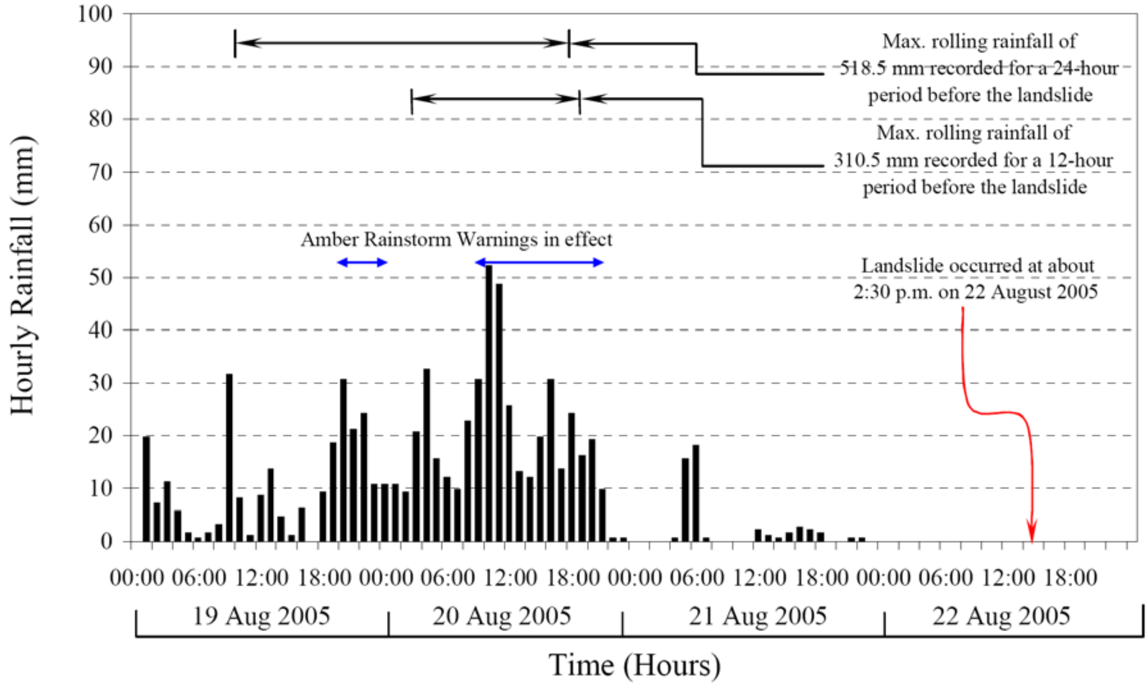


(a) Daily Rainfall Recorded at GEO Raingauge No. N42 between 21 July 2005 and 25 August 2005



(b) Hourly Rainfall Recorded at GEO Raingauge No. N42 between 19 August 2005 and 22 August 2005

Figure 9 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N42

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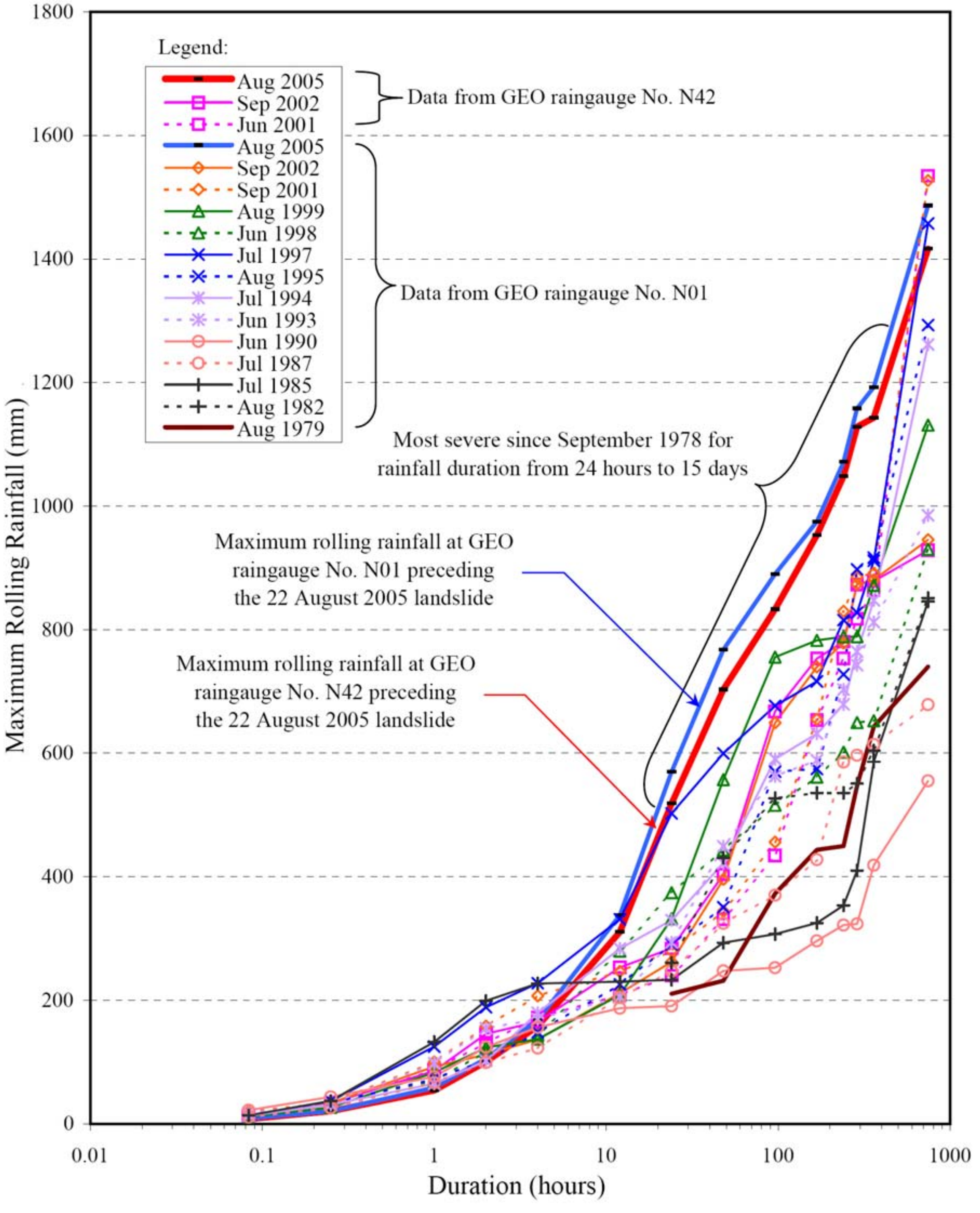

Notes: (1) Maximum rolling rainfall are evaluated from daily rainfall (for the period between 1978 and 1982) and 5-minute rainfall (for the period between 1983 and 2005) from GEO raingauges Nos. N01 and N42, located at about 1.9 km and 0.5 km to the west and north of the landslide site respectively.

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N01 since September 1978 and at GEO raingauge No. N42 since October 1999 when the raingauges became operational.

Figure 10 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N01 and N42

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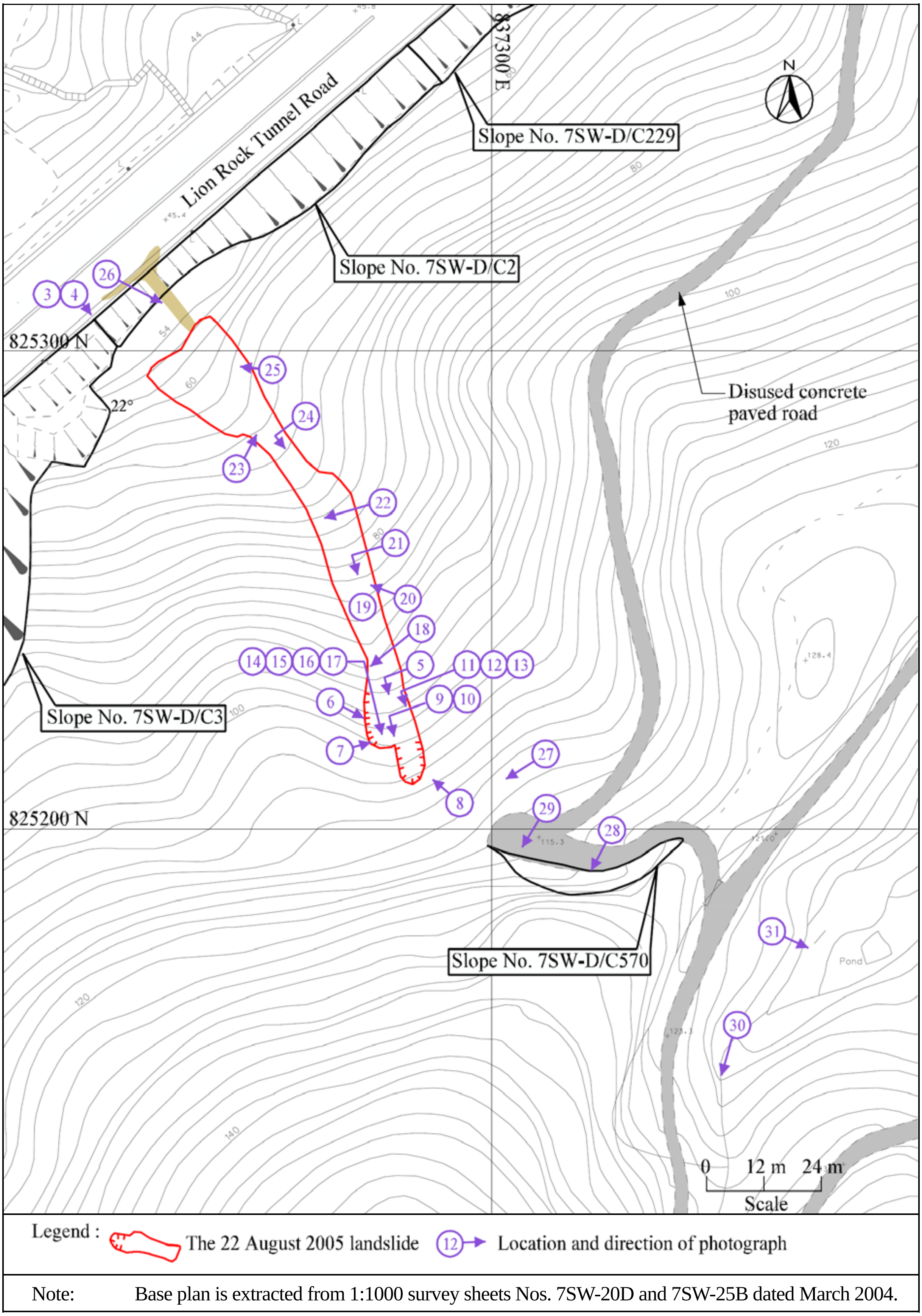

Figure 11 - Location and Direction of Photographs

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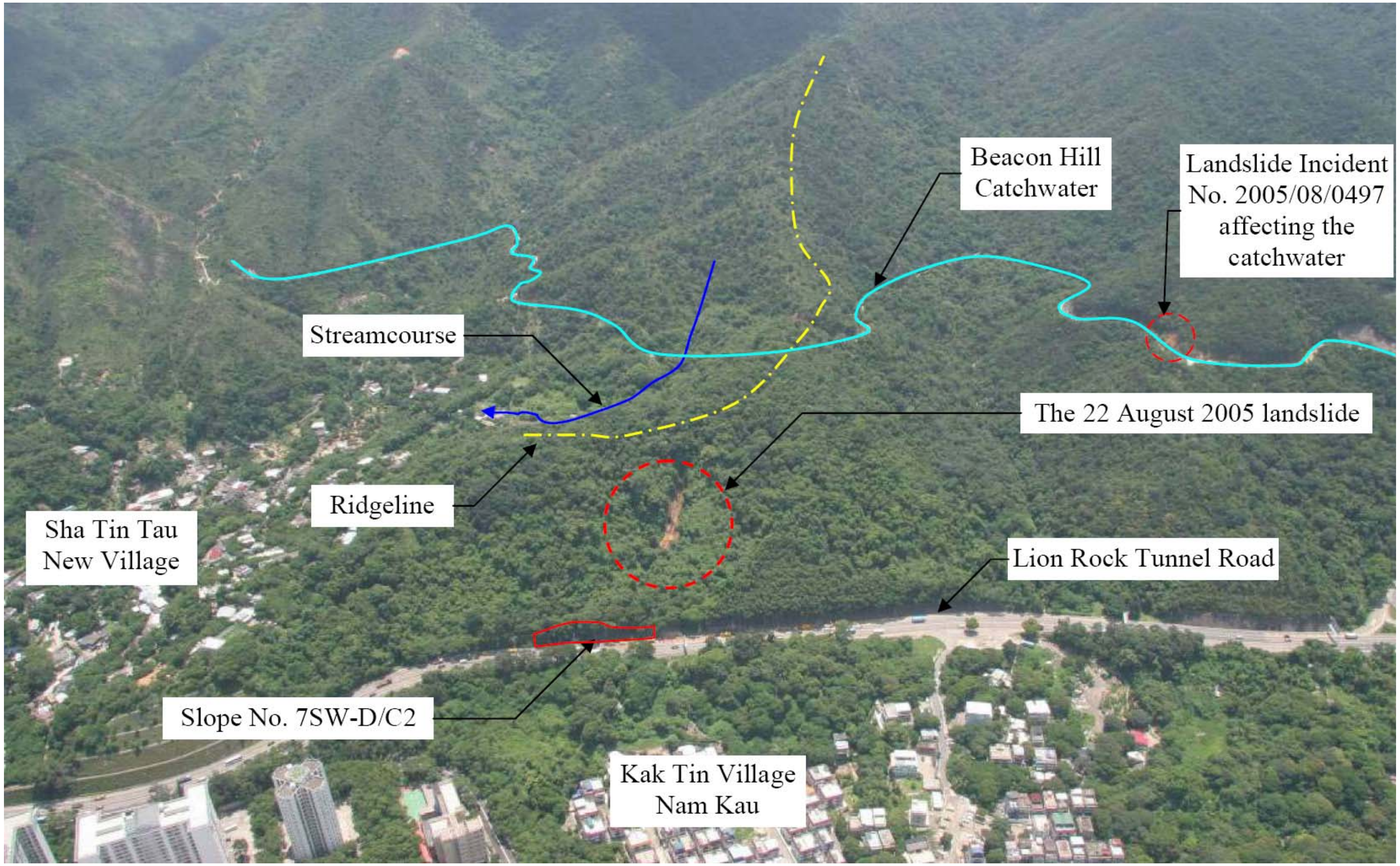

Plate 1 - Oblique Aerial View of the 22 August 2005 Landslide (Photograph taken on 23 August 2005)

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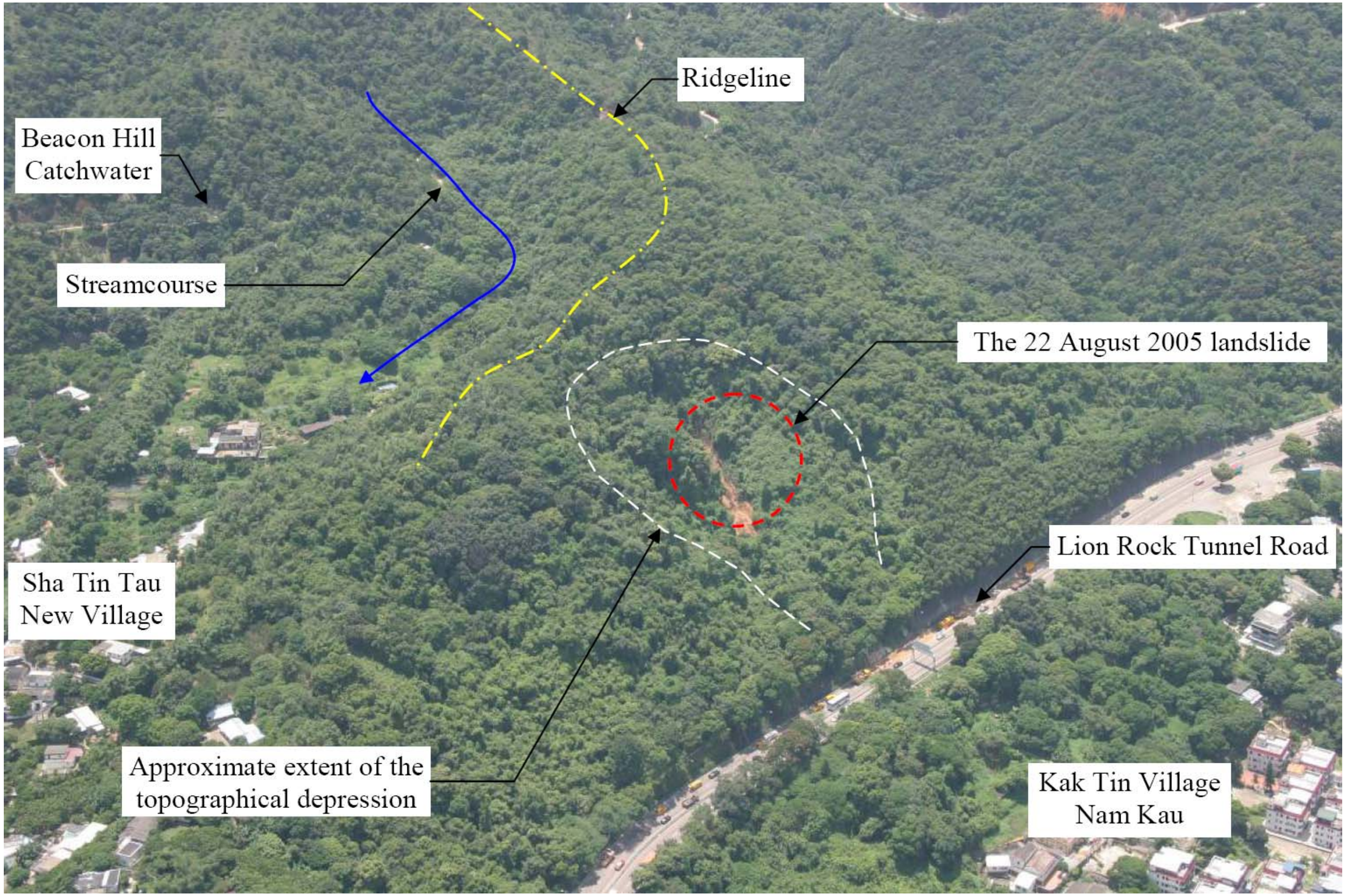

Plate 2 - Oblique Aerial View of the Landslide Site (Photograph taken on 23 August 2005)

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Plate 3 - Muddy Water Flow from Stepped Channel of Slope No. 7SW-D/C2 (Photograph taken on 23 August 2005)

Plate 4 - Water Flow from Raking Drains of Slope No. 7SW-D/C2 (Photograph taken on 23 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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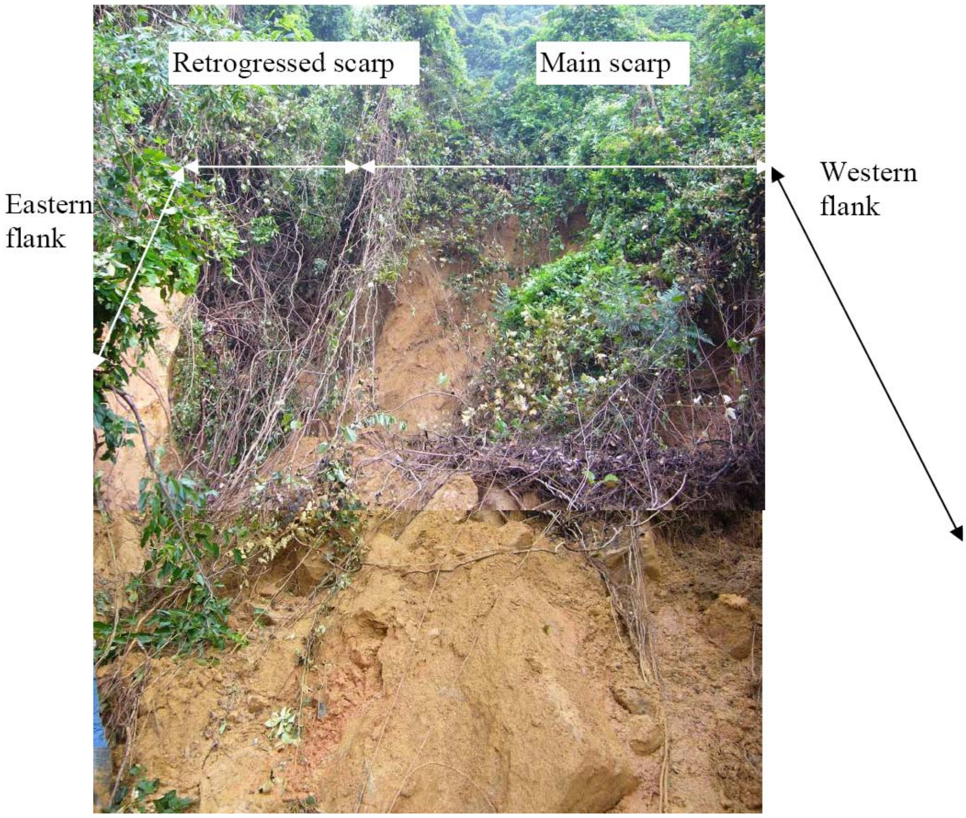

Plate 5 - General View of Source: Looking from Near Toe of Rupture to Main Scarp (Photograph taken on 24 August 2005)

Plate 6 - General View of Source: Looking from Toe of Rupture towards Retrogressed Scarp (Photograph taken on 24 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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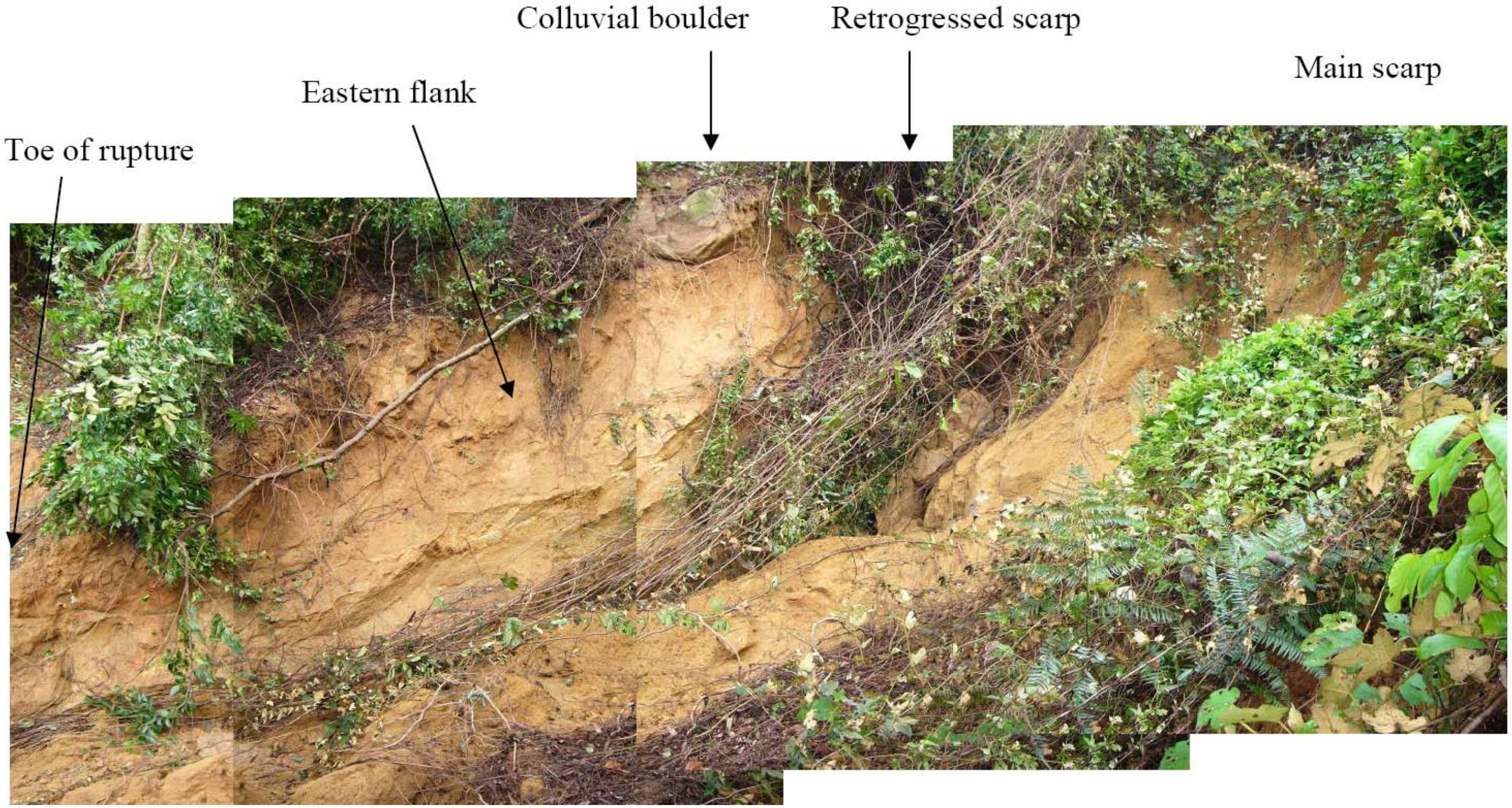

Plate 7 - General View of the Eastern Flank of the Landslide (Photograph taken on 24 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 8 - Scarp of Retrogressed Source from Undisturbed Ground Surface Looking Downslope (Photograph taken on 24 August 2005)

Plate 9 - Main Scarp of Retrogressive Area Showing In-situ Material with Distinct Block Displacement and Joint Opening (Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 10 - Close-up View of Main Scarp of Retrogressive Area Showing Distinct Block Displacement and Joint Opening (Photograph taken on 29 August 2005)

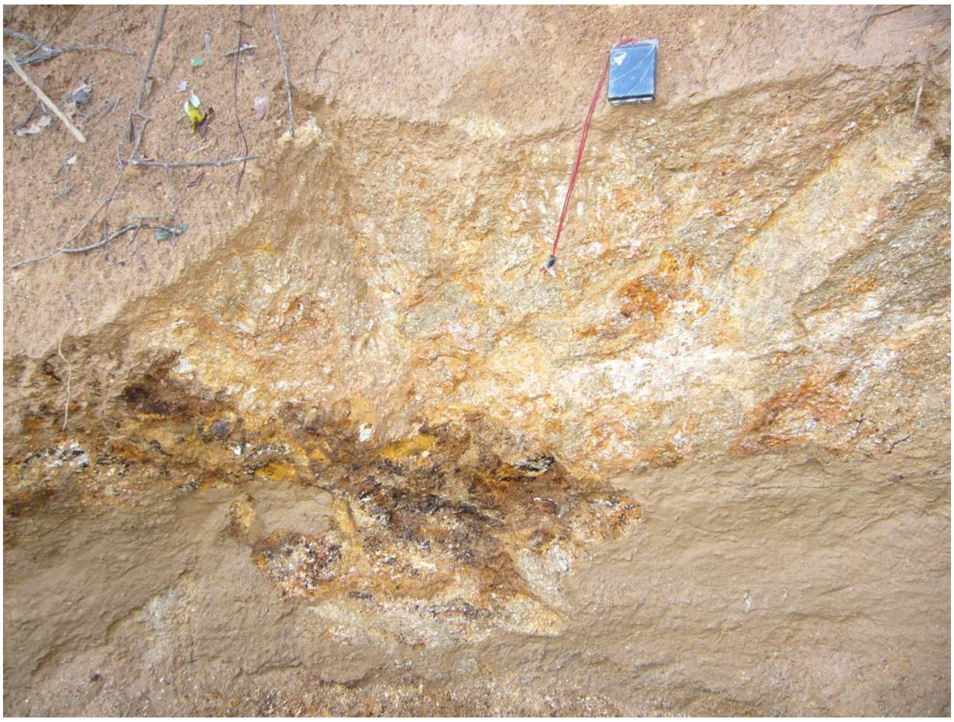

Plate 11 - General View of East Flank: Water Eroded Ditch below the Base of Photograph, Toe of Rupture to Left (Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 12 - Kaolinisation of Grade V Granite in the Eastern Flank
(Photograph taken on 29 August 2005)

Plate 13 - Close-up View of Pocket of Kaolin Seam in Eastern Flank
(Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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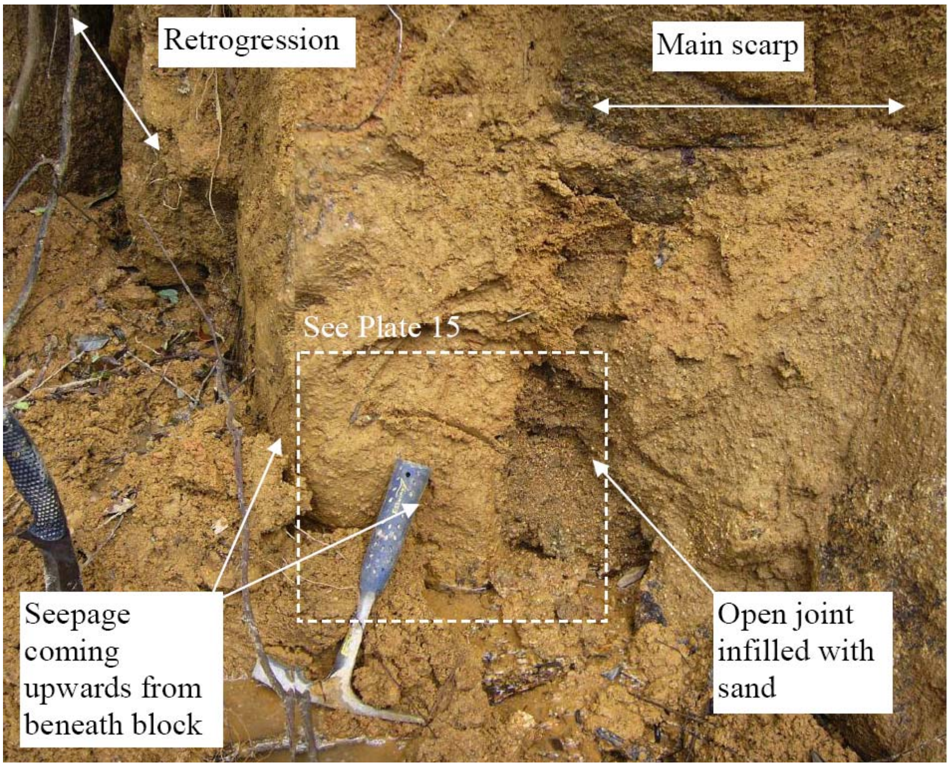

Plate 14 - Active Seepage from Centre of Main Scarp
(Photograph taken on 29 August 2005)

Plate 15 - Close-up View of Seepage at Centre of Main Scarp
(Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 16 - Active Seepage from Sandy Joint Infill of Main Scarp (Photograph taken on 29 August 2005)

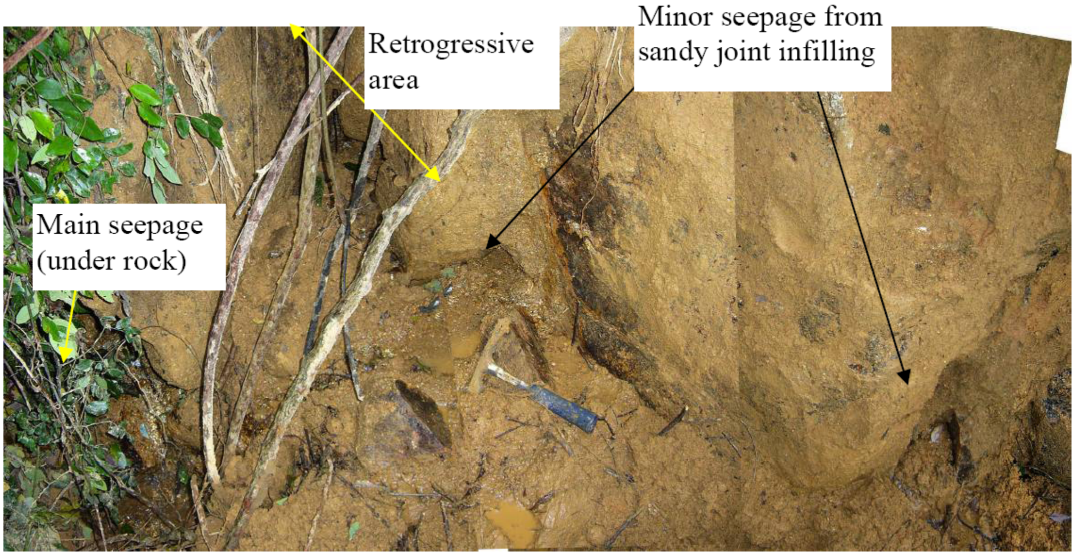

Plate 17 - Active Seepage from Centre of Main Scarp and from Retrogressive Area (Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 18 - Exposure of Colluvium in Western Flank
(Photograph taken on 24 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 19 - Debris Trail: Looking Downslope from Toe of Rupture
(Photograph taken on 29 August 2005)

Plate 20 - Debris Trail: Looking Downslope to Rock Step
(Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 21 - Debris Trail: Looking Upslope to Rock Step
(Photograph taken on 29 August 2005)

Plate 22 - Displaced Boulders on Northeast Flank of Debris Trail
(Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 23 - Debris Trail: Looking Upslope to Terrace Wall
(Photograph taken on 29 August 2005)

Plate 24 - Sandy Debris on Terrace Surface (Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 25 - Debris Trail: Looking Downslope to Slope No. 7SW-D/C2 and Lion Rock Tunnel Road (Photograph taken on 29 August 2005)

Plate 26 - Debris Trail: Looking Upslope from Slope No. 7SW-D/C2 (Photograph taken on 29 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 27 - View of Hillside area behind the Landslide Scar
(Photograph taken on 23 August 2005)

Plate 28 - Exposure Upslope (Southwest) of Landslide Source, Showing Decomposed Granite, Kaolinisation and Slickensides (Photograph taken on 25 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 29 - Exposure of Moderately Decomposed Granite Rock Upslope (Southwest) of Landslide Source (Located west of the exposure in Plate 28, Photograph taken on 25 August 2005)

Plate 30 - Active Water Discharge in Stream Upslope (Southeast) of Landslide Scar (Photograph taken on 23 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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Plate 31 - Active Water Discharge in Stream Upslope (Southeast) of Landslide Scar
(Photograph taken on 23 August 2005)

Note: See Figure 11 for the location and direction of photographs.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

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A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1963 and 2004. A list of the aerial photographs studied is presented in Table A1 and a location plan (Figure A1) is also attached.

YEAR	OBSERVATIONS
1963	The study area is located on the northwest-facing natural hillside in a shallow depression (defined by a rounded convex break-in-slope) between two rounded spurs trending northwest and north-northwest. The upper catchment is delineated by a well-defined northeast-trending ridge with an unpaved track. The natural hillside is generally covered with thin vegetation comprising grass, bushes and scattered trees (Plate A1). Four relict landslides are visible within the depression between two spurs. All of them are located near the crest of the study catchment. They can be seen as shallow depressions and are covered with thin vegetation. Accumulation of colluvium is observed at the footslopes area. A shallow topographical depression can be seen northeast of the study area, possibly related to landslide activities, although no debris was noted at the toe area and the depression. An area of cultivation terraces with isolated squatter structures can be seen on the lower footslopes of the study area (at the approximate location of the present-day location of Kak Tin Village Nam Kau, downhill of Lion Rock Tunnel Road). Lion Rock Tunnel Road has not been formed yet. Squatter structures and cultivation terraces can be seen on the southeast-facing hillside to the south of the ridgeline and the catchment is generally drained to the northeast by a major drainage line. A section of the drainage line appears to have been modified into a man-made drainage channel. The catchwater has been constructed in its present-day alignment.
1973	The photographs only covered the lower portion of the study area. Lion Rock Tunnel Road has been constructed and is in its present-day alignment. Slopes Nos. 7SW-D/C2 and 7SW-D/C3 have been formed by cutting into the natural hillside and appear to be sparsely vegetated with some local areas covered with masonry walls. The area of cultivation terraces in Kak Tin Village Nam Kau has been further extended.

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YEAR	OBSERVATIONS
1974	The density of vegetation on the natural hillside has increased. An area along the ridge above the study catchment is cleared of vegetation, probably associated with anthropogenic activities. A disturbed area can be seen adjacent to a section of the drainage line, probably associated with cultivation activities.
1977	This single photograph shows that a paved access road has been constructed that transverses the hillside leading from Lion Rock Tunnel Road to the ridge area. An area of disturbance is evident along the ridge area. A rectangular feature is noted within the disturbance area which appears to be a water-retaining structure. The disturbed area is probably used for cultivation purposes.
1978	No observable changes, except there is a slightly increase in vegetation cover on the disturbed area observed in the 1977 photograph. Lion Rock Tunnel Road has been widened into a two-lane dual carriageway.
1982	No significant changes, except that the vegetation density of the study area continues to increase.
1983	No observable changes.
1985	A reflective appearance can be seen at the lower terrain of the study area; it seems to be associated with cultivation activities. The road previously identified in 1977 appears to be no longer in use.
1986	No observable changes.
1987	There is evidence showing that an increase in cultivation terraces near the lower terrain of the study area.
1988	No observable changes.
1989	This single photograph shows no observable changes.
1990	The cultivation terraces along the lower terrain of the study area appear to be abandoned.
1991	No observable changes.
1993	This single photograph shows no observable changes.

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YEAR	OBSERVATIONS
1994	Slope No. 7SW-D/C2 and the lower batter of slope No. 7SW-D/C3 have been shotcreted recently as inferred from areas of high reflectivity. The remaining batters of slope No. 7SW-D/C3 are sparsely vegetated.
1996	No observable changes.
1998	Slope No. 7SW-D/C3 is now densely vegetated, except the lower batter.
1999	No observable changes.
2000	This single photograph shows no observable changes.
2001	A fence has been erected along the toe of slope No. 7SW-D/C2. Possibly slope upgrading works were in progress.
2003	No observable changes.
2004	No observable changes.

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Table A1 - List of Aerial Photographs Reviewed

Date Taken	Altitude (ft)	Photograph Number
26 January 1963	3900	Y08742-43
23 June 1973	1600	4397-98
28 February 1974	3000	8325-26
12 December 1977	4000	20044-45
7 November 1978	4000	23075
28 July 1982	4000	43256
13 December 1983	5000	51960-61
3 October 1985	4000	A02442-43
28 April 1986	4000	A04874-75
10 December 1987	4000	A11104-05
5 June 1988	4000	A13976-77
17 January 1989	4000	A16206
18 October 1990	4000	A23458-59
19 September 1991	4000	A27154-55
30 May 1993	4000	A34709
26 May 1994	3500	A38611-12
26 April 1996	4000	CN13311-12
30 October 1998	4000	A48700-01
3 September 1999	5500	A49926-27
10 August 2000	3000	CN27826
15 May 2001	3000	AW51924-25
31 May 2003	4000	CW47504-05
4 March 2004	4000	CW55579-80

Note: Aerial photographs are in black and white except for those prefixed with CN or CW.

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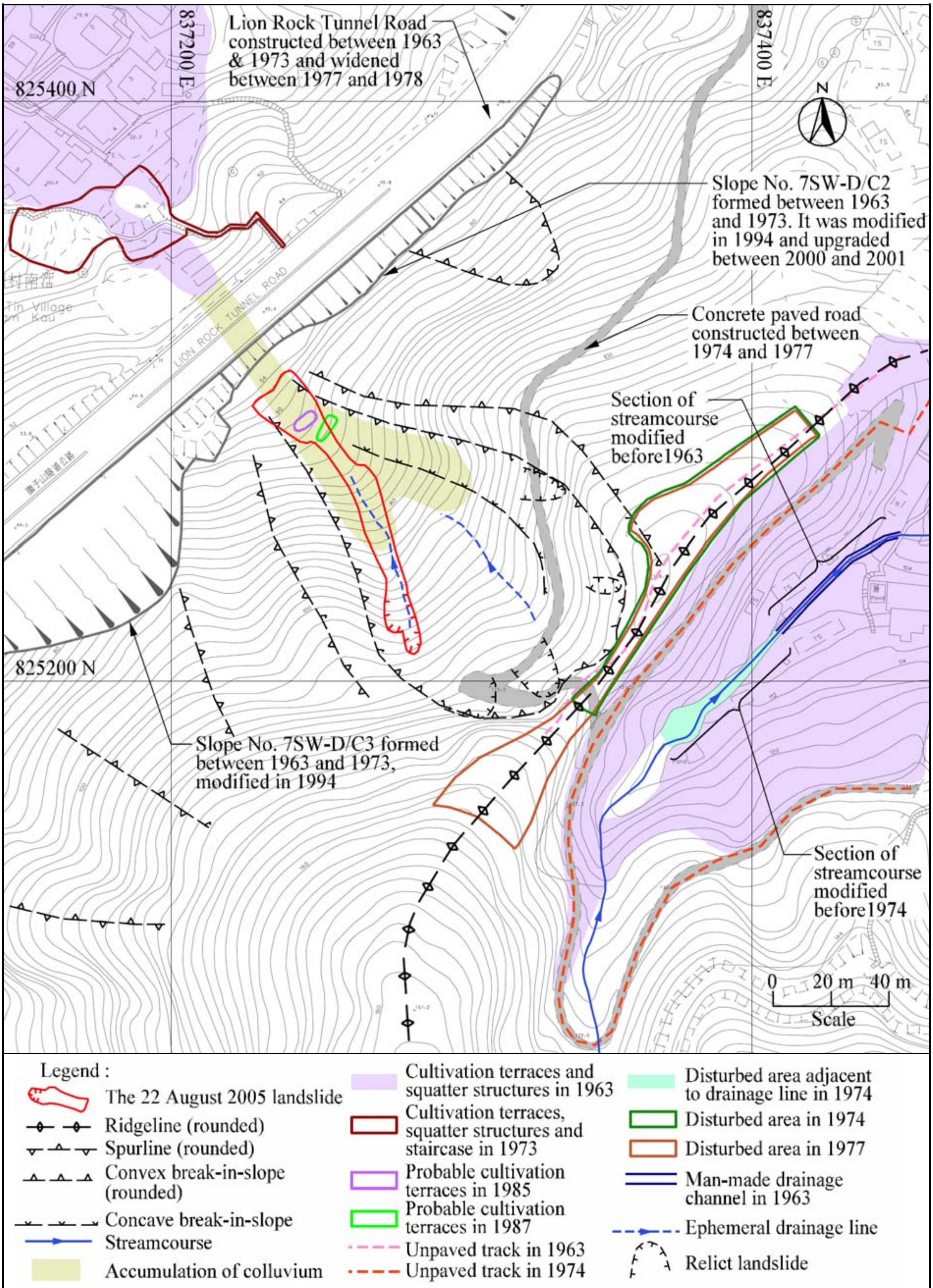

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7SW-20D and 7SW-25B dated March 2004.

Figure A1 - Aerial Photograph Interpretation

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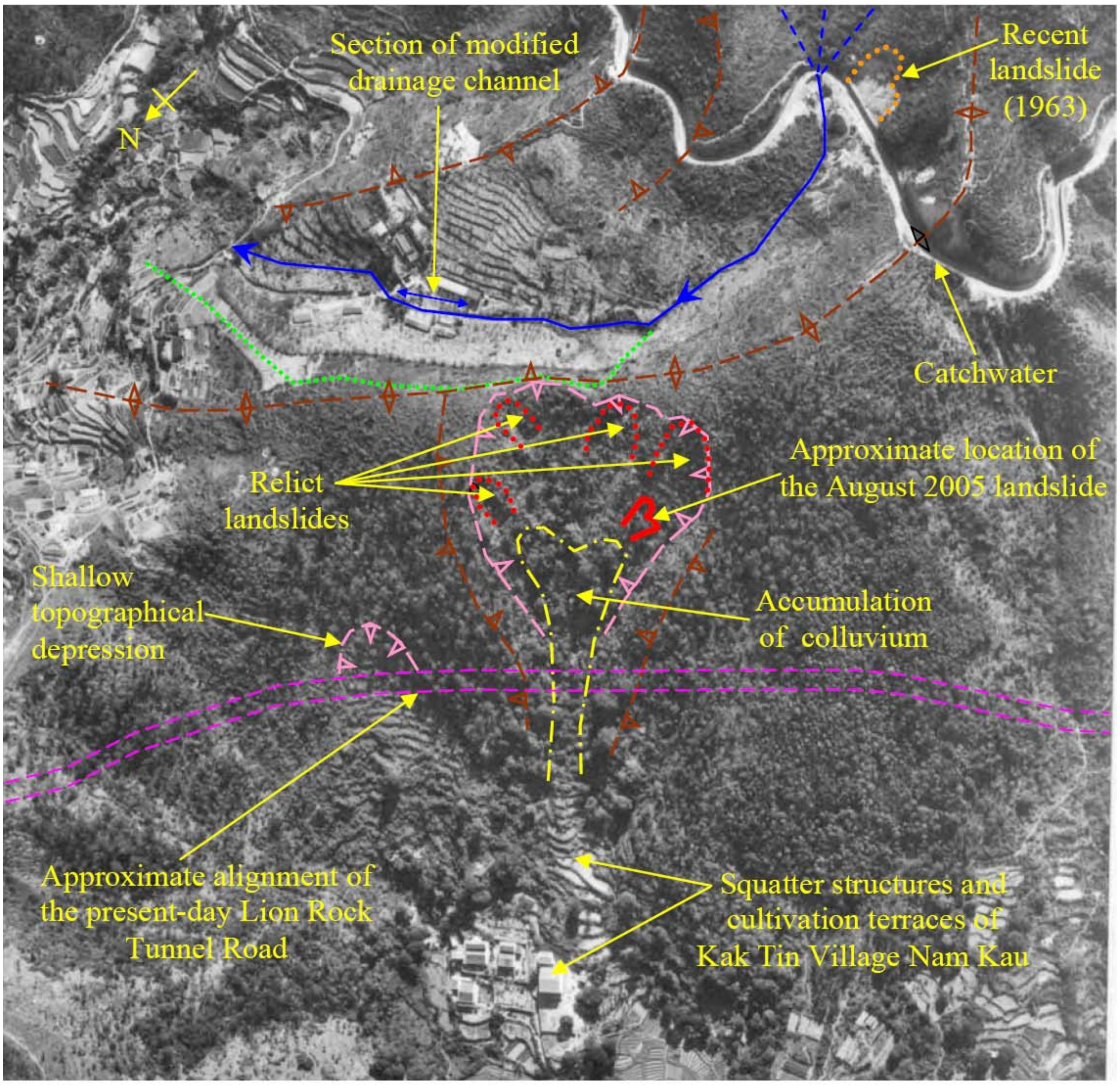

(Photograph Y08743 taken on 26 January 1963)

Legend:

	Rounded ridgeline		Relict landslide scar
	Rounded spurline		Recent landslide scar (year first observed)
	Streamcourse		Convex break in slope
	Ephemeral drainage line		Access track

Plate A1 - Interpretation of 1963 Aerial Photograph

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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), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

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

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 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.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents