REVIEW OF THE 22 AUGUST 2005 LANDSLIDE ON THE NATURAL HILLSIDE ABOVE BEACON HEIGHTS, LUNG PING ROAD, KOWLOON

GEO REPORT No. 235

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 13/2007 produced in December 2007

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Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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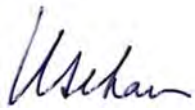
PREFACE

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
Head, Geotechnical Engineering Office
November 2008

FOREWORD

This report presents the findings of a review of a landslide (Incident No. 2005/10/0554) that occurred on the natural hillside above Beacon Heights, Lung Ping Road, Kowloon. The landslide was reported in the evening of 22 August 2005 following the heavy rainfall on 19 and 20 August 2005.

The landslide involved a failure volume of about 200 m^3. Much of the debris was deposited at the toe of the landslide source with a small proportion of the debris travelling into the boulder-filled drainage line below. No casualties were reported 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 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.

L.J Endicott

Dr. L.J. Endicott
Project Director
Maunsell Geotechnical Services Limited

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

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1. INTRODUCTION

On the evening of 22 August 2005, following heavy rainfall on 19 and 20 August 2005, a landslide (Incident No. 2005/10/0554) was reported to have occurred on a natural hillside above Beacon Heights, Lung Ping Road, Kowloon (Figure 1 and Plate 1). The landslide involved a failure volume of about 200 m^3 with much of the debris deposited at the toe of the landslide source and about 30 m^3 of the debris reaching the boulder-filled drainage line below and travelling along it for a distance of about 30 m. No casualties were reported as a result of the landslide.

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, relevant background information, results of a limited ground investigation and observations from the detailed geological mapping of the landslide source area and surrounding terrain. The scope of the review does not include a 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 the eastern flank of a steep-sided (about 65° to 70°) topographical depression, about 250 m north of Beacon Heights, a residential development, and approximately 40 m south of slope No. 11NW-B/C519 on Lung Yan Road (Figure 2). The topographical depression is defined by a prominent and sharp convex break-in-slope (Figure 2, Plates 2 and 3), with a size of about 25 m wide by 30 m long. The depression is situated at the head of a boulder-filled (with boulders up to 8 m across), incised drainage line on a south-facing hillside of Beacon Hill (Plate 2), which is flanked by relatively sharp southwest and southeast trending spurs (Figure 2 and Plate 4). The drainage line is densely-vegetated with shrubs and many mature trees. The landslide source area is located at an elevation of approximately 230 mPD, immediately below the convex break-in-slope (Figure 3).

An east-west trending rock trap (see Section 4) crosses the drainage line approximately 120 m downhill and south of the head of the drainage line. Beacon Heights is located a further 100 m downhill and on the eastern side of the drainage line (Figure 2). The drainage line runs down the hillside at about 20 °to 25° and enters a culvert near Lung Ping Road at an elevation of about 100 mPD. The residential blocks of the Beacon Heights are located on both the northern side and southern side of Lung Ping Road (Figures 1 and 2).

The hillside above the August 2005 landslide is inclined at about 30° to 35°. The hillside is generally covered with dense vegetation and there are clusters of boulders on the hillside above the August 2005 landslide. Lung Yan Road traverses the hillside further upslope at about 40 m to the north where there are cut slopes on either side of the road (Figure 2).

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.

2.3 Land Status

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

2.4 Regional Geology

According to the published geological information (GCO, 1986; Sewell *et al.*, 2000; Strange & Shaw, 1986), the landslide site is underlain by medium-grained Kowloon granite of the Lion Rock Suite. The Kowloon granite intrudes the coarse-grained Shatin granite of the Kwai Chung Suite, with the boundary running east-west across the southern slopes of Beacon Hill, about 100 m north of the August 2005 landslide site (Figure 4). Quaternary debris flow deposits are indicated along the drainage line below the landslide site. A generally north-south trending photolineament is indicated along the drainage line. A fault with a similar trend is located about 100 m to the east (Figure 4).

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. I - Hong Kong and Kowloon (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.

The Generalised Limitations and Engineering Appraisal Map indicates that the hillside with the August 2005 landslide comprises a zone of constraints for development. The Geotechnical Land Use Map (GLUM) designates the terrain as GLUM Class IV (i.e. with extreme geotechnical limitations) and the Physical Constraints Map indicates zones of general instability associated with predominantly colluvial and *in situ* terrain for the terrain affected by the August 2005 landslide.

3. SITE HISTORY AND PAST INSTABILITY

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 presented in Appendix A and the major development history of the site is summarised below.

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3.1 Site History

In the earliest aerial photographs reviewed, which were taken in 1924, the August 2005 landslide site was a sparsely-vegetated, south-facing hillside, with a well-defined topographical depression delineated by a relatively sharp convex break-in-slope at the crest (Figure 5).

The earliest signs of anthropogenic activities on the hillside in the vicinity of the August 2005 landslide were footpaths crossing the hillside in 1924. Quarrying activities were evident in 1954 on the western spur about 50 m southwest of the August 2005 landslide site, and quarrying continued until the early 1970s. Lung Yan Road and the associated roadside slopes were formed between 1967 and 1973. The platforms for the Beacon Heights development were formed between 1973 and 1977. The rock trap ditch to the south was constructed in late 1981. Within the same period a surface drainage channel, which diverted surface water flow from an adjacent streamcourse towards the drainage line below the August 2005 landslide site, was constructed on the hillside to the southeast. Beacon Heights were developed between 1981 and 1987. The Dynasty Heights complex, which is situated approximately 90 m downhill and southwest of the landslide site, was developed between 1995 and 1998 (Figure 5).

The August 2005 landslide is clearly visible in the October 2005 aerial photographs (Plate 2) and can be seen to comprise two scars separated by a narrow strip (about 1 m to 2 m wide) of vegetation. Landslide repair works, comprising the construction of a reinforced shotcrete cover on the landslide scar, were carried out by Highways Department in May 2006.

3.2 Past Instabilities

3.2.1 Natural Terrain Landslide Inventory, Enhanced Natural Terrain Landslide Inventory 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 and King, 1999). According to the NTLI records, two landslides (with tag Nos. 11NWB0060 and 011NWB2005), which occurred in 1989 and 1997 respectively, are indicated on the hillside between 20 m and 30 m to the west of 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). According to the ENTLI records, there are no recent or relict landslides in the immediate vicinity of the August 2005 landslide. The two NTLI features were recommended for deletion under ENTLI, as both were considered to be erosional features on the steep flanks of the topographical depression at the head of a drainage line and were associated with a relict gully system.

The August 2005 landslide is not located within a Historical Landslide Catchment (HLC; i.e. a catchment with an ENTLI record that is close to buildings and important transport corridors) as identified under the ENTLI project. Since there is no sensitive structure in the close vicinity of the crest of the landslide or near the toe of the debris trail, the catchment does not meet the criteria for inclusion in the HLC Inventory after the August 2005 landslide.

According to GEO's large landslide database (Scott Wilson, 1999), there is no record of a large landslide in the immediate vicinity of the August 2005 landslide.

3.2.2 Aerial Photograph Interpretation

Based on the earliest aerial photographs reviewed which were taken in 1924, the August 2005 landslide site is within an area of surface erosion on sparsely vegetated, south-facing hillside. The erosion gullies, which trend approximately north-northwest to south-southeast, are visible on the relatively sharp southwest and southeast trending spurs on the eastern and western flanks of the topographical depression (Figure 5).

An area of bare soil on the western side of the topographical depression was exposed in 1975 (Figure A2) revealing a sub-vertical cliff-like feature, with a set of sub-vertical joints which appeared to strike generally northwest to southeast. The exposed area of soil remained visible for several years and may have occurred as a result of a landslide.

In 1989, a landslide was observed on the western side of the crown of the topographical depression, which remained visible in subsequent photographs and may have been the site of possible further minor erosion in 1992 (Figure A1). Although the 1989 landslide is attributed to erosion under the ENTLI, site inspection carried out as part of this study indicates that the feature was probably a landslide scar.

3.2.3 GEO's Landslide Database

According to the GEO's landslide database, there are no records of past instability on the natural hillside or in the immediate vicinity of the study area. Two landslide incidents (Nos. 2005/08/0449 and ArchSD/WST&ST/2005/08/002, see Figure 6), both of which occurred during the August 2005 rainstorm on cut slopes directly above Lung Yan Road, are located about 80 m and 180 m north of the August 2005 landslide.

4. PREVIOUS ASSESSMENTS AND SLOPE WORKS

In accordance with the Conditions of Sale of the site for the Beacon Heights residential development, an assessment of the surface boulders on the natural hillsides above the site was carried out by Freeman Fox & Partner (Far East) in 1982 (Grigg & Wong, 1987). The assessment, which was submitted to the Building Development Department (BDD, renamed Buildings Department in 1993) for comments in January 1982, included an appraisal of the geomorphology of the hillsides, the likely mode of surface boulder development and the possible mode of boulder movement as well as a mitigation scheme. It did not include an assessment of the natural terrain hazards such as identification of landslides and projection of landslide debris runout or boulder falls. The boulders were subsequently surveyed in detail and a mitigation scheme was developed and implemented. The mitigation scheme involved trimming the hillside above the existing cut slope (Figure 5), clearing all boulders within 10 m from the crest of the trimmed slope, construction of a 2 m wide by 1.5 m deep rock trap ditch across the hillsides about 40 m from the crest of the trimmed slope behind Beacon Heights (Figure 5), and provision of rock trap basins at several locations along the streamcourses.

All the potentially unstable boulders on the hillsides below the rock trap ditch were stabilised. The rock trap ditch was considered to be effective in stopping boulders of less than 3 m in diameter only. Boulders over 3 m in diameter on the hillsides above the rock trap ditch were inspected and individually assessed, with mitigation measures carried out for those boulders that were deemed to be potentially unstable. The range of measures adopted included break-up and removal of boulders, buttressing, dowelling, etc.

The boulder assessment report and mitigation proposal were approved by BDD on 16 April 1982. The mitigation works were carried out between May and November 1982. The records of boulder stabilisation works were submitted to BDD in March 1983 and were accepted by the GCO in May 1983.

5. THE AUGUST 2005 LANDSLIDE AND POST-FAILURE OBSERVATIONS

5.1 General

According to GEO's records, the incident was first reported by a resident of the Beacon Heights development on 22 August 2005 at about 9 p.m. The landslide may have occurred earlier, soon after the heavy rainstorm on 19 and 20 August 2005. The landslide debris came to rest about 30 m down the drainage line below. No facilities were affected and no casualties were reported as a result of the landslide.

MGSL carried out an initial inspection of the landslide site on 19 October 2005. Since the landslide occurred on a steep natural hillside and no safe access was available, inspection was made only from the toe of the hillside, adjacent to Beacon Heights (Plate 1). The second inspection was conducted on 25 May 2006, when the landslide repair works were in progress at the landslide scar by Highways Department (Plate 3). Although access to the landslide scar was made possible by the scaffolding erected as part of the landslide repair works, close inspection of the surface of rupture was not possible due to the on-going works. Vegetation clearance was undertaken and access to the toe of the landslide debris was provided in April 2007, following which the toe area and the drainage line below the landslide were inspected.

5.2 Observations at the Landslide and the Surrounding Hillsides

During the course of the site inspection carried out on 25 May 2006, two landslide source areas separated by a narrow strip of vegetation, were identified within a steep-sided topographical depression at the head of the drainage line (Plate 3). The larger landslide source area was approximately 15 m high by 20 m wide and about 0.5 m deep. The smaller landslide source area was about one-third of the size of the main source. The total estimated volume of failure from both sources was about 200 m^3.

The landslide affected the southwest-facing side of the steep-sided topographical depression, with the surface of rupture extending from the base of the depression retrogressively cutting through the sharp convex break-in-slope at the crest of the depression and at the head of the drainage line. The surface of rupture appeared to be entirely within highly decomposed granite and was planar, possibly a joint surface, suggesting a structure-controlled failure. The rupture surface was inclined at between about 65° and 70°,

and was sub-parallel to the steep sides of the topographical depression which may also have developed from previous landsliding. There were no signs of seepage from the landslide scar at the time of the inspection in May 2006. A cross section through the landslide and along the drainage line is presented in Figure 3.

Much of the debris, that varied from a very sandy silt to a silty/clayey medium to coarse sand, was deposited at the toe of the surface of rupture and there was little evidence that much of the landslide debris had travelled into the drainage line below (Plate 4). The accumulated debris occupied an area about 15 m wide by 20 m long, which had been covered by shotcrete during the repair works carried out in 2006 (Figure 3 and Plate 5).

The inspection also included the uphill area above the landslide scar and no signs of distress (e.g. tension cracks) were observed. There were no obvious open joints or joint offsets within the exposed highly decomposed granite, and there appeared to be only little completely decomposed granite in the immediate vicinity of the landslide.

A minor ephemeral drainage line was observed to run from north to south on the hillside above the crest of the landslide (Figures 2 and 5; Plate 6).

On the western side of the topographical depression, a highly decomposed granite surface was exposed at the location of the landslide identified in the 1989 aerial photographs. The exposed surface is sub-vertical and defined by a joint plane with an orientation of 62°/235° (Plate 7).

Large (up to 3 m diameter) rounded to sub-rounded boulders were observed on the adjacent spur to the east of the topographical depression (Plate 8) and along which the temporary inspection access has been formed. Substantial clusters of sizeable boulders (some up to 8 m in diameter) were observed within the drainage line below the August 2005 landslide (Plate 9). An accumulation of possible debris from a previous minor failure was observed within the drainage line further downstream of the debris from the August 2005 landslide (Plate 10).

Two minor old failure scars (generally with a failure volume less than 30 m^3) within highly decomposed medium-grained granite were identified on the downhill side and to the southeast of the August 2005 landslide (Figure 2). Subvertical steeply dipping and southwest-facing joint surfaces, with the orientations of 82°/298° and 73°/220°, were identified at the back scarps of the older landslide scars (Plate 11).

To the north and uphill of the August 2005 landslide, exposures of an equi-granular pale pink granite (Kowloon Granite) were identified at cut slopes Nos. 11NW-B/C519 and 11NW-B/C520 (Plate 12 and Figure 2), located approximately 30 m to 40 m uphill of the August 2005 landslide respectively and alongside Lung Yan Road. Two joint sets with orientations of 20°/240° and 62°/157° were identified at the rock exposure of slope No. 11NW-B/C519. Further northwest, an exposure of completely decomposed coarse-grained granite (Shatin Granite) was identified at slope No. 11NW-B/C521 (Figure 2 and Plate 13). These observations correlate closely with the geological boundary indicated on the 1:20 000 scale Geological Map Sheet 11 (GCO, 1986).

6. GEOLOGY AND GEOMORPHOLOGY

The geology of the site was established from desk study and through field mapping. The desk study comprised a review of all the available data and published geological information (GCO, 1986; Sewell *et al.*, 2000; Strange & Shaw, 1986). Examination of field samples indicated that the rocks in the study area are consistent with the published geology (see Sections 2.2 and Section 4).

6.1 Previous Ground Investigation

The nearest available ground investigation (GI) was carried out at slope No. 11NW-B/FR254, located approximately 50 m northwest of the August 2005 landslide. The GI was undertaken by Enpack (HK) Limited for a project in 2001 under the Landslip Preventive Measures (LPM) Programme. The GI included three drillholes (Nos. DH26/1 to DH26/3) and 17 trial pits (Nos. TP26/1 to TP26/3, TP26/5 to TP26/18, which were terminated at depths of between 3 m and 3.5 m in fill material). The locations of the drillholes are shown on Figure 7. A layer of fill (about 5 m to 7 m thick) was underlain by completely to highly decomposed medium-grained granite (more than 15 m thick), with occasional corestones. The drillholes were terminated at a pre-defined depth of up to 20 m and none of them reached bedrock.

6.2 Recent Ground Investigation

A total of 12 GCO Probe tests (Nos. P1 to P12, see Figure 7) was carried out under this study to determine the thickness of debris that had been accumulated at the toe of the landslide scar from earlier landslides. The GCO probes reached refusal (i.e. more than 100 blows per 100 mm of probing) at depths ranging from 1.7 m to a maximum of 4 m with an average of about 2.9 m. The blow count is as low as 4 at a depth of 3.4 m at Probe No. P4 (Figure 8).

6.3 Geology

The superficial deposits encountered at the site essentially comprise a very thin (less than 0.5 m) cover of colluvium (probably derived from slope wash processes) that typically consisted of firm sandy silt (Plate 14). Several boulders, mostly rounded but occasionally sub-angular, of moderately decomposed granite up to 5 m across were encountered on the hillsides. Several of the boulders exhibited exfoliation weathering. There were many granite boulders, some up to 8 m across within the drainage line below the August 2005 landslide.

The solid geology in the vicinity of the August 2005 landslide comprises completely to moderately decomposed medium-grained and coarse-grained granite. A possible layer of residual soil was also observed at the site (Plate 14). Based on the results from the previous GI and site inspection, the granite appears to be deeply weathered with pervasive iron oxide staining.

6.4 Geomorphology and Hydrogeology

The geomorphological setting of the August 2005 landslide site is a steep-sided topographical depression located at the head of a boulder-filled incised drainage line within south-facing rounded granitic terrain. The granite is deeply weathered with the presence of a photolineament along the drainage line and evidence from API of possible structural influence on the location and orientation of the drainage line (see Appendix A). This steep-sided, probably structure controlled, topographical depression was likely to have formed as a result of multiple small-scale landslides, similar to the August 2005 landslide, rather than a single large-scale landslide.

The deeply weathered granite and possible structural influence on the drainage line may direct subsurface groundwater flow towards the landslide site, which is situated at the head of the drainage line. The minor ephemeral drainage line above the crest of the landslide (Plate 6) could also concentrate surface runoff toward the failure scar. Without a detailed GI and groundwater monitoring of the site, the hydrogeological setting is conjectural only.

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. K06, which is located approximately 1 km to the west of the August 2005 landslide on the roof of Carnation House, So Uk Estate, Cheung Sha Wan (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. K06 from 21 July to 25 August 2005, together with the hourly rainfall readings for the period between 19 and 22 August 2005, is presented in Figure 9.

Amber Rainstorm Warnings were hoisted in the evening of 19 August 2005 and in the morning of 20 August 2005. Intense rainfall was recorded until the evening of 20 August 2005. According to the records from GEO, the landslide was reported at about 9 p.m. on 22 August 2005 (see Section 4). Given the remote location of the site and the inclement weather, the landslide may have occurred anytime between 19 and 22 August 2005 when it was first identified. Since the exact time of the landslide is not certain, it has been assumed that the landslide occurred before 9:00 p.m. on 22 August 2005. No rainfall was recorded between 11:00 p.m. on 21 August 2005 and 9:00 p.m. on 22 August 2005. The daily rainfall on 21 August 2005 was 39.5 mm. The maximum 12-hour and 24-hour rolling rainfalls before the incident were 295 mm and 506.5 mm respectively, which were recorded on 20 August 2005. The maximum 1-hour rolling rainfall was recorded as 28 mm between 2:40 p.m. and 3:40 p.m. on 20 August 2005 (Table 1).

An analysis of the return periods for various durations of rolling rainfall recorded at raingauge No. K06, with reference to the historical rainfall data at the HKO at Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994), shows that medium to long duration rainfall (48 hours or more) before the landslide was the most severe with corresponding return periods ranging from 82 years to 128 years (Table 1).

The August 2005 rainstorm was also assessed using local rainfall data to evaluate the spatial variability of rainfall. The return periods were assessed based on the statistical

parameters derived by Evans & Yu (2001) for rainfall data recorded by the local raingauge No. K06 between 1984 and 1997. The 24-hour and 48-hour rainfalls were assessed to be most critical with return periods of 87 years and 67 years respectively (Table 1), the latter being less than that estimated using the historical rainfall data at the HKO.

The maximum rolling rainfall for the August 2005 rainstorm has been compared with the past major rainstorms recorded by raingauge No. K06 between 1983 and 2004 (Figure 10). The 20 August 2005 rainstorm was the most severe for rainfall durations between 24 hours and 15 days.

8. DISCUSSION

The timing of the August 2005 landslide and the preceding heavy rainfall on 19 and 20 August 2005 suggest that the landslide was triggered by rainfall. The landslide was reported almost two days after the end of the intense rainstorm, but as the landslide was in a fairly remote location and did not affect any facilities, it could have occurred earlier than the reported time.

The August 2005 landslide occurred within a steep-sided, probably structure controlled, topographical depression previously affected by small-scale landslides. Surface runoff and subsurface groundwater flow could have been directed towards the landslide site, which is situated at the head of a drainage line. The failure probably involved the build-up of transient elevated cleft water pressure within the steeply dipping joints in the highly decomposed granite.

The landslide debris only travelled for a distance of about 30 m down the incised drainage line. The limited runout was probably due to the presence of large boulders along the drainage line. The thickness of debris deposited at the toe of the August 2005 landslide is difficult to ascertain with only the GCO probe results but it is estimated to have a minimum thickness of about 3.5 m. The cluster of large boulders at the toe of the debris and along the drainage line would probably restrain debris from further landslides at the head of the drainage line.

The overall orientation of the rupture surface, striking approximately north-northwest to south-southeast, was sub-parallel to the orientation of the erosion gullies on the hillside close to the August 2005 landslide site (Figure 5). The similarity in orientation supports the inference that the instability was structurally controlled.

The August 2005 landslide appears to be a retrogressive failure that is typical of the landslides within the vicinity of a topographical depression. The structurally controlled, retrogressive failure mechanism may continue as the hillside condition deteriorates progressively with time. However, no signs of incipient large-scale instability could be observed in the vicinity of the August 2005 landslide at the time of inspection.

The mitigation measures undertaken previously on the hillside were to combat boulder fall hazards, as stipulated in the conditions of the land-sale site. It would appear that no detailed assessment of natural terrain landslides was carried out. It is noted that the catchment did not satisfy the criteria of a Historical Landslide Catchment even subsequent to the August 2005 landslide.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. K06 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 K06 from Evans & Yu (2001)
5 Minutes	7.0	4:40 a.m. on 20 August 2005	< 2	< 2
15 Minutes	18.0	11:15 a.m. on 20 August 2005	< 2	< 2
1 Hour	28.0	3:40 p.m. on 20 August 2005	< 2	< 2
2 Hours	51.0	3:50 p.m. on 20 August 2005	< 2	< 2
4 Hours	117.0	1:10 p.m. on 20 August 2005	2	< 2
12 Hours	295.0	3:35 p.m. on 20 August 2005	11	8
24 Hours	506.5	6:30 p.m. on 20 August 2005	50	87
48 Hours	686.0	9:45 p.m. on 20 August 2005	128	67
4 Days	782.5	6:35 a.m. on 20 August 2005	95	24
7 Days	855.0	10:35 p.m. on 20 August 2005	96	32
10 Days	946.0	10:35 p.m. on 20 August 2005	107	26
12 Days	1012.5	8:45 p.m. on 20 August 2005	120	24
15 Days	1038.0	10:35 p.m. on 20 August 2005	82	16
31 Days	1300.0	8:45 p.m. on 20 August 2005	93	8

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(3) Return periods were also derived from the statistical parameters of raingauge No. K06 extracted from Appendix B of Evans & Yu (2001) with interpolation of rainfall parameters for 10 days and 12 days to assess the spatial variability of rainfall.
(4) According to the record from GEO, the landslide was first reported at about 9:00 p.m. on 22 August 2005.
(5) The nearest GEO raingauge to the landslide site is raingauge No. K06, which is situated about 1 km to the west of the landslide site.

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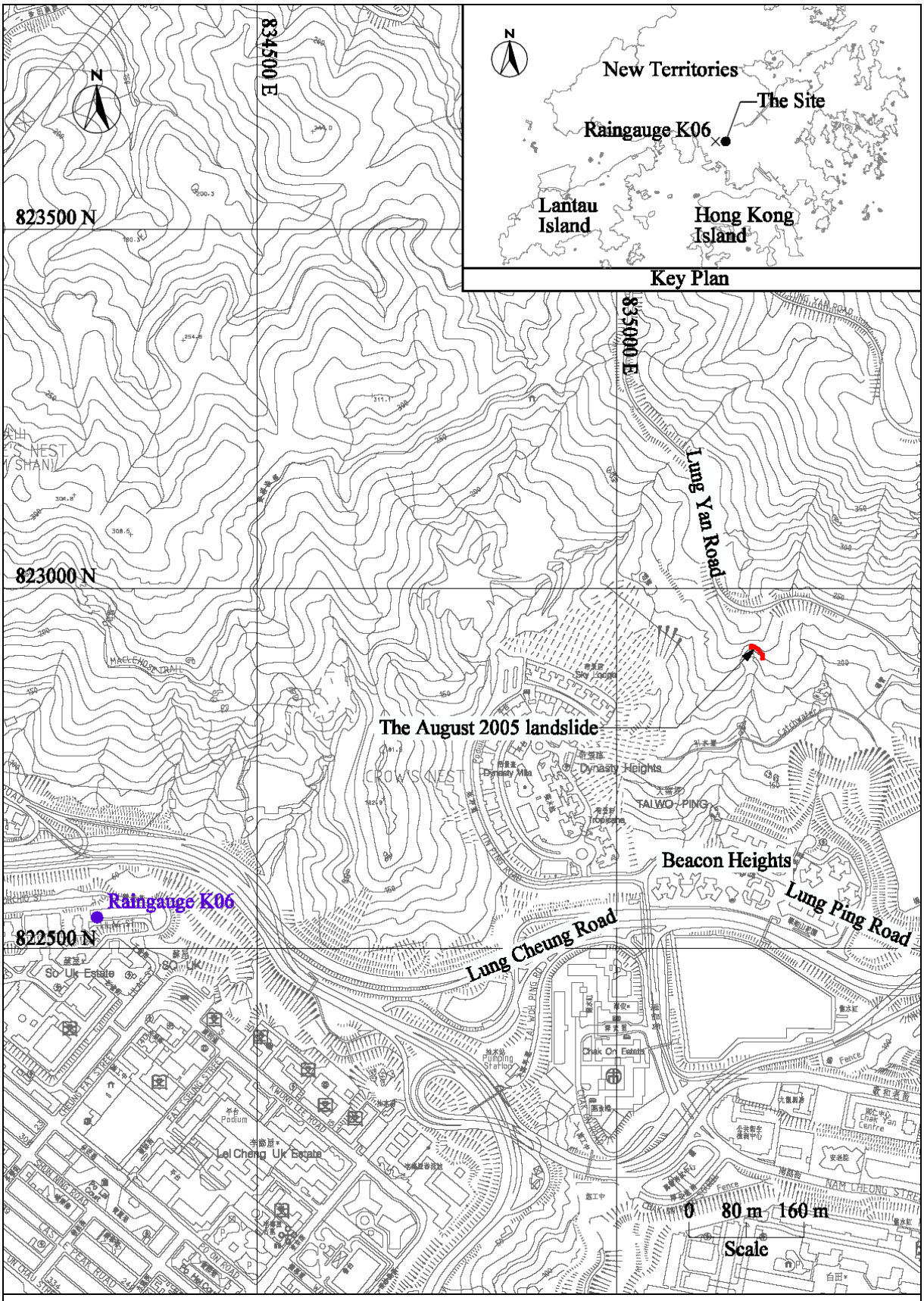

Note: Base plan is extracted from 1:5000 survey sheet No. 11NW-B dated March 2004.

Figure 1 - Location Plan

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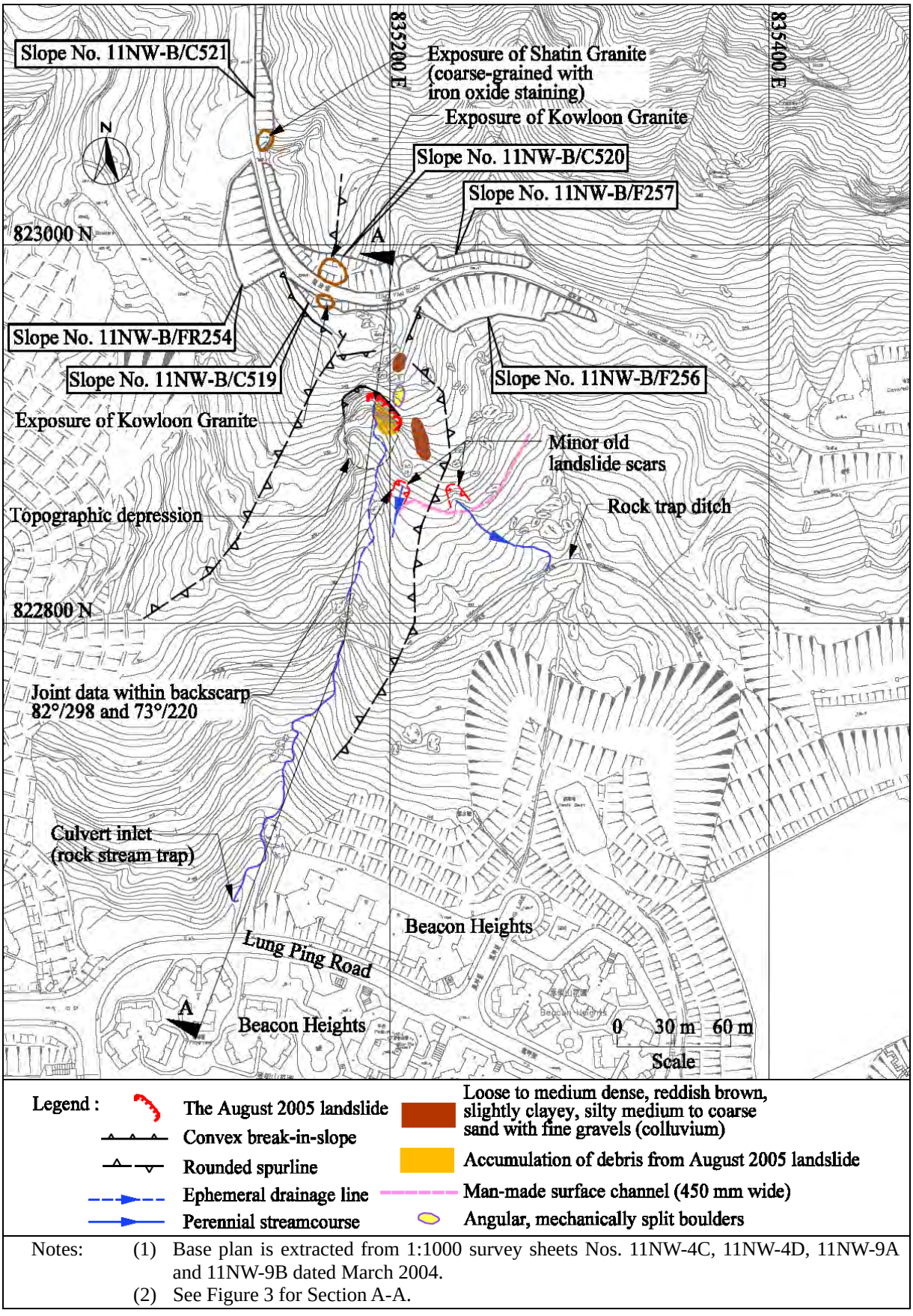

Notes: (1) Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.
(2) See Figure 3 for Section A-A.

Figure 2 - Site Layout Plan and Field Observations

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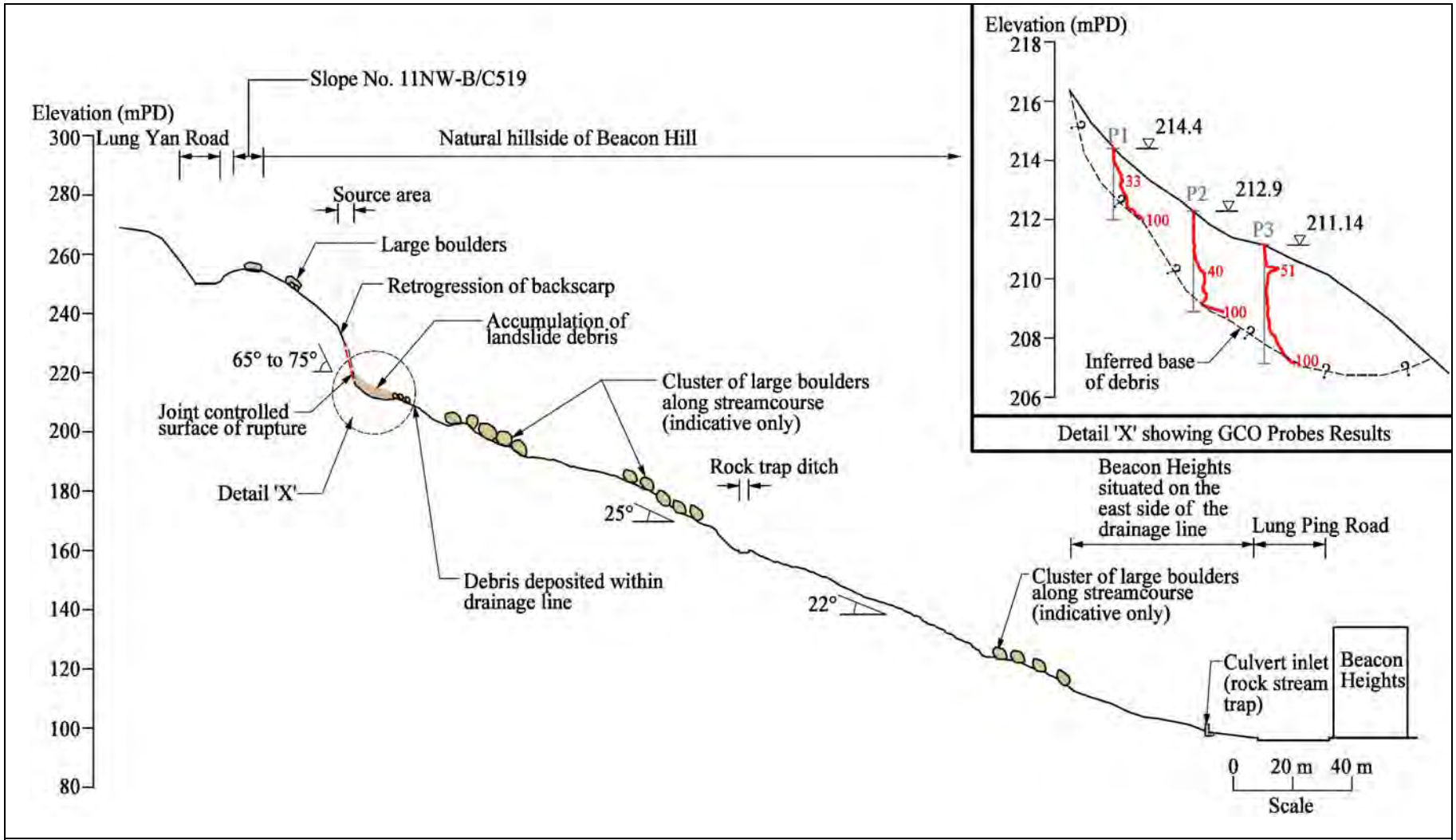

Legend:	100 GCO probe blow count per 100 mm penetration
Note:	See Figure 2 for the location of the section line.

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

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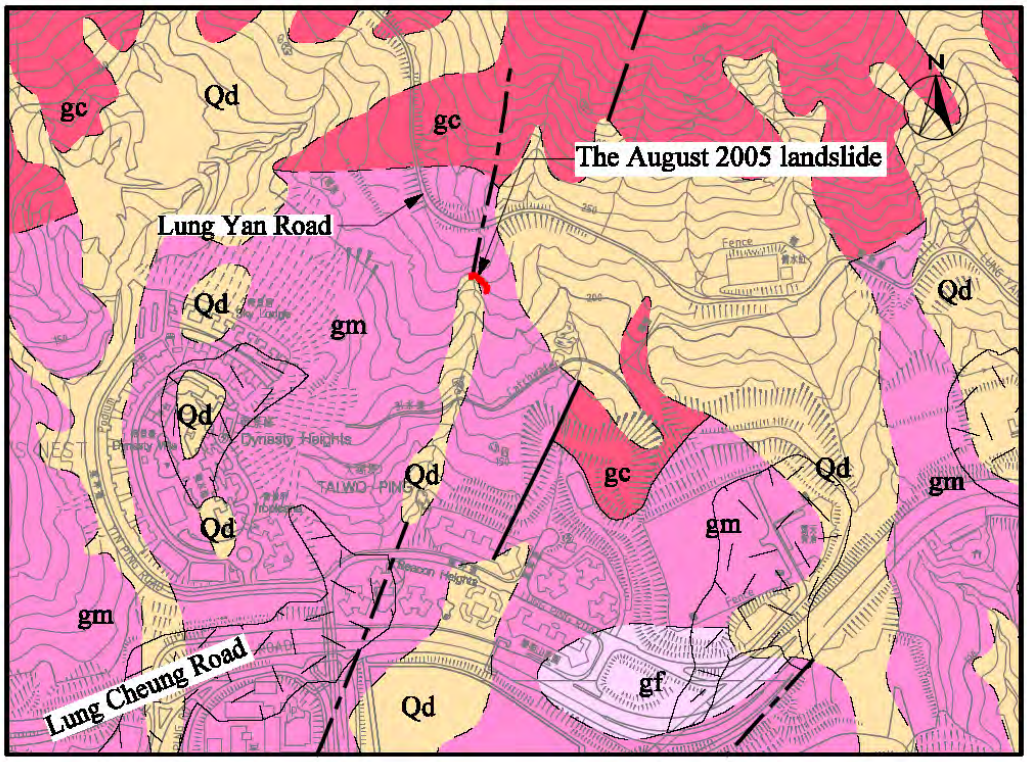


Legends:

0 80 m 160 m
Scale

Superficial deposits

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

Solid geology

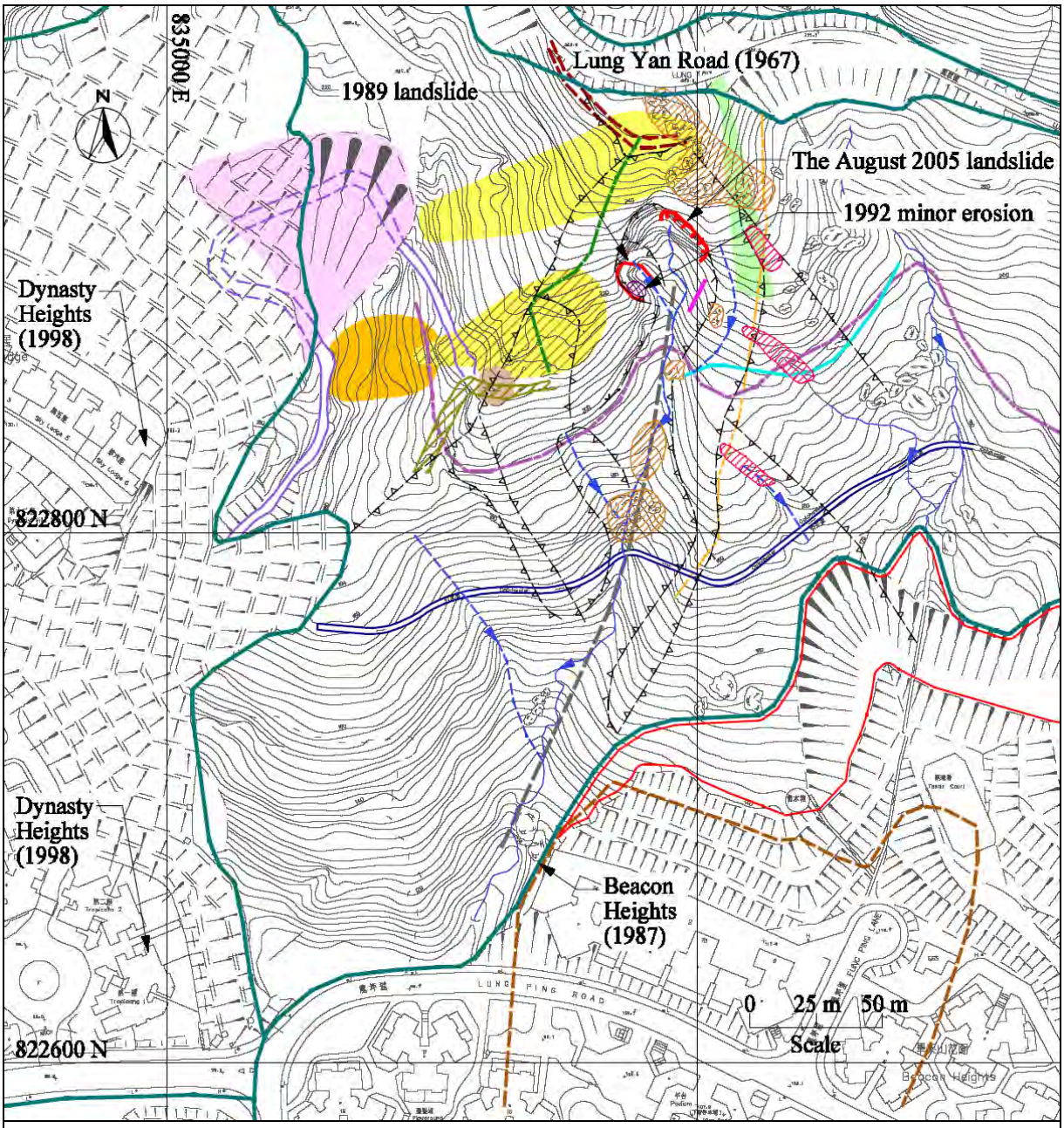
gf	Fine-grained granite, < 2mm
gm	Medium-grained granite, 2 - 6mm
gc	Coarse-grained granite, > 6mm

Geological lines

- Geological boundary, superficial deposits
- Geological boundary, soild rock
- Fault
- Photogeological lineament

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

Figure 4 - Regional Geology



Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure 5 - Site History and Geomorphology

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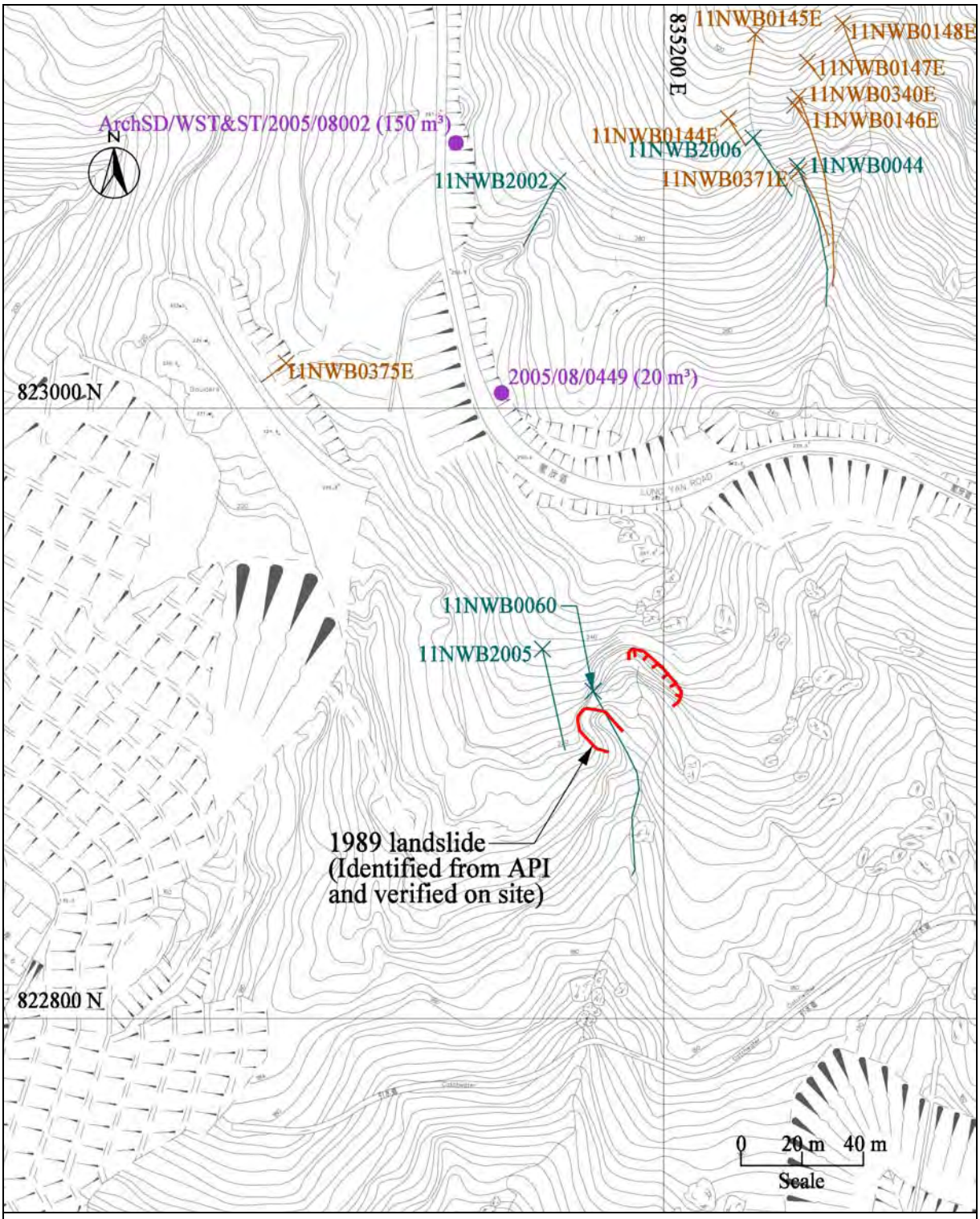

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure 6 - Past Instabilities

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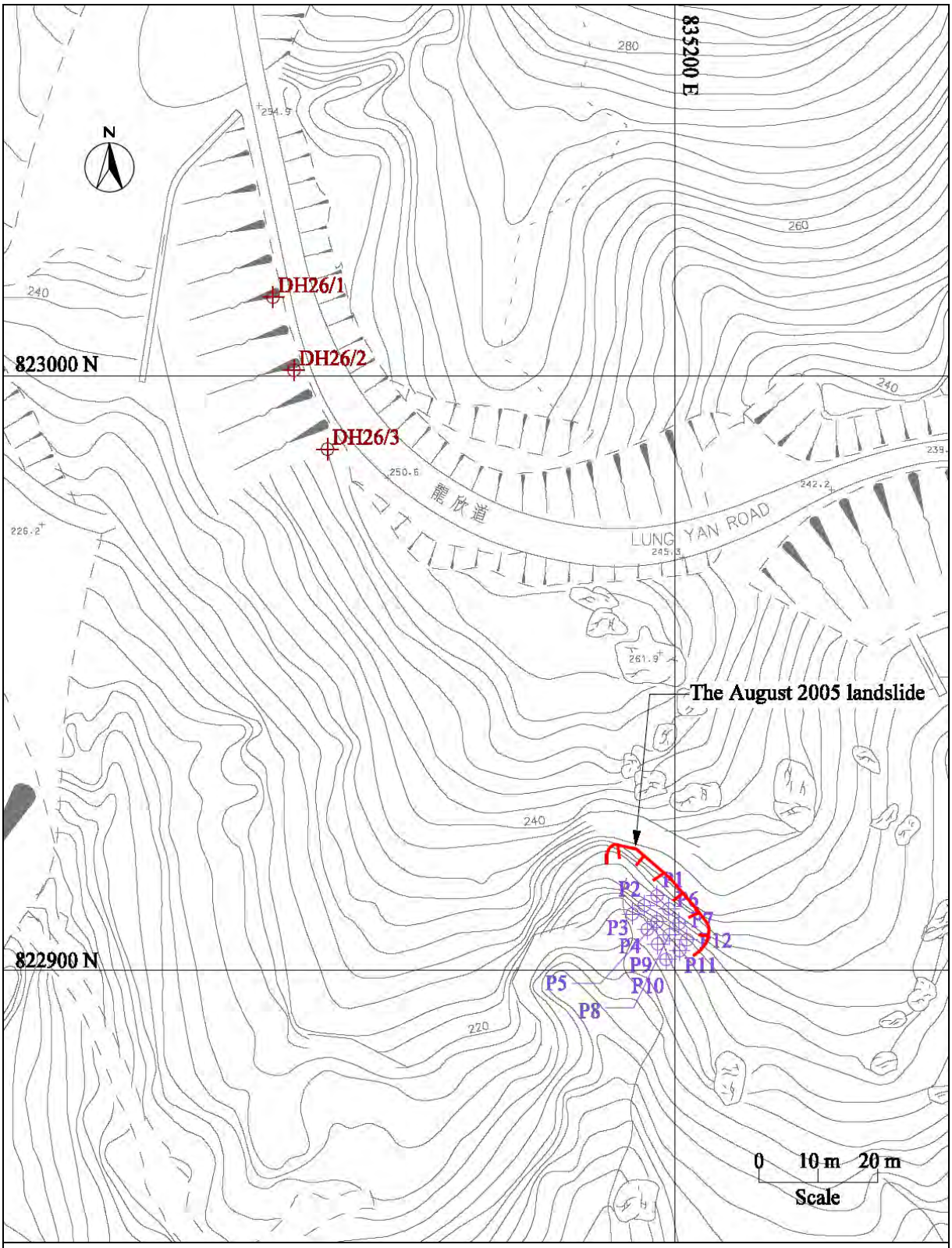

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure 7 - Location of Ground Investigation Stations

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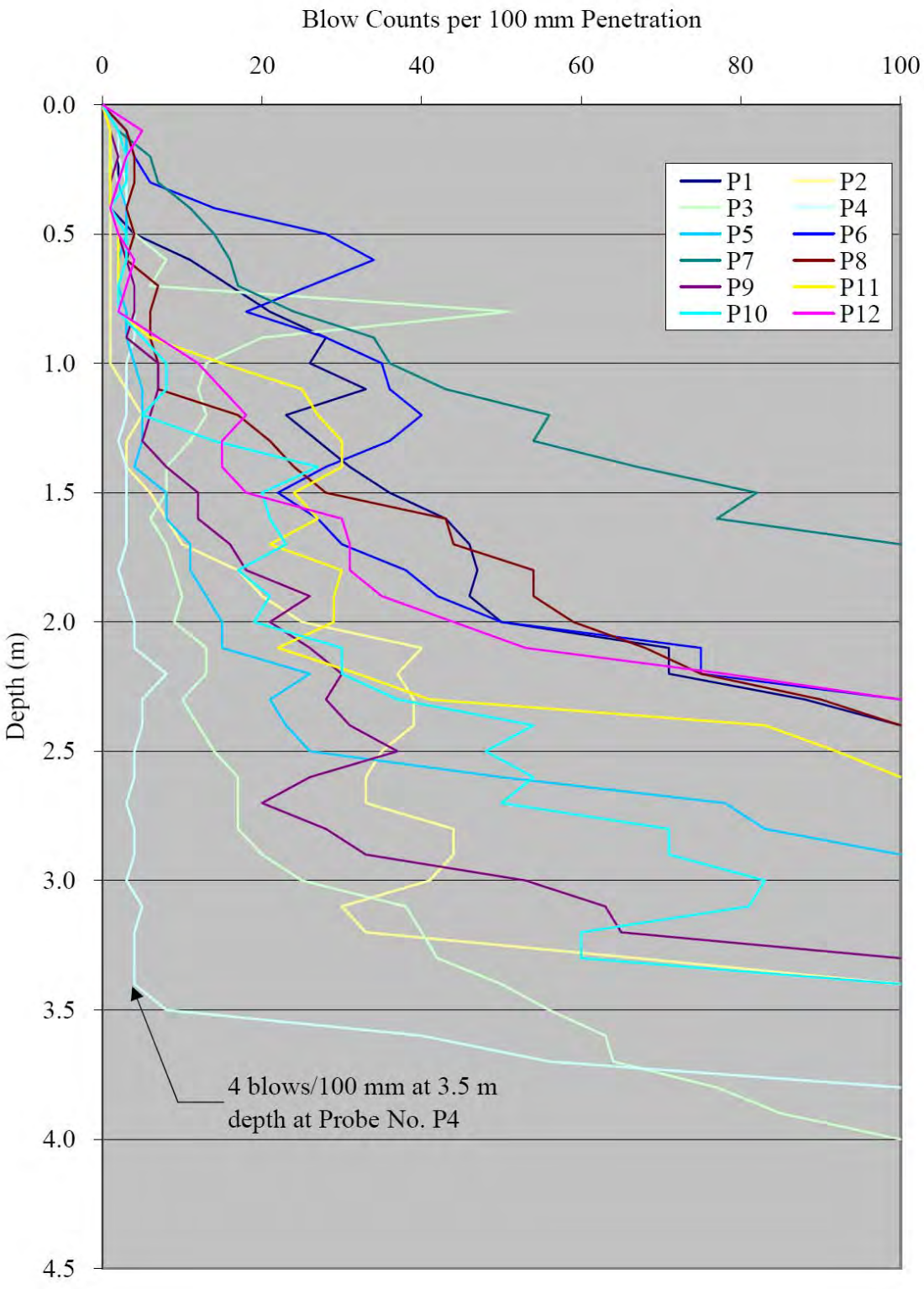
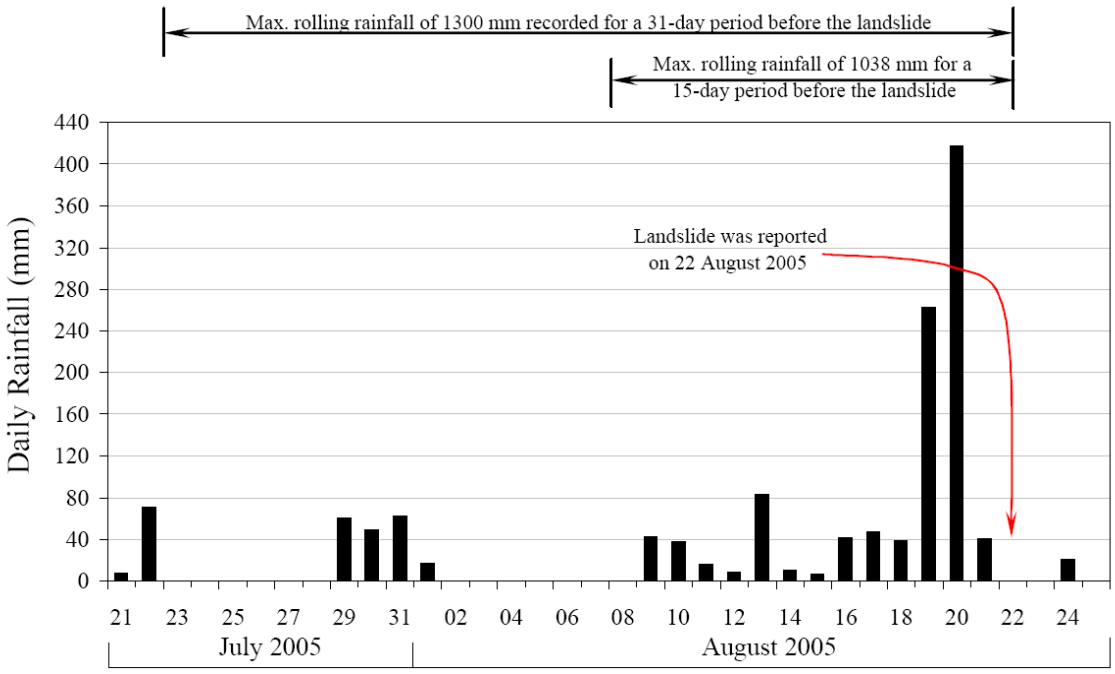
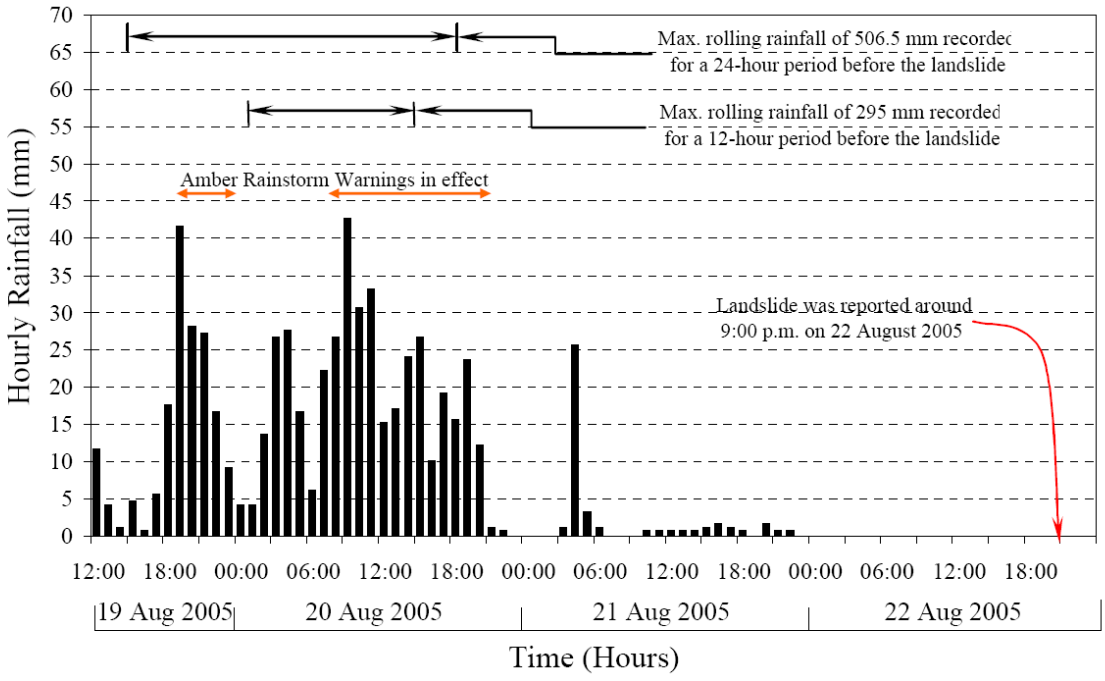


Note: The GCO probe reached refusal when more than 100 blows per 100 mm penetration.

Figure 8 - Summary of GCO Probes Results

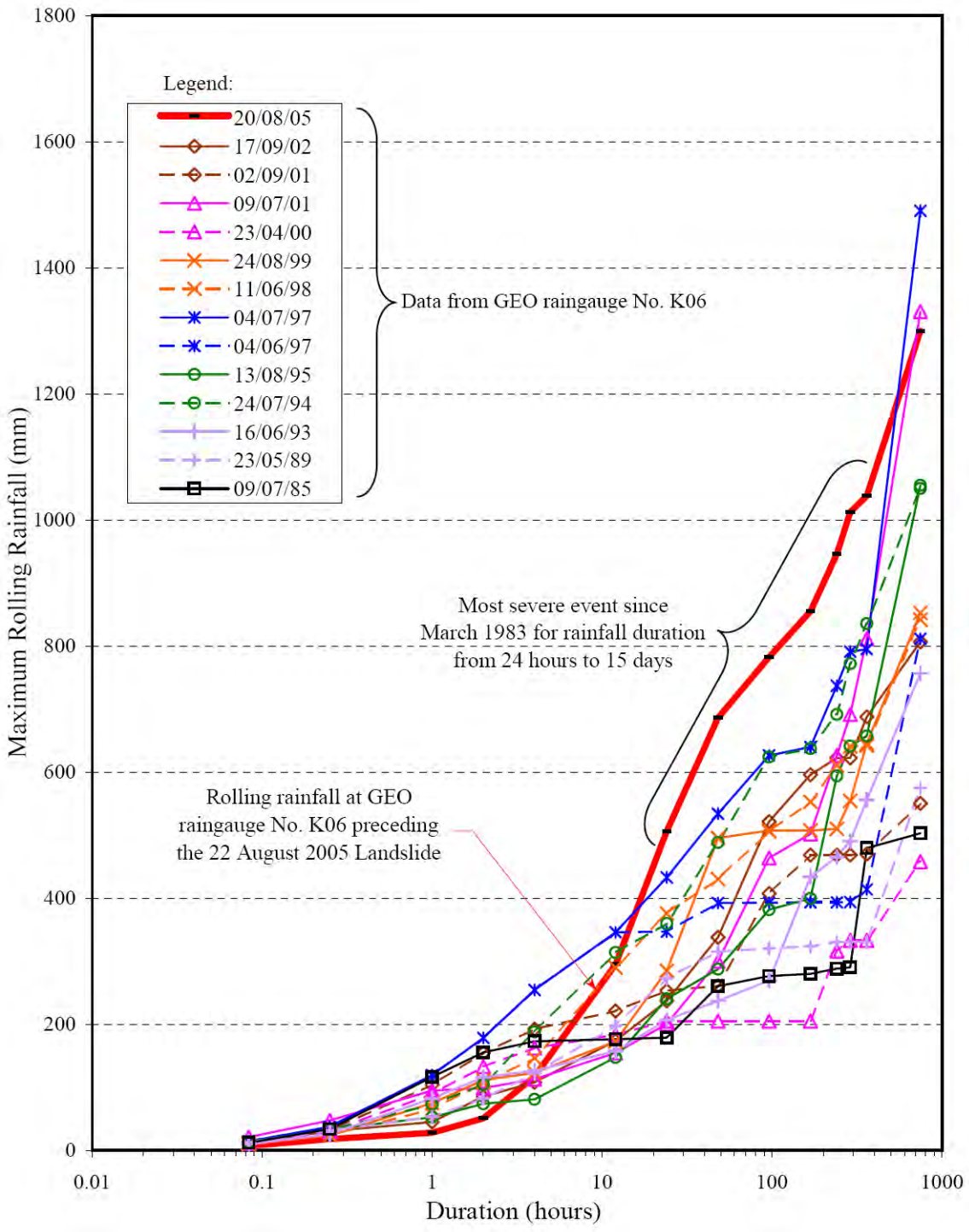


(a) Daily rainfall recorded at GEO Raingauge No. K06 between 21 July 2005 and 25 August 2005



(b) Hourly rainfall recorded at GEO Raingauge No. K06 between 19 August 2005 and 22 August 2005

Figure 9 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. K06



Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. K06 situated at about 1 km to the west of the site.
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. K06 since March 1983 when the raingauges became operational.

Figure 10 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. K06

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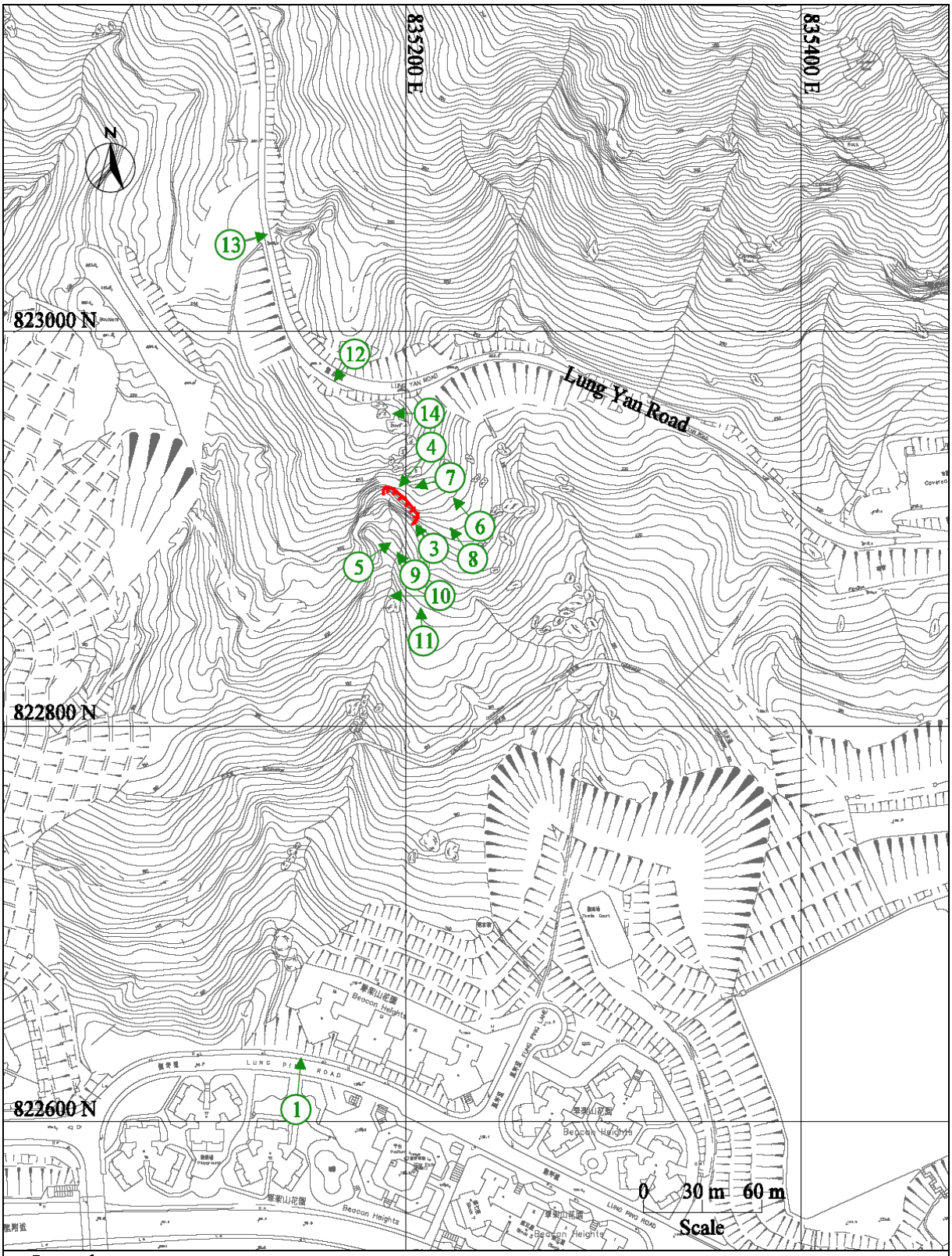

Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure 11 - Locations and Directions of Plates

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Plate 1 - General View of the August 2005 Landslide and the Hillside of Beacon Hill (Photograph taken on 24 October 2005)

Note: See Figure 11 for location and direction of photograph.

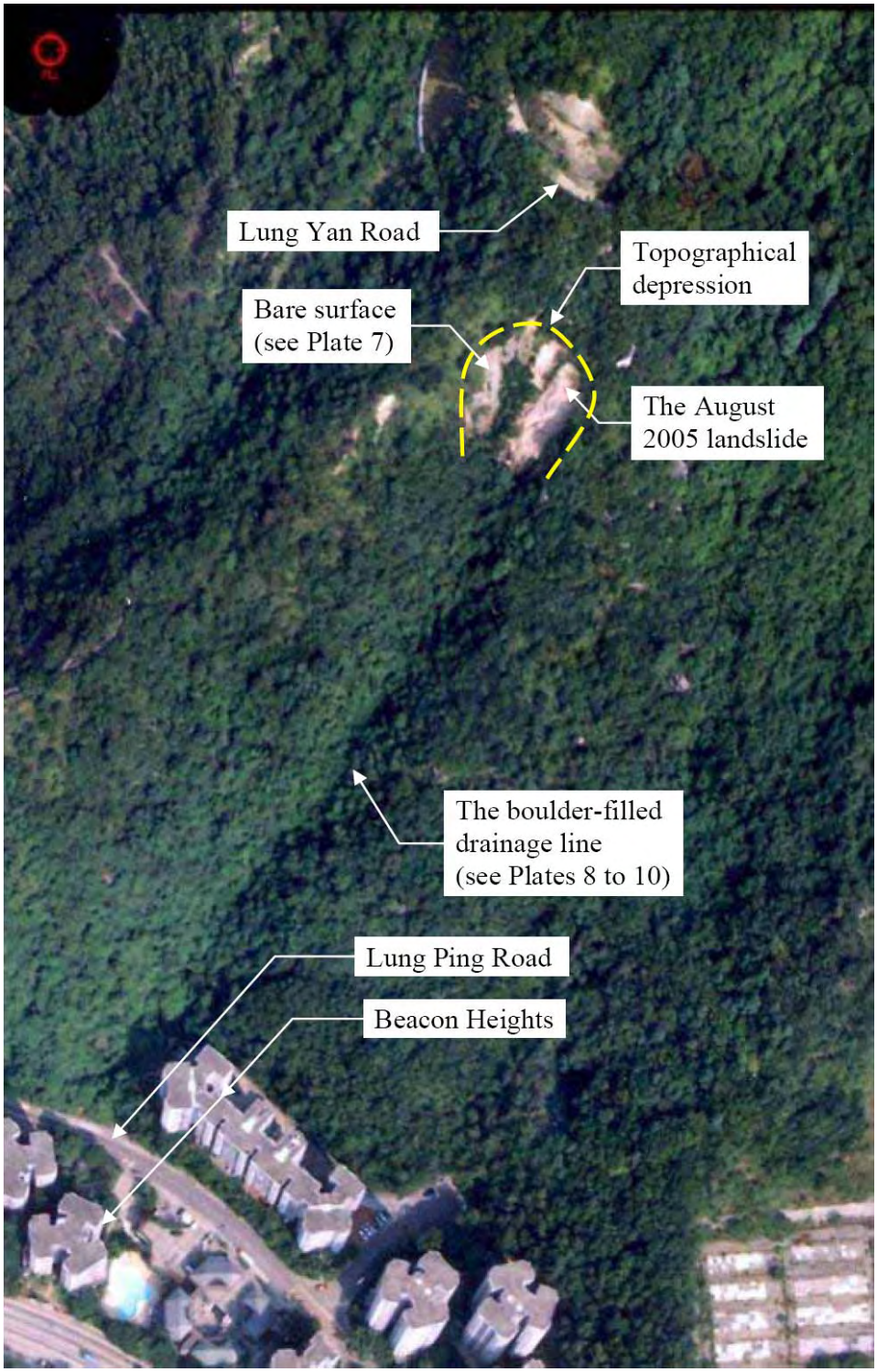

Plate 2 - Aerial View of the August 2005 Landslide (Aerial Photograph No. CW65668 taken on 24 October 2005)

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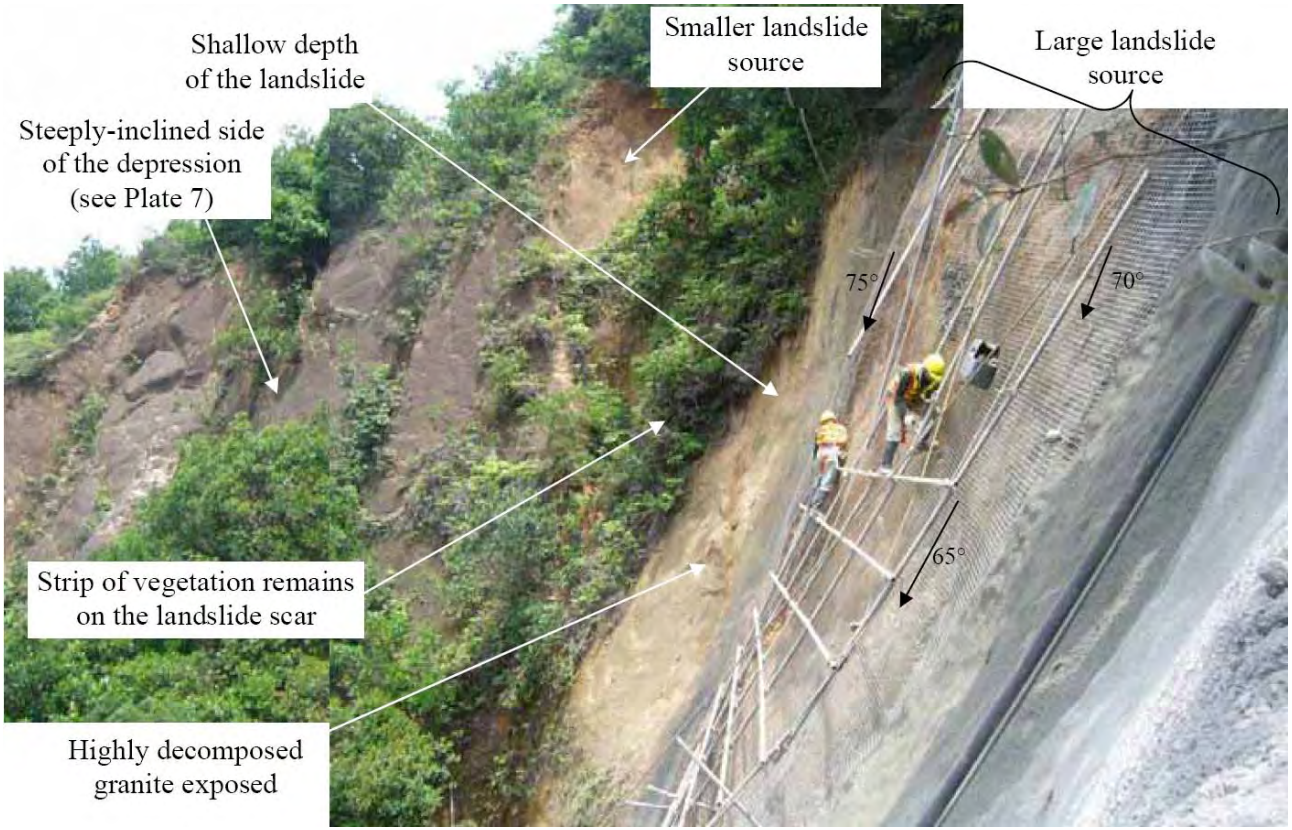

Plate 3 - View of the Landslide Source Area and the Urgent Repair Works (Photograph taken on 25 May 2006)

Note: See Figure 11 for location and direction of photograph.

Plate 4 - View of the Drainage Line and Beacon Heights from the Crest of the August 2005 Landslide (Photograph taken on 25 May 2006)

Note: See Figure 11 for location and direction of photograph.

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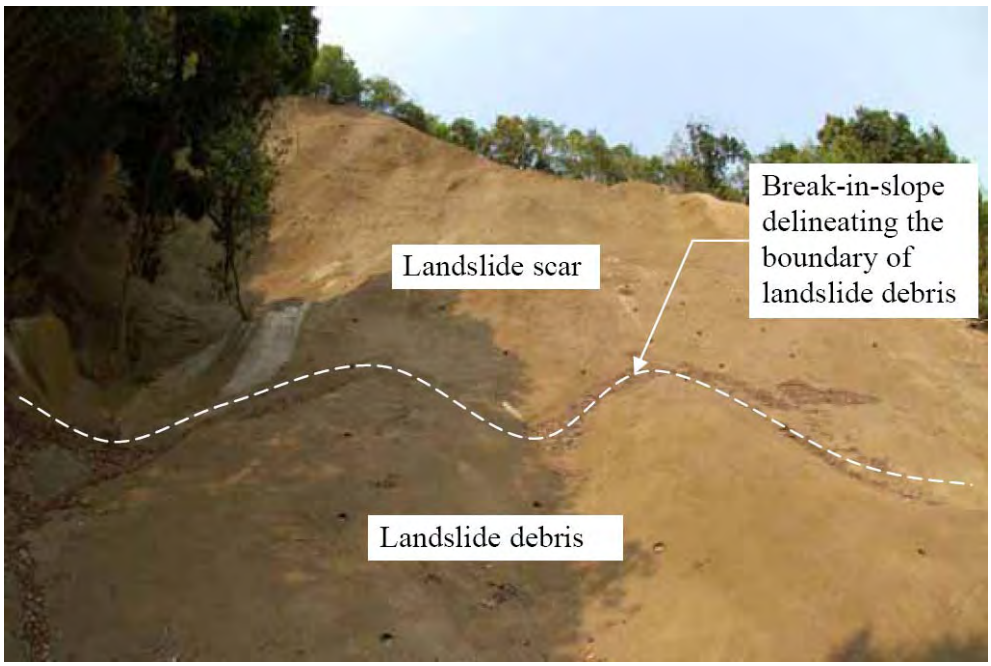

Plate 5 - Landslide Debris Covered by Shotcrete (Photograph taken on 13 April 2007)

Plate 6 - A Minor Ephemeral Drainage Line behind the Crest of the August 2005 Landslide (Photograph taken on 13 April 2007)

Note: See Figure 11 for locations and direction of photograph.

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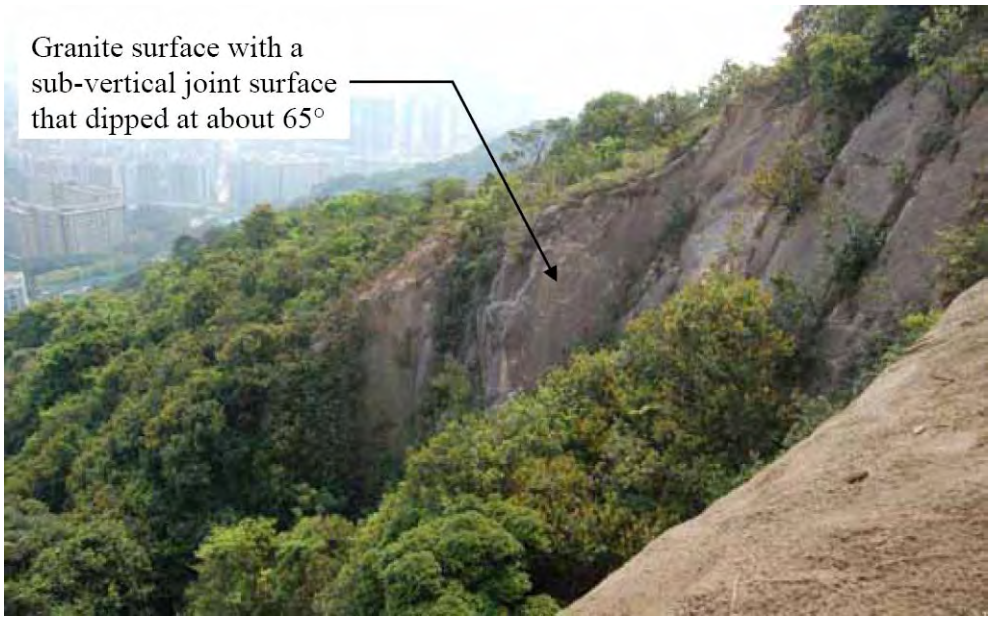

Plate 7 - Highly Decomposed Granite Surface on the Western Side of the Topographical Depression (Photograph taken on 13 April 2007)

Plate 8 - Large Rounded to Sub-rounded Boulders on Adjacent Spur (Photograph taken on 13 April 2007)

Note: See Figure 11 for locations and direction of photograph.

Plate 9 - Cluster of Sizeable Boulders within Drainage Line below the August 2005 Landslide (Photograph taken on 13 April 2007)

Plate 10 - Accumulation of Possible Debris from Previous Failures (Photograph taken on 13 April 2007)

Note: See Figure 11 for locations and direction of photograph.

Plate 11 - Sub-vertical Steeply Dipping, Southwest-facing Joint Surfaces at Backscarp of Older Landslide Scar (Photograph taken on 13 April 2007)

Plate 12 - Exposure of Pale Pink Kowloon Granite at Cut Slopes Nos. 11NW-B/C519 and 11NW-B/C250 (Photograph taken on 27 April 2007)

Note: See Figure 11 for locations and direction of photograph.

Plate 13 - Exposure of Completely Decomposed Coarse-grained Shatin Granite at Slope No. 11NW-B/C521 (Photograph taken on 27 April 2007)

Plate 14 - Colluvium Overlying Residual Soil (Photograph taken on 27 April 2007)

Note: See Figure 11 for locations and direction of photograph.

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

Detailed observations from examining the available aerial photographs taken between 1924 and 2006 are presented below. A list of the reviewed aerial photographs is presented in Table A1. The major site development history is shown on Figure A1 and the general geomorphology and hydrology of the site are presented on Figure A2.

YEAR OBSERVATIONS

1924 High altitude, poor resolution aerial photographs.

The study area is located on the mid-slopes of the south-facing hillside of Beacon Hill. The study area and the adjacent hillsides are affected by erosion. A footpath traversing the hillside to the south of the study area is observed.

1945 High altitude, fair resolution aerial photographs.

The study area consists of a well-defined topographical depression at the head of a southward draining perennial streamcourse. The flanks of the depression are observed to be steep/sub-vertical. The depression is characterised by a prominent convex breaks-in-slope at the crest, and the area is also flanked by relatively sharp southwest and southeast trending spurs. A relatively small and incised topographical depression is evident within the upper portion of the eastern spur, to the southeast of the August 2005 landslide, which forms a discontinuous ephemeral drainage line.

The topographical depression is covered with sparse vegetation with the head of the streamcourse appearing to be bare soil. The flanks of the depression are affected by erosion, with erosion gullies present on both spurs. Large boulders are evident within the streamcourse, as well as scattered over the hillside in the vicinity.

1954 High altitude, fair resolution aerial photographs.

The topographical depression and the general hillside in the vicinity remain sparsely vegetated, though the head of the streamcourse in which the August 2005 landslide occurred can be clearly observed as a steep-sided almost rectangular shaped feature. The erosion previously affecting the flanks of the spurs becomes less prominent.

Some localised excavation works are evident within the middle portion of the western spur about 50 m southwest of the head of the streamcourse. The excavation works may be related to some early days quarrying activities.

YEAR	OBSERVATIONS
1959	High altitude, fair resolution aerial photographs.
	The quarrying activities have become more extensive along the western spur within the study area, as well as on the hillside further west. The quarry spoils are evident on the hillsides to the west of the topographical depression.
	A large number of single-storey buildings, possibly squatter settlements, have been built on either side of Lung Cheung Road (under construction), about 250 m south and downhill of the study area.
1961	High altitude, fair resolution aerial photographs.
	The high reflectivity of the steep-sided head of the streamcourse, possibly indicative of minor landslides or significant erosion within the previous two years.
	A north-south trending footpath is observed along the eastern spur. An access track is evident within the quarrying area to the west of the topographical depression.
1963	Low altitude, excellent resolution aerial photographs.
	The study area has a generally sparse cover of vegetation, with large boulders clearly observed within the streamcourse as well as scattered over the hillside in the vicinity.
	It appears that the spur on the eastern side, which is sparsely vegetated, has been affected by erosion with some northwest-southeast trending erosion gullies present on the hillside. Quarrying works remain evident immediately upslope of the study area, as well as on the lower portion of the western spur.
1967	No changes of significance are observed in the immediate vicinity of the August 2005 landslide area. Excavation works are still underway at the quarry southwest of the August 2005 landslide site. General disturbance due to the construction works is evident on the spur to the west of the study area.
1973	Lung Yan Road (running north of the August 2005 landslide site) and the associated cut and fill slope features; including slopes Nos. 11NW-B/C519, 11NW-B/C520 and 11NW-B/F256 have been formed uphill of the study area. The general study area is covered with dense vegetation and the streamcourse below the August 2005 landslide site has a denser vegetation cover. It appears that some fill material has been placed within the upper portion of the study area as well as on the middle spur to the west probably during the construction works in previous years, and sign of erosion is evident.
	The area of squatter settlements along Lung Cheung Road has been cleared and site formation is underway. Construction works is also observed on the hillside to the west of the study area.

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YEAR	OBSERVATIONS
1975	Bare soil is exposed (Figure A2), revealing a sub-vertical cliff-like feature at the back of the topographical depression, indicating possible rock joint surfaces with a possible retrogressive sub-vertical joint-controlled failure. A sub-vertical joint set generally striking northwest-southeast is also evident at the back scarp. There is evidence of erosion along the spurs at the flanks of the study area. Vegetation density is observed to have increased within the streamcourse below the August 2005 landslide area. The site formation works observed in 1973 was complete with platforms and associated roads and slope works formed.
1977	Single aerial photograph. The topographical depression area remains densely vegetated, except for the back scarp on the western flank, which is exposed in 1975. The spurs at its flanks appear sparsely vegetated. Most of the large boulders within the streamcourse channel are obscured by the dense vegetation, whilst the boulders at the crest of the study area as well as on the flanking spurs are prominent. Site formation works continue on the downhill side to the southeast and southwest of the study area respectively.
1978	No changes of significance are observed, except the back scarp of the topographical depression is more apparent (more reflective), which may imply further back-sapping of the surface material.
1979	No changes of significance are observed.
1980	No changes of significance are observed. The study area remains densely vegetated, whereas the back scarp on the western flank is clearly exposed.
1984	Single aerial photograph. A rock trap (see Section 4) has been constructed along the hillside to the south of the study area. A footpath is evident along the upper spur on the western side of the study area, whist an area of wider cutting/excavation is observed directly below the footpath within the middle portion of the western spur. A strip of vegetation has been cleared along the upper portion of the eastern spur, which extends to Lung Yan Road and has been protected with a hard surface cover. An access path has been formed near the crest of the cut slope No. 11NW-B/C519, along Lung Yan Road. A network of east-west trending surface channels has been constructed on the downhill side to the southeast of the study area, which diverts the surface water flow from the adjacent streamcourse.

YEAR	OBSERVATIONS
1986	Single aerial photograph.
	No changes of significance are observed. Beacon Heights development is underway on the platform formed in 1975.
1987	Single aerial photograph.
	No changes of significance are observed within the study area.
	The development of the Beacon Heights together with the associated slopes and drainage works have been formed to the north of Lung Cheung Road.
1988	No changes of significance are observed within the study area.
	The study area and its general vicinity remain densely vegetated. The access path at the crest of the cut slope No. 11NW-B/C519 is also covered with dense vegetation growth.
1989	Single aerial photograph.
	The study area and vicinity remain covered with dense vegetation. An area of high reflectivity, which might be related to a recent landslide along a possible joint plane, is observed within the western back scarp (Figure A1).
1991	Single aerial photograph.
	No changes of significance are observed, except that the scar of the 1989 landslide is partially covered with vegetation.
1992	No changes of significance are observed except that the vegetation density on the 1989 landslide scar appears to have decreased and is more easily identified suggesting minor erosion of the 1989 landslide scar.
1995	Single aerial photograph.
	The general area remains densely vegetated. A large scale site formation is underway on the hillside to the southeast for the residential development of Dynasty Heights.
1998	Single aerial photograph.
	An area of local excavation is observed within the middle portion of the western spur. The development of the Dynasty Heights together with the associated slope works has been completed.

YEAR	OBSERVATIONS
1999	Non-stereo pair aerial photographs.
	The general study area remains densely vegetated. The area of local excavation is still evident.
2003	Single aerial photograph.
	No changes of significance are observed.
2004	No changes of significance are observed. The general study area is covered with dense vegetation growth.
2005	Non-stereo pair aerial photographs.
	The August 2005 landslide is evident. The debris trail has a short extent below the landslide scar.

LIST OF TABLES

Table A1 - List of Aerial Photographs Reviewed

Date Taken	Altitude (ft)	Photograph Number
1924	12500	Y104-05
10 November 1945	20000	Y606-07
18 November 1954	29200	Y2685-86 Y2705-06
5 October 1959	40000	Y4620-21
17 January 1961	30000	Y4908-09
25 January 1963 27 January 1963	2700	Y8110 Y8150-51
16 May 1967	6250	Y13417-18
24 October 1973 10 December 1973	1800 3000	5375 6871-72
2 December 1975	2500	11504-05
15 September 1977	2000	19251
7 November 1978	4000	23079-80
1 October 1979	4000	27322-24
16 April 1980	2000	29710-11
5 November 1984	4000	57022
3 March 1986	4000	A4374
11 June 1987	4000	A9500
6 October 1988	4000	A14712-13
16 August 1989	4000	A17915
20 September 1991	4000	A27509
26 August 1992	3000	CN3110-11
27 September 1995	3500	CN11357
31 October 1998	4000	CN21251
11 June 1999 11 December 1999	2600 4000	CN23176 CN25312
25 November 2003	4000	CW53339
5 October 2004	4000	CW60291-92
24 October 2005	4000	CW65550 CW65666

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

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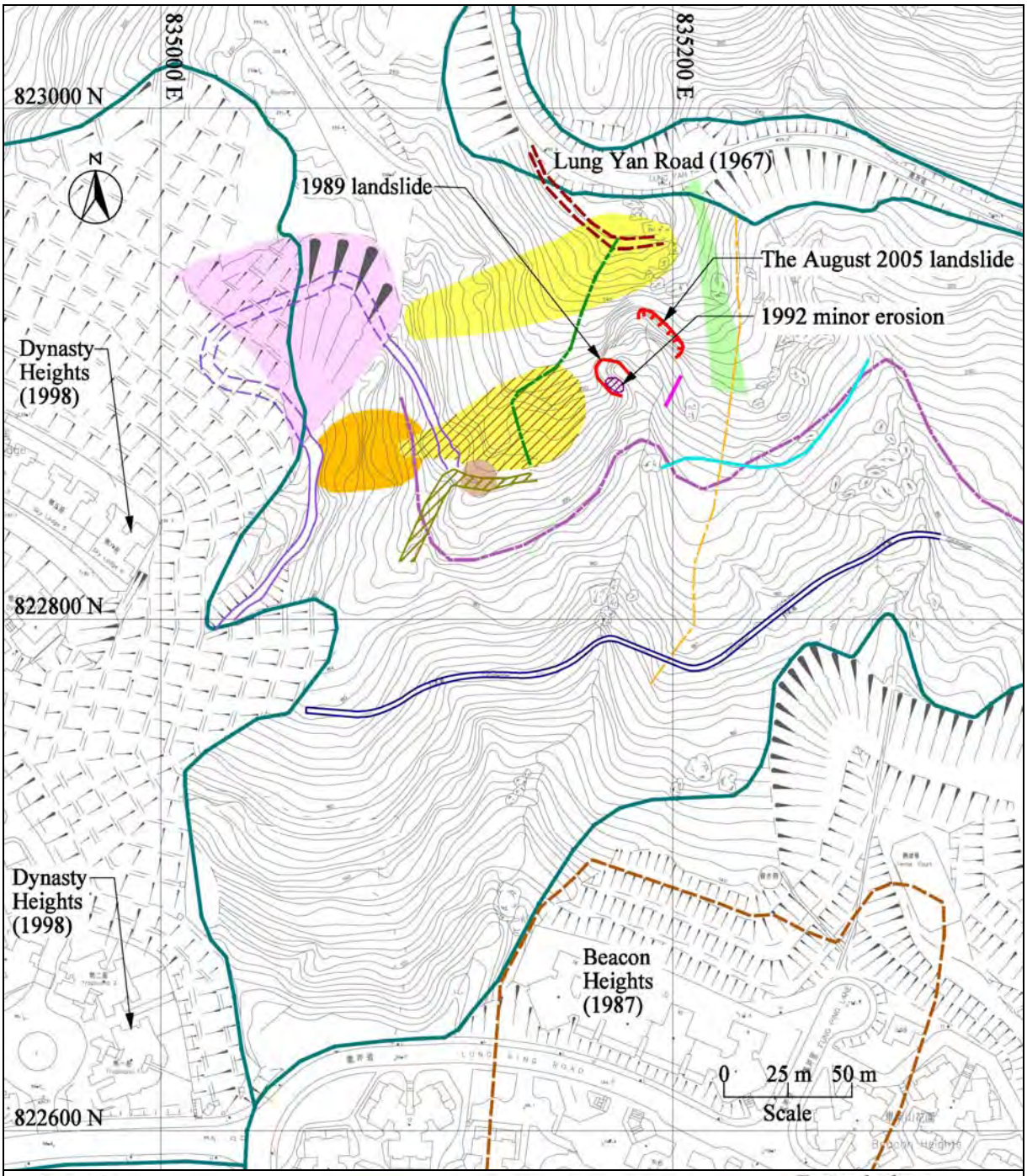

Notes: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure A1 - Site Development History

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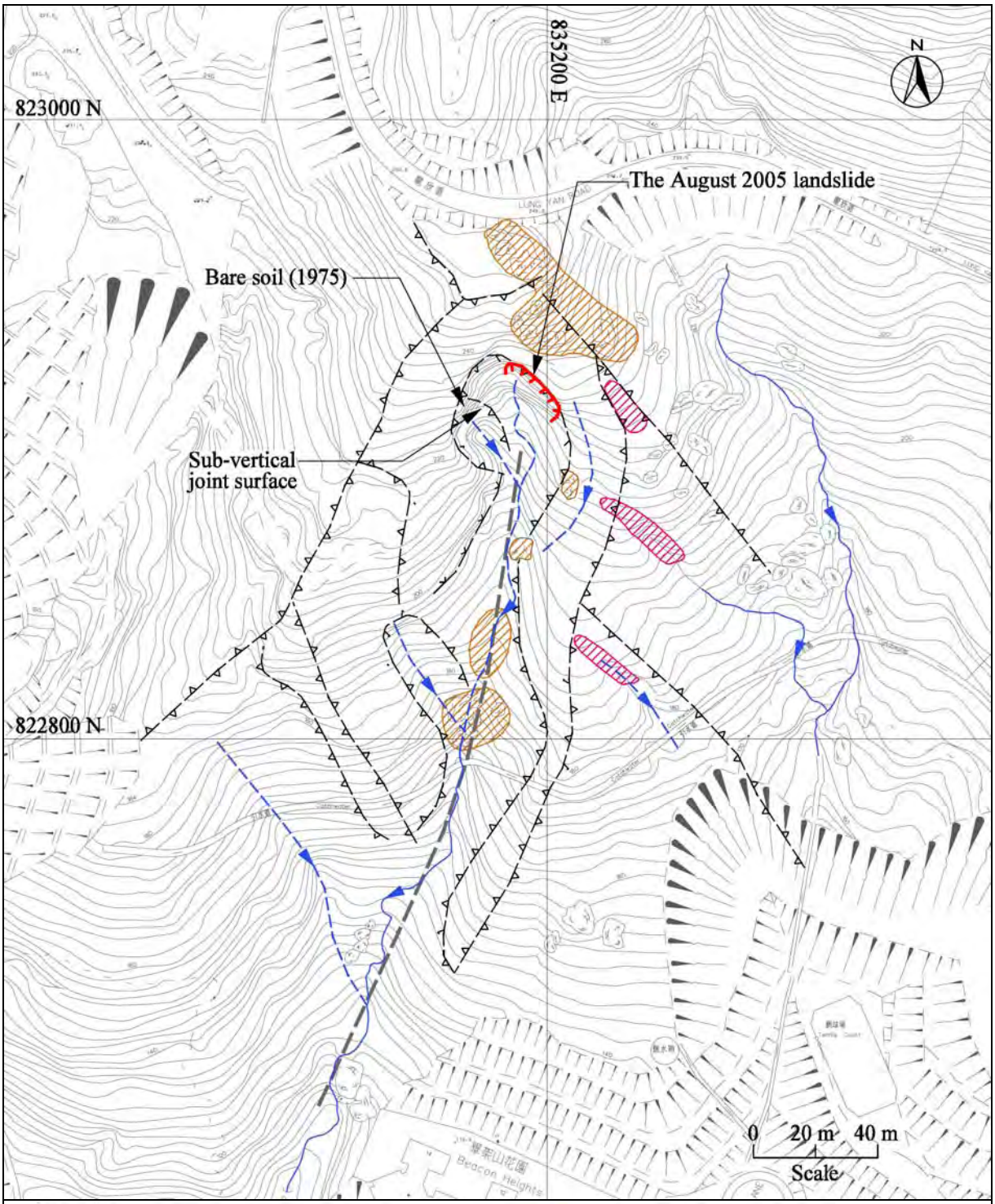

Notes: Base plan is extracted from 1:1000 survey sheets Nos. 11NW-4C, 11NW-4D, 11NW-9A and 11NW-9B dated March 2004.

Figure A2 - Site Geomorphology and Hydrology

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

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

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

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

writing to
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

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

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港中環花園道
美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

或
- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址爲 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000，1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
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