DETAILED STUDY OF THE 9 JUNE 2001 ROCKFALL INCIDENT AT SLOPE NO. 11NW-A/C58 AT CASTLE PEAK ROAD BELOW WAH YUEN CHUEN

GEO REPORT No. 151

Maunsell Geotechnical Services Ltd.

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

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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 last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
December 2004

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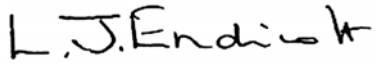
FOREWORD

This report presents the findings of a detailed study of a rockfall incident (GEO Incident No. MW2001/06/007) which occurred on the evening of 9 June 2001 on a soil and rock cut slope adjacent to Castle Peak Road below Wah Yuen Chuen, Kwai Chung. The rock debris hit a Post Office van that was travelling on the inside lane of the southeast bound carriageway of Castle Peak Road. A rock fragment punched through the windscreen of the van. The driver became unconscious and lost control of the van, which continued along the road and crashed into the toe of the slope before coming to a halt. As a result, the driver and the only other passenger, who was also in the front seat, were injured.

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

The report was prepared as part of the 2001/2002 Landslide Investigation Consultancy for landslides reported within Kowloon and the New Territories between April 2001 and the end of 2002, for the Geotechnical Engineering Office, Civil Engineering Department, under Agreement No. CE72/2000. This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Ltd.



Dr. L.J. Endicott
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Agreement No. CE 72/2000
Landslide Investigation Consultancy for Landslides Reported within Kowloon and the New Territories between April 2001 and the End of 2002

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1. INTRODUCTION

At about 6:00 p.m. on 9 June 2001, some 3 hours after a rainstorm, a rockfall (GEO Incident No. MW2001/06/007), with an estimated failure volume of about 0.05 m³, occurred on cut slope No. 11NW-A/C58 adjacent to Castle Peak Road below Wah Yuen Chuen, Kwai Chung (Figure 1). A fragment of the falling rock debris hit a Post Office van which was travelling on the inside lane of the southeast bound carriageway of Castle Peak Road. The rock fragment punched through the windscreen of the van (Plate 1). The driver became unconscious and lost control of the van, which continued along the road and crashed into the toe of the slope before coming to a halt (Plates 2 and 3). As a result, the driver and the only other passenger, who was also in the front seat, were injured.

Following the incident, Maunsell Geotechnical Services Ltd. (MGSL), GEO's landslide investigation consultants, carried out a detailed study of the incident under Agreement No. CE 72/2000.

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

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

(a) review of relevant documentary records relating to the development history of the site and the sequence of events leading to the incident,

(b) detailed inspections and measurements at the site,

(c) aerial photograph interpretation (API),

(d) analysis of rainfall data,

(e) interviews with witnesses to the incident, and

(f) diagnosis of the probable causes of the incident.

2. THE SITE

2.1 Site Description

The rockfall incident occurred on cut slope No. 11NW-A/C58 on the northeast side of the section of Castle Peak Road below Wah Yuen Chuen, to the southeast of the Carmel Alison Lam Foundation Secondary School (Figure 1 and Plates 4 and 5). The slope is a soil and rock cut slope and is approximately 210 m long and up to about 35 m high. The slope comprises four batters formed at about 60° to the horizontal with three 1.0 m to 1.3 m wide berms (Figure 2 and 3).

The slope is mostly covered with shotcrete except for the exposed rock portion (about

100 m long) with a slope angle of about 60° to 65°, around the middle and southeast of the first and second batters (enumerated upwards from the toe of the slope) and the middle portion (about 40 m long) of the third and fourth batters. Unplanned vegetation has largely obscured the shotcrete cover at the middle of the third batter (Plate 5). The exposed rock face exhibits closely to medium spaced jointing throughout and is partly covered with unplanned vegetation, including grass and shrubs, which is growing in the joints.

Details of the slope surface drainage provisions are shown in Figure 2. Perimeter U-shaped surface channels, which are stepped in places, are provided along the crest and sides of the slope, except for a portion of about 45 m along the slope crest near the middle of the slope where no drainage channels have been constructed. Each of the berms to the northwest of the exposed rock portion of the slope carries a half-round surface channel, which drains southeast and discharges directly onto the exposed rock portion at the middle of the slope. There are no surface drainage channels on the berms of the exposed rock portion of the slope, or on any of the berms in the shotcrete covered portion of the southeast of the slope (Plate 6).

Steel maintenance ladders have been erected on the shotcreted portion to the southeast of the slope. Access to part of the northwest portion of the slope is provided by an old stairway, which has been covered by shotcrete (Figure 2 and Plate 5). Tree planter boxes have been built with brick at intervals along the slope toe.

The residential development, Wah Yuen Chuen, is situated above the crest of the slope. Castle Peak Road, a dual four-lane carriageway with a 1 m wide footpath, is situated at the toe of slope No. 11NW-A/C58. A strip (about 10 m in width, inclined at about 30°) of densely vegetated natural hillside is present along the crest of slope No. 11NW-A/C58 between the slope and the podium of Wah Yuen Chuen and broadens out along the southeast perimeter of the slope.

There are no water-carrying services within or in the vicinity of slope No. 11NW-A/C58.

2.2 Maintenance Responsibility

According to records in Lands Department (Lands D), slope No. 11NW-A/C58 is located within Kwai Chung Town Lot (KCTL) No. 316 (Figure 4), except for a small area at the southeast. Lot No. 316 has been granted to Wah Yuen Chuen Co-operative Building Society since September 1979.

In 1996, the Lands D commissioned a project entitled “Systematic Identification of Maintenance Responsibility of Slopes in the Territory” (SIMAR) to identify the maintenance responsibility of all man-made slopes registered in the Government’s New Catalogue of Slopes. A SIMAR report prepared in March 1997 indicated that the owners of KCTL No. 316 and the Highways Department (HyD) are responsible for maintenance of the private portion and the government portion of slope No. 11NW-A/C58 respectively.

2.3 Subsurface Conditions

2.3.1 Geology

The 1: 20 000 scale geological map of Hong Kong (GEO, 1986) shows that the site is mainly underlain by Jurassic/Cretaceous coarse-grained granite. The geological map also shows a contact between coarse-grained and fine-grained granite along Castle Peak Road. Examination of the exposed rock cut portion of slope No. 11NW-A/C58 by MGSL identified coarse-grained granite to the southeast and fine-grained granite to the northwest.

2.3.2 Previous Ground Investigation

In February 1978, Lam Construction Co. Ltd. carried out a ground investigation (GI), under the supervision of the geotechnical consultant, Fugro (Hong Kong) Ltd. (Fugro), for the design of site formation and foundations of the Wah Yuen Chuen residential development project (see Section 2.5.2). A total of 30 drillholes was drilled and the drillhole records were incorporated in Fugro's 'Geotechnical Investigation Report-1' (see Section 2.5.2). Eleven of the drillholes were located on the area above the crest of slope No. 11NW-A/C58 but none were drilled within the boundary of slope No. 11NW-A/C58 (Figure 5). The drillholes in the area above the crest of the subject slope generally terminated about 5 m below "sound rock". There are no records in Fugro's geotechnical report of any slope stripping or trial pitting on slope No. 11NW-A/C58, which is partly covered with chunam (Figure 6).

Colluvium, to depths 5 m and 7 m respectively, overlying completely weathered granite (CWG), is recorded in only the two drillholes to the northwest, Nos. BH21 and BH22, drilled from about the present-day platform level (122 mPD). The rest of the drillholes are collared in CWG to highly weathered granite (HWG), which varies in thickness from very thin up to 13.80 m, below the present-day platform level. Below this zone of completely to highly weathered granite (C/HWG), the drillholes pass into slightly to moderately weathered granite (SWG).

The colluvium is described as brownish yellow loose to dense sand. The CWG is generally described as yellowish brown very dense silty sand and overlies HWG which is described as a very dense soil or a soft rock. This HWG is variable in extent and thickness and overlies generally pinkish grey SWG with very closely to moderately widely spaced jointing. There is no mention of infill or angle of dip of the joints in any of the drillhole logs and the general description of the SWG is consistent with observations of the exposed rock portion of slope No. 11NW-A/C58 made by MGSL for this study (see Section 3.2). Figure 6a shows the geological section drawn by Fugro and presented in their geotechnical report.

Standpipe piezometers were installed in four of the drillholes above the crest of slope No. 11NW-A/C58 and monitoring of the groundwater levels was carried out a few weeks after the completion of drilling. Each day between 14 and 18 March 1978, water levels in drillholes BH7, BH22 and BH23 were recorded and gave the highest recorded groundwater level of 6.65 m, 3.97 m and 3.0 m respectively below the top of SWG. The groundwater level in drillhole BH10 (5.65 m below the top of SWG) was recorded only on 2 April 1978. Fugro noted that the "groundwater level was generally found to be close to the slightly weathered granite bedrock level".

2.4 Site History

2.4.1 History of Development

The history of development at the site (Figure 7) has been determined from an examination of old survey maps (dated between 1913 and 1958), together with an interpretation of aerial photographs and a review of relevant documentary information. Detailed observations from the aerial photograph interpretation (API) are given in Appendix A.

The section of Castle Peak Road at the toe of slope No. 11NW-A/C58, was constructed, probably by Government, as a two-lane carriageway between 1913 and 1924. It was realigned and widened, probably by Government, between 1954 and 1963 (Figure 7). The cut slope of concern (registered as slope No. 11NW-A/C58 since 1977) was formed during this latter development. Distinctive light colouration on parts of the slope, seen in 1963 aerial photographs, suggests that these areas of the slope might be covered by a hard surface. Seepage, from a maximum height of about 15 m above the slope toe, is noted at two localities on the rock outcrop section (Figure A2) in 1964 and is still evident at the same localities in 1969. Some re-surfacing is apparent in aerial photographs (Figure A2) taken between 1972 and 1973. The extent of the hard cover, which appears to be chunam, was essentially unchanged in 1977 as shown in photographs (Plates 7 and 8) taken by Binnie and Partners (Hong Kong) Ltd. (B&P) (see Section 2.5.1). The slope profile has remained largely unchanged since then with the exception of some minor levelling of the crest of slope No. 11NW-A/C58 during the site formation of the Wah Yuen Chuen platforms in 1980.

Between 1969 and 1980, the natural hillside above slope No. 11NW-A/C58 was cut to form a series of level platforms for the Wah Yuen Chuen development at elevations of between approximately 115 mPD and about 150 mPD. In 1980, the middle and northwest portions of the slope crest were removed during construction of the lower platforms at an elevation of about 122 mPD.

Based on API, by 1980 scattered shrubs had developed on the berms of slope No. 11NW-A/C58 and by 1985 the density of unplanned vegetation had increased notably. Subsequent changes in the density of unplanned vegetation between 1985 and 1996 are not easily distinguished in the aerial photographs.

On 11 September 1996, the Design Division of the GEO requested HyD to inform GEO if any slope was programmed for shotcreting, to allow prior geological mapping by the GEO for the purpose of identifying any “potential candidates for the LPM Programme”. On 28 October 1996, HyD informed GEO by memo that slope No. 11NW-A/C58 “will be sprayed with concrete” under their 'Roadside Slope Improvement Programme'. (The plan attached to the memo referred to the entire area of the slope, including that portion located within private lot KCTL No. 316). On 31 October 1996, HyD issued a works order to their term contractor for carrying out shotcreting work and clearance of vegetation and U-channels on slope No. 11NW-A/C58. GEO followed up by inspecting slope No. 11NW-A/C58 on 18 November 1996 and noted that the top batter at the northwest of the slope had just been shotcreted (Figure 7 and Plate 9). The remainder of the slope, apart from the exposed rock portion, was noted by the GEO to be largely covered with chunam (Plate 9). The photographs taken by the GEO for this inspection also show heavy growth of unplanned vegetation on the exposed rock portion of the slope (Plate 10). According to HyD’s record,

the re-surfacing of the remaining northwest portion of the slope and the associated works were completed by HyD on 28 December 1996.

On 4 June 1997, a minor landslide occurred on the third batter at a chunam covered area of the southeast portion of the slope (see Section 2.4.2). Subsequent to this incident, HyD replaced the chunam cover at the southeast portion of the slope with shotcrete cover, which included shotcreting of the landslide scar (see Section 2.4.2) that was recommended by GEO as a part of the urgent repair works. The shotcreting works were completed on 12 June 1997. Plate 11 shows a summary of the sequence of the application of shotcrete cover to slope No. 11NW-A/C58.

Photographs taken by Halcrow Asia Partnership Ltd. (HAP) under the Stage 2 Study in July 1997 (see Section 2.5.7) show that the shotcreting works to the slope had been completed by HyD and the portion of slope without hard surface cover had been largely cleared of vegetation (Plates 11 and 12). Plate 13, taken from a Routine Maintenance Inspection by HyD in December 1998, shows vegetation re-establishing on the exposed rock face and re-growing on the shotcreted sections which is in marked contrast to Plate 12 taken by HAP in July 1997. Plate 14, taken by the Slope Safety Division of the GEO in July 1999, shows the continuing spread and thickening of the unplanned vegetation. The growth of unplanned vegetation on slope No. 11NW-A/C58 as of August 2001 and September 2001 is shown in Plates 4 and 5 respectively.

2.4.2 Previous Landslides

According to the GEO's landslide database, a minor landslide (GEO Incident No. MW97/6/35A) occurred on slope No. 11NW-A/C58 on 4 June 1997 resulting in the closure of one lane of Castle Peak Road. The photograph attached to the GEO Incident Report (reproduced as Plate 15) shows that the landslide, with an estimated volume of less than 10 m^3, occurred at a chunam covered portion of the third batter of the slope (Figure 7 and Plate 11). Urgent repair works, recommended by GEO to HyD at a joint site inspection, comprised removal of loose materials on the failure surface, trimming back of the failure scar to remove any oversteepened area, provision of surface protection (with weepholes) to the failure surface, repair of any damaged drains and replacement of cracked/damaged chunam.

No other landslides were noted by MGSL in the API study (see Appendix A) but gully erosion was observed in the 1963 photographs at the head of the streamcourse in the natural hillside above the southeast end of slope No. 11NW-A/C58 (Figure 7).

2.5 Previous Assessments

2.5.1 Inspection by Binnie & Partners (HK) Ltd.

In June 1977, B&P inspected slope No. 11NW-A/C58 under the project entitled 'Landslide Studies, Phase I Re-appraisal, Cut & Natural Slopes and Retaining Walls' for the purpose of slope registration in the 1977/78 Catalogue of Slopes. The condition of the slope at that time is shown in Plates 7 and 8. B&P noted erosion at the top of the slope but no seepage was observed. The slope condition was described by B&P as "Fair". The recommendations given in the inspection report were to repair the chunam and remove grass

from the weepholes. There was no mention in the inspection report of any loose rock blocks or unplanned vegetation.

2.5.2 Wah Yuen Chuen Residential Development

After the completion of the GI (see Section 2.3.2) in March 1978, a report entitled 'Geotechnical Investigation Report - 1' was prepared by Fugro, the geotechnical consultant for the Wah Yuen Chuen residential development project.

Shear strength parameters ($c' = 9.6$ kPa and $\phi' = 46°$) with a maximum stress level of 200 kPa for completely to highly weathered granite were obtained by Fugro using the method of least square from the results of triaxial tests on samples collected from the GI.

The geological cross-section of slope No. 11NW-A/C58 as interpreted by Fugro (Figure 6a) shows about 10 m of completely weathered granite overlying some 8 m of highly weathered granite which overlies slightly weathered granite. Fugro used shear strength parameters of $c' = 9.6$ kPa and $\phi' = 45°$ for completely and highly weathered granite in their stability assessment. No reference was made by Fugro in the geotechnical report to explain the minor difference in the adopted shear strength (ϕ') parameter. Fugro reported that groundwater level was generally "close to the slightly weathered granite bedrock level" and suggested that "Existing water level was assumed to rise up to 10 m under the influence of a rainstorm with a 1000 year return period, and lesser amounts for a storm with a 10 year return period". Fugro's section for the stability analysis (Figure 6b) shows only a 3 m to 4 m (not 10 m) rise in groundwater level above the slightly weathered granite bedrock level for a 1000 year return period event. This discrepancy is not referred to in the geotechnical report. Fugro calculated the minimum factor of safety of the soil portion of slope No. 11NW-A/C58 for groundwater conditions corresponding to a 1000 year return period rainfall as being 1.6, with a maximum depth of the slip surface of about 8 m below the slope surface.

Fugro commented that "The lower rock cut [of slope No. 11NW-A/C58] along Castle Peak Road is formed in moderately to slightly weathered granite and joints are favourably orientated for stability". No reference was made in Fugro's report to any rock joint mapping for slope No. 11NW-A/C58. There is no reference in Fugro's report to loose rock blocks, seepage or unplanned vegetation and no slope works were proposed for slope No. 11NW-A/C58 in Fugro's geotechnical report.

On 30 June 1978, Tsuen Wan New Town Development Office (TWNTDO), as part of their preparation of the grant conditions for the residential development, forwarded Fugro's report to the Geotechnical Control Branch (GCB) of Building Ordinance Office (BOO) for comment. On 17 August 1978, GCB provided comments on Fugro's report to TWNTDO and noted that "The ϕ' values used in the Fugro's analysis appear higher than normal values used locally. Although these values are determined by triaxial tests and undisturbed soil samples obtained from drill holes, a complete set of laboratory test results which should include method of sampling and specimen selection and preparation, data on density determination, saturation, consolidation, strain and stress, pwp measurements etc. will be required for consideration". GCB also suggested that "Cracked chunam surfacing and damaged or blocked surface channels should be remedied".

On 19 August 1978, the Authorized Person (AP) of "Wah Yuen Chuen Residential Development" project, Wong & Ouyang & Associates, Architects and Engineers, Hong Kong (W&O), submitted a site formation plan, together with Fugro's Geotechnical Investigation Report - 1 to the BOO for approval.

The drawings, which accompanied the site formation submission, show the layout plan of slope No. 11NW-A/C58 and include some detail of spot heights along the berms. Figure 8 shows the relevant information on slope drainage provisions from the drawings. The drawing indicates that the drainage channels on the first and second berms were not continuous for approximately 85 m and 40 m respectively across the exposed rock portion of the slope while the drainage channel on the third berm ran across the entire slope. Based on the spot levels shown on the approved drawing, the first and second berm channels at the northwest portion of the slope appear to fall towards the southeast and discharge surface runoff directly onto the exposed rock portion of the slope. Fugro's geotechnical report did not contain any proposals for drainage works on slope No. 11NW-A/C58.

On 24 October 1978, the BOO approved the site formation plan and commented that W&O were "required to assess the overall stability of those slopes where shallow foundations are to be constructed on, or at the crest of slopes". In May 1980, W&O submitted slope stability analyses and bearing capacity calculations (which could not be located in BD's private development submission file, nor in an archive search by W&O) for Blocks 2 and 3 (i.e. the present-day Wah Yee Court and Wah Lai Court respectively) Podium Carpark above slope No. 11NW-A/C58, to BOO for approval. The BOO approved their submission on 12 June 1980.

2.5.3 1991/92 LPM Programme

In 1989, slope No. 11NW-A/C58 was included in the LPM selection exercise for the 1991/92 LPM Programme. On 1 February 1990, the District Lands Officer, Kwai Tsing informed GCO that slope No. 11NW-A/C58 was within KCTL No. 316 and was the responsibility of Wah Yuen Chuen Co-operative Building Society Limited. The slope was subsequently excluded from the 1991/92 LPM Programme.

2.5.4 Systematic Inspection of Features in the Territory and Systematic Identification and Registration of Slopes in the Territory

In 1992, the GEO commenced a consultancy entitled 'Systematic Inspection of Features in the Territory' (SIFT). This assignment aimed to search systematically for slope features not included in the 1977/78 Catalogue of Slopes and to update information on previously registered features, by studying aerial photographs together with limited site inspections. The Phase 2 SIFT Study of slopes in the vicinity of the June 2001 rockfall site was carried out in August 1994. Slope No. 11NW-A/C58 was designated SIFT Class "C1", i.e. a slope "Assumed formed pre-1978 … …".

In July 1994, the GEO initiated a project entitled 'Systematic Identification and Registration of Slopes in the Territory' (SIRST), to update the 1977/78 Catalogue of Slopes. The slope was inspected by HyD through their "Roadside Slope Inventory and Inspections"

project in March 1995 (see Section 2.5.5). The slope was not inspected by the SIRST consultants. On 20 July 1999, slope No. 11NW-A/C58 was inspected by the Slope Safety Division of the GEO for updating of slope information. Inspection record noted slight to moderate seepage below about mid-height of the exposed rock portion of the slope (Plate 16). No obvious distress or other observation of any loose rock blocks or unplanned vegetation on the slope was noted in the inspection record. No New Priority Classification System score (Wong, 1998) was obtained because the slope had been subject to the LPM action in 1997.

2.5.5 Roadside Slope Inventory and Inspections

On 6 March 1995, under Agreement No. CE 29/94, "Roadside Slope Inventory and Inspections" administered by HyD, Fugro (Hong Kong) Limited, Mouchel Asia Limited and Rendel Palmer Tritton (Asia) of High Point Rendel (Hong Kong) Limited (FMR) carried out an inspection of slope No. 11NW-A/C58, which included both the government portion under HyD's maintenance responsibility and the private portion of the slope. The inspection report recorded that the hard surface cover was in a poor condition and noted the following: "rigid surface cover is cracked", "drainage channels are blocked with vegetation" and "Recent seepage from within slope - fast".

The FMR report noted that the overall state of slope maintenance was "POOR" and recommended maintenance works including "Remove loose rocks or soil blocks", "Repair damaged slope surfacing" and "Remove surface vegetation causing damage". The location plan, which is included in the FMR report, delineates areas on the slope where these maintenance works were required, including works to the privately owned portion of slope No. 11NW-A/C58. It is uncertain whether any of recommended works were carried out.

2.5.6 Slope Inspection by GEO in November 1996

On 28 October 1996, HyD informed the GEO that they would shortly shotcrete slope No. 11NW-A/C58 (see Section 2.4.1). The GEO's Design Division inspected the slope in November 1996 just after the commencement of the shotcreting works. The GEO inspection record noted seepage along joints on the exposed rock portion of the slope below the second berm. No record of loose rock blocks was mentioned in the GEO's inspection record. Areas of unplanned vegetation on the exposed rock portion of the slope are shown in the accompanying photographs (Plate 10) and indicated in a sketch attached to the inspection record.

2.5.7 LPM Stage 2 Study

In December 1995, HyD nominated slope No. 11NW-A/C58 for inclusion in the LPM Programme. The slope was subsequently included in an LPM Agreement for an LPM Stage 3 Study in April 1997. In May 1997, GEO sent the SIMAR report (see Section 2.2) to the LPM consultants, HAP, confirming that the private owners of KCTL Lot No. 316 were responsible for the maintenance of most of the slope. The slope was subsequently transferred to a Stage 2 Study (i.e. a safety-screening study) under the LPM Programme in June 1997.

The Stage 2 Study was completed by HAP in August 1998. There is no mention in the Stage 2 Study report by HAP of a check on the status of the slope in terms of whether it has been through the Slope Safety System or not. Apart from joint mapping at the lower part of the rock portion of the slope, no GI works were undertaken for the Stage 2 Study.

Photographs taken by HAP in mid-1997 (Plate 11) show extensive new shotcrete on the northwest and southeast portions of slope No. 11NW-A/C58. HAP's observations of the surface drainage are shown in Figure 9. HAP noted that the surface drainage channels on all three berms to the northwest of the exposed rock portion drain towards the northwest. These observations are inconsistent with the post-failure site observations made by MGSL (see Section 2.1) that the drainage channels on the northwest portion of the slope drain to the southeast and onto the exposed rock portion of the slope (Figure 2). On the southeast portion of the slope, HAP observed no drainage on any of the berms, which is consistent with MGSL's observations (see Section 2.1), whereas W&O's approved site formation plan (Figure 8) shows drains on each of the berms with spot heights that indicate falls towards the southeast. It is possible that the drains on the southeast portion of the slope have been concealed by the shotcreting applied in 1997 (see Section 2.4.1). For the central, exposed rock slope portion, HAP noted "A small number of shrubs and unplanned vegetation were present".

HAP carried out stability analyses of the soil and rock portions of slope No. 11NW-A/C58. HAP reviewed the shear strength parameters adopted by Fugro in 1978 and commented that "the shear strength parameters obtained from the 1978 GI are considered to be unreliable" since they "exceed the upper bound limits stated in Table 8, Geoguide 1" and "In particular, unrealistically high effective cohesive values were obtained". The report also noted that as part of their "site examination of the slope … the shear strength of the materials was observed to be less than indicated by the test results". HAP referred to the Stage 1 report completed by the Planning Division of the GCO in 1987 for the nearby slope No. 11NW-A/C60 and adopted shear strength parameters from that report of $c' = 5$ kPa and $\phi' = 38°$ for completely decomposed granite or completely to highly decomposed granite, and $c' = 15$ kPa and $\phi' = 40°$ for highly decomposed granite for the purpose of slope stability assessment.

HAP observed seepage from rock joints at the central portion of the slope as indicating groundwater above the toe. They also referred to Fugro's Geotechnical Investigation Report (Fugro, 1978) and quoted Fugro's assumption that the groundwater level was generally consistent with the bedrock level. By using the wetting band approach, HAP estimated that the groundwater level would rise about 2.5 m above the rockhead level under a 1 in 10 year rainfall event.

The main findings of the HAP study were:

(a) For the soil cut portion of the slope, based on an upper bound "estimated water table to represent a 1 in 10 year rainfall event (i.e. 2.5 m above rockhead ……" and "conservative material parameters …… for the nearby feature 11NW-A/C60", the calculated minimum FOS for overall stability (0.92 to 1.18) and the individual batters (0.99 to 1.11) "are unacceptable for both wet and dry

conditions" and there was the potential for deep-seated failure with slip surfaces to depths of up to 6 m.

(b) Rock joint mapping was carried out for the lower part of the rock portion of the slope and a stereographic plot was constructed from all the joint measurements (see Appendix B), which "did not identify any adverse joint sets". The report concluded that "rock joint analysis and observation of rock fragments at the toe indicate that localized minor rock fall is likely".

(c) The "portion of the slope at the eastern corner, maintained by HyD is defined to be stable".

The report concluded that slope No. 11NW-A/C58, except that portion maintained by HyD at the eastern corner, had inadequate factors of safety against both shallow and deep-seated failure and, in addition, localized minor rockfall was likely. In August 1998, on completion of their Stage 2 Study, HAP recommended that a Dangerous Hillside (DH) Order be issued to the owners of the private portion of slope No. 11NW-A/C58 i.e. the owners of KCTL No. 316. On 12 September 1998, GEO recommended to the Buildings Department (BD) that a DH Order be served on the owners of KCTL No. 316 for the concerned portion of the slope.

2.5.8 Routine Maintenance Inspections

Routine maintenance inspections of the government portion of slope No. 11NW-A/C58 were carried out by HyD in December 1998, November 1999 and December 2000. The inspection reports recommended that no action was necessary with regard to maintenance works. None of the inspection reports mentioned any loose rock blocks or unplanned vegetation on the slope.

2.6 Dangerous Hillside Order

Follow the recommendation of 12 September 1998 by the GEO, BD served a DH Order on the owners of KCTL No. 316 (Incorporated Owners of Wah Yuen Chuen) on 25 June 1999, noting that their portion of the slope was liable to become dangerous. The DH Order required the owners to appoint an Authorized Person (AP) within two months of the issue of the DH Order, to commence investigation on site within three months of the issue of the DH Order and to submit remedial designs to BD for approval within seven months of the issue of the DH Order. In the covering letter, which accompanied the DH Order, it is made clear that the AP must be, or must engage, a suitably qualified geotechnical engineer and that the AP should be responsible for monitoring the stability of the slope until the remedial/preventive works are completed and should give warning of impending danger.

The owners appealed against the DH Order on 10 July 1999. The owners also made several requests for additional time to gather information about the ownership and availability of remedial measures. The appeal was based on the owners' contention that the slope was not part of their private lot and, in any event, the "Government" had assumed responsibility

by carrying out extensive slope repair works on the feature in June 1997. The Appeal Tribunal (Buildings) dismissed the appeal more than a year later (i.e. on 22 August 2000). In rejecting the arguments, the Appeal Tribunal stated that "There is no doubt that the feature is within the boundary of KCTL 316" and "It cannot be said the Government by the exercise of such power, [that vested in the Building Authority under the Buildings Ordinance (BO)] is to be taken to have accepted that it is the owner of the slope or that it must thereafter ensure the safety of the slope".

There are no records in BD to suggest that an AP has been engaged to investigate the stability of the slope and to design any necessary stabilisation works since then and prior to the June 2001 failure. By the time of the rockfall in June 2001, BD had not declared the owners in default on their obligations under the DH Order.

On 13 June 2001, BD wrote to the Incorporated Owners of Wah Yuen Chuen referring to the DH Order and stating that they had not received any notice of the appointment of an AP and allowing 14 days for notification of the appointment of an AP or a reasonable explanation for failure to commence works. On 16 June 2001, after a joint (GEO, HyD, BD) site visit to the rockfall site, GEO wrote to BD confirming that the emergency works (the construction of two concrete buttresses to support two loose rock blocks) should be carried out. GEO also requested the status of the DH Order and suggested that BD consider taking action to safeguard the safety of the public. On 18 June 2001, BD issued a reminder to the Incorporated Owners of Wah Yuen Chuen of appropriate measures to be taken to ensure the safety of the public during the wet season. They also reminded the owners to "expedite the appointment of an Authorized Person".

On 6 February 2002, BD wrote to the Incorporated Owners of Wah Yuen Chuen stating that the DH Order had expired two years previously and advising that at the recommendation of the GEO, the exposed rock portion of the slope and the vegetated area above should be provided with wire mesh as a safety measure. In the same letter, BD advised the private owners that, if this safety measure were not carried out prior to 15 March 2002 (i.e. before the onset of the rainy season), urgent action under the BO would be taken by the BD at the private owners' expense to protect the public. By 15 March 2002, no actions were taken by the private owners to comply with the requirements stated in the BD's letter of 6 February 2002. On 23 March 2002, BD initiated urgent works including the installation of wire mesh on the exposed rock portion of the slope and the vegetated area above. Up to April 2002, an Authorized Person was yet to be engaged by the private owners to monitor the stability of the slope, to give warning of impending danger, to investigate the slope and to submit the necessary remedial proposals, as required by the Statutory Order. As of April 2002, the DH Order had not been declared by BD to be in default.

3. THE INCIDENT

3.1 Description of the Incident

The description of the incident is based on information in the Police Incident Report and the GEO Incident Report and interviews with the police officer who attended the incident and with the driver and passenger of the Post Office van.

The rockfall occurred at about 6:00 p.m. on 9 June 2001. It was not raining at the

time of the rockfall. The incident involved detachment of at least two boulder-sized rock fragments from the slope and some minor rock debris with a total volume of approximately 0.05 m^3.

According to the driver and the passenger of the van, the road surface was slightly wet at the time. Just before the accident, the driver of the Post Office van observed a rock fragment as it fell onto the road some 10 m in front of the van while the van was travelling on the inside lane of the southeast bound carriageway of Castle Peak Road. Another rock fragment punched through the windscreen and severely damaged the steering wheel (Plate 1). The driver and the passenger could not identify the source of the fallen rocks. The driver became unconscious and lost control of the van which continued along the road, mounted the footpath and skidded along the toe of the slope before coming to a halt against the slope. As a result, the driver and the only passenger, who was also in the front seat of the van, were injured.

The rock fragment which punched through the windscreen was sub-angular, spherical in shape and about 300 mm in size (Plate 2). It is apparent that the van travelled some distance after the rockfall but this distance is unknown and it is therefore difficult to determine the exact location on the rock face from which the rock fragments have detached. The poor condition of the rock face with unplanned vegetation and a notable number of loose blocks also renders it difficult to establish the precise location of the source of the rockfall. The position of the van after the accident is shown on Figure 2. Based on the skid marks along the slope toe (Plate 3), the van probably travelled at least 10 m after the impact by the rock fragment.

3.2 Site Observations

MGSL carried out detailed post-failure site inspections, the first of which was on 10 June 2001, the day following the rockfall incident. MGSL also carried out a discontinuity survey along the lower part of the exposed rock portion of the slope and constructed a stereographic projection of the measured joints (Appendix B).

The exposed rock portion of the slope consists of slightly to moderately decomposed granite (generally PW 90/100) which is generally strong to moderately strong. The southeast portion of the exposed rock slope consists of coarse-grained, locally porphyritic granite, which in places is highly decomposed and moderately weak, while the northwest portion comprises fine-grained granite with bands of coarse-grained granite. The coarse-grained granite is generally pinkish grey where slightly decomposed and where highly decomposed is brownish yellow. The fine-grained granite is predominantly dark grey in colour.

Joints are generally closely, locally medium spaced, rough and slightly undulating and often iron stained to brown and brownish yellow, generally tight to very narrow with no evidence of extensive infill. MGSL measured the typical slope orientation as 60°/228° and the most common joint sets as 59°/082°, 76°/144° and 86°/325°, and concluded that there were no major adverse joint sets. The stereoplots produced by MGSL and HAP are reproduced in Appendix B and both suggest that the slope is liable to minor toppling failure. However, site observations by MGSL showed adversely orientated sheeting joints striking

parallel to the slope surface and dipping steeply towards Castle Peak Road (Plate 17) at several localities along the first batter of the rock portion of the slope. Minor wedge failures (Plate 18) were also noted by MGSL which appear to have resulted from the intersection of two of the major joint sets (59°/082° and 86°/325°) with a minor joint set dipping out of the rock face at about 20° to 30°. The intersection of the same two sets of joints (viz. 59°/082° and 86°/325°) with the sheeting joints (60° to 70°/220°) could mean that larger potential wedge failures are kinematically feasible.

The joints have been exploited by unplanned vegetation leading to the development of discrete rock blocks (Plates 19 and 20). There are, however, some localities on the rock slope portion where the broken fragments are so small and irregular (Plate 21) that they may be a result of blasting during the original slope formation.

The boundary between the coarse-grained granite to the southeast and the fine-grained granite to the northwest is hidden by a patch of shotcrete (Plate 22) and, higher up the slope, by unplanned vegetation. As a result, the geological nature and engineering significance of the contact cannot be determined.

MGSL observed moderate seepage up to about mid-height of the first batter near the middle of the exposed rock portion of the slope. This position is close to the contact between coarse-grained and fine-grained granite and might suggest that the coarse-grained granite is more permeable that the fine-grained granite. However, this cannot be confirmed as the area is obscured by unplanned vegetation.

MGSL made several ascents of the exposed rock portion of the slope to look for the exact source of the detached rock blocks which had caused the June 2001 incident (Plate 23). It was noted that that closely spaced jointing and unplanned vegetation were generally common to most of the exposed rock portion of the slope and hence the exact source area of the rockfall could not be determined.

Numerous angular rock fragments were littered along the toe of the rock slope indicating similar minor failures in the past (Plate 24).

Unplanned vegetation covering much of the exposed rock portion and all the berms of slope No. 11NW-A/C58 was observed (Plate 5 and Plates 22 to 26). MGSL's observations of the size and direction of the drainage channels are shown on Figure 2. Most of the half-round channels on berms were partly blocked by unplanned vegetation (Plate 27). MGSL also noted that the surface channels on the berms of the northwest portion of the slope apparently discharge directly onto the exposed rock face (Plate 28).

Several sizeable items of domestic rubbish were seen on the natural hillside area adjacent to the podium area of Wah Yuen Chuen. Other areas of the natural hillside within the portion of the private lot were covered with dense vegetation and could not be accessed for close inspection.

4. ANALYSIS OF RAINFALL RECORDS

On the day of the rockfall incident, Amber Rainstorm Warning was in force between

4:15 a.m. and 9:30 a.m. and this was upgraded to Red Rainstorm Warning between 9:30 a.m. and 1:30 p.m. The Rainstorm Warning was changed to Amber at 1:30 p.m. and lowered at 3:30 p.m.

The nearest GEO automatic raingauge No. N04 (which has been in service since September 1978) to the rockfall site is located at Kai Kwong Lau, Cho Yiu Estate, about 640 m to the southwest of the site (Figure 1). The daily rainfall recorded in May and June 2001, together with the hourly rainfall from 7 to 9 June 2001, is shown in Figure 10.

Rain was heavy on 9 June 2001 between 10:30 a.m. and 11:30 a.m. No rainfall was recorded by raingauge No. N04 between 2:20 p.m. and the time of rockfall (at about 6:00 p.m.). The 12-hour and 24-hour rainfalls before the incident were 116.5 mm and 128 mm respectively. Some 533 mm and 649 mm of rain respectively were recorded by raingauge No. N04 over the 15 days and 31 days before the rockfall.

The estimated return periods for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) are given in Table 1. For rainfall durations between one hour and 24 hours, the return periods were less than two years. For rainfall durations between four days and seven days, the return periods were about four years. The return periods for various durations based on the data recorded by raingauge No. N04 between 1984 and 1997 have also been assessed based on the statistical parameters derived by Evans & Yu (2001). It is noted that there is no significant difference between the estimated return periods based on the historical rainfall data at the Hong Kong Observatory and that at raingauge No. N04.

The maximum rolling rainfalls for the rainstorm on 9 June 2001 have been compared with the previous available data on severe rainstorms since automatic raingauge No. N04 became operational in September 1978 (Figure 11). The maximum rolling rainfalls for the rainstorm on 9 June 2001 were not exceptionally heavy compared with previous rainstorms.

5. DIAGNOSIS OF THE PROBABLE CAUSES OF THE FAILURE

The correlation between the timing of the 9 June 2001 rockfall and the rainstorm prior to the failure suggests that the rockfall was likely to have been triggered by rainfall.

There is no evidence that the rockfall originated other than from the exposed rock portion of slope No. 11NW-A/C58. There were no clear marks on the shotcrete cover of the slope or any rock fragments lying on the berms to suggest that the detached rock fragments might have originated from the ground above the cut slope. However, within the exposed rock portion of the cut slope, the exact location from which the rock block detached cannot be precisely determined. This is because detailed examination of the exposed rock portion revealed that the conditions which probably contributed to the detachment of the small rockfall fragments exist across most of the rock exposure within the boundary of slope No. 11NW-A/C58. It is, therefore, probable that the source area for the rockfall is within the 15 m high, exposed rock portion of slope No. 11NW-A/C58.

The rocks of the exposed portion of slope No. 11NW-A/C58 comprise generally moderately strong to strong coarse-grained and fine-grained granites. Areas of moderately

weak rock within the coarse-grained granite suggest that it is locally more susceptible to weathering. The rock mass is extensively affected by closely spaced joints, allowing the development of discrete rock blocks. The joints are iron-stained but, in general, otherwise clean and there is no evidence that joint infill has been a contributory factor to the rockfall. Site observations also identified the presence of adversely orientated sheeting joints (Plate 17) and the possibility of small wedge failures in local areas (Plate 18). In places, the rock mass is broken up into irregular, angular, coarse gravel-sized fragments (Plate 20), which might have been the result of blasting during the road widening works carried out some time between 1954 and 1963.

Seepage has been identified, even in the dry season, in some areas of the exposed rock cut portion of the slope in API in 1963 and 1969 and in subsequent studies and inspections, as well as site observations as part of this landslide study. The drainage channels from the berms to the northwest of the exposed rock portion of the slope apparently discharge directly on the exposed rock face and there are no drainage channels on the berms on the shotcreted slope portion to the southeast of the exposed rock slope portion. Post-failure inspections show that the surface drainage channels were blocked and had subsequently been overgrown. As a result of the discharge of the surface drainage onto the unprotected rock slope and the persistent seepage, unplanned vegetation, in the form of small trees, shrubs and grasses, has flourished and has been unchecked since having been cleared prior to the shotcreting works on the slope in 1997 (see Section 2.4.1 and contrast Plate 5 and Plate 11). This unplanned vegetation has exploited the heavily jointed and locally shattered rock mass, with the root action jacking open the joints of the discrete rock fragments.

Infiltration of surface water and a relatively high local groundwater level in the rock portion of the slope are liable to have lead to the development of cleft water pressure and elevated water pressure in discontinuities bounding discrete rock blocks.

The rockfall can be attributed to a combination of the heavily jointed nature of the rock mass and the progressive deterioration of the slope condition. The susceptibility of the slope to minor failures is exacerbated by poor detailing of the surface drainage provisions and inadequate slope maintenance.

6. CONCLUSIONS

It is concluded that the source area of the 9 June 2001 rockfall was likely to be within the exposed rock portion of cut slope No. 11NW-A/C58. The rockfall can be attributed to a combination of a heavily jointed, locally shattered, rock mass which is prone to the detachment of small rock blocks and progressive deterioration of the slope condition. The susceptibility of the slope to minor failure is exacerbated by poor detailing of the surface drainage provisions which allows surface water to be discharged from the U-channels on the slope berms directly onto the exposed rock portion of the slope. This probably resulted in concentrated water ingress into the jointed rock mass and exacerbated the condition of the slope. This, together with consistent seepage through the rock mass, probably contributed to progressive deterioration of the exposed portion of the rock slope and promoted the growth of unplanned vegetation in the form of small trees, shrubs and grasses. The unplanned vegetation has exploited the rock joints, leading to the progressive opening up of the joints and allowing water ingress and local build-up of water pressure behind the jointed rock face.

Inadequate maintenance of the exposed rock portion of the slope was a significant contributory factor to the failure. The rainfall preceding the failure was not particularly heavy. The critical return periods of the rainfall were only about four years and the rainfall was not as severe as some of the past rainstorms experienced by the site since the nearest automatic raingauge was installed in 1978. Based on records from the nearest automatic raingauge, the 9 June 2001 rockfall occurred some three hours after the rainstorm had practically ceased (i.e. it was a delayed failure).

Although the rockfall was relatively small in volume (0.05 m^3), it was a serious incident in terms of the resultant injuries to the driver and passenger of the Post Office van travelling along the heavily trafficked road. The rockfall incident was a 'near-miss' in that the consequences could have been extremely serious.

The subject slope (viz. No. 11NW-A/C58) had been through the slope safety system in 1978 when the geotechnical submission, including the stability assessment of the slope, was checked and approved by the BOO. Since then, the exposed rock portion of the slope has not been adequately maintained and its condition has suffered progressive deterioration (growth of unplanned vegetation, etc.). A landslide with an estimated volume of less than 10 m^3 occurred in the chunam covered soil portion of the slope in June 1997. The presence of rockfall debris at the toe of slope No. 11NW-A/C58 observed shortly after the 9 June 2001 incident suggests that similar rockfalls to that of 9 June 2001 probably occurred before the incident but there are no documented records of such detachments.

7. REFERENCES

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Selected Durations Preceding the Rockfall on 9 June 2001 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	11.0	10:35 on 9 June 2001	< 2
15 Minutes	29.0	10:35 on 9 June 2001	2
1 Hour	63.0	11:10 on 9 June 2001	< 2
2 Hours	80.0	11:40 on 9 June 2001	< 2
4 Hours	107.0	11:45 on 9 June 2001	< 2
12 Hours	126.5	14:20 on 9 June 2001	< 2
24 Hours	130.5	11:45 on 9 June 2001	< 2
48 Hours	272.5	14:05 on 9 June 2001	3
4 Days	416.0	14:20 on 9 June 2001	4
7 Days	432.0	14:20 on 9 June 2001	4
15 Days	532.5	14:20 on 9 June 2001	3
31 Days	649.0	14:20 on 9 June 2001	< 2

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 (2000). The return periods obtained by the two methods do not show a significant difference.
(3) The use of 5-minute data for return period of rainfall durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.
(4) The landslide occurred at approximately 6:00 p.m. on 9 June 2001.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N04 situated at about 0.7 km to the southwest of the site.

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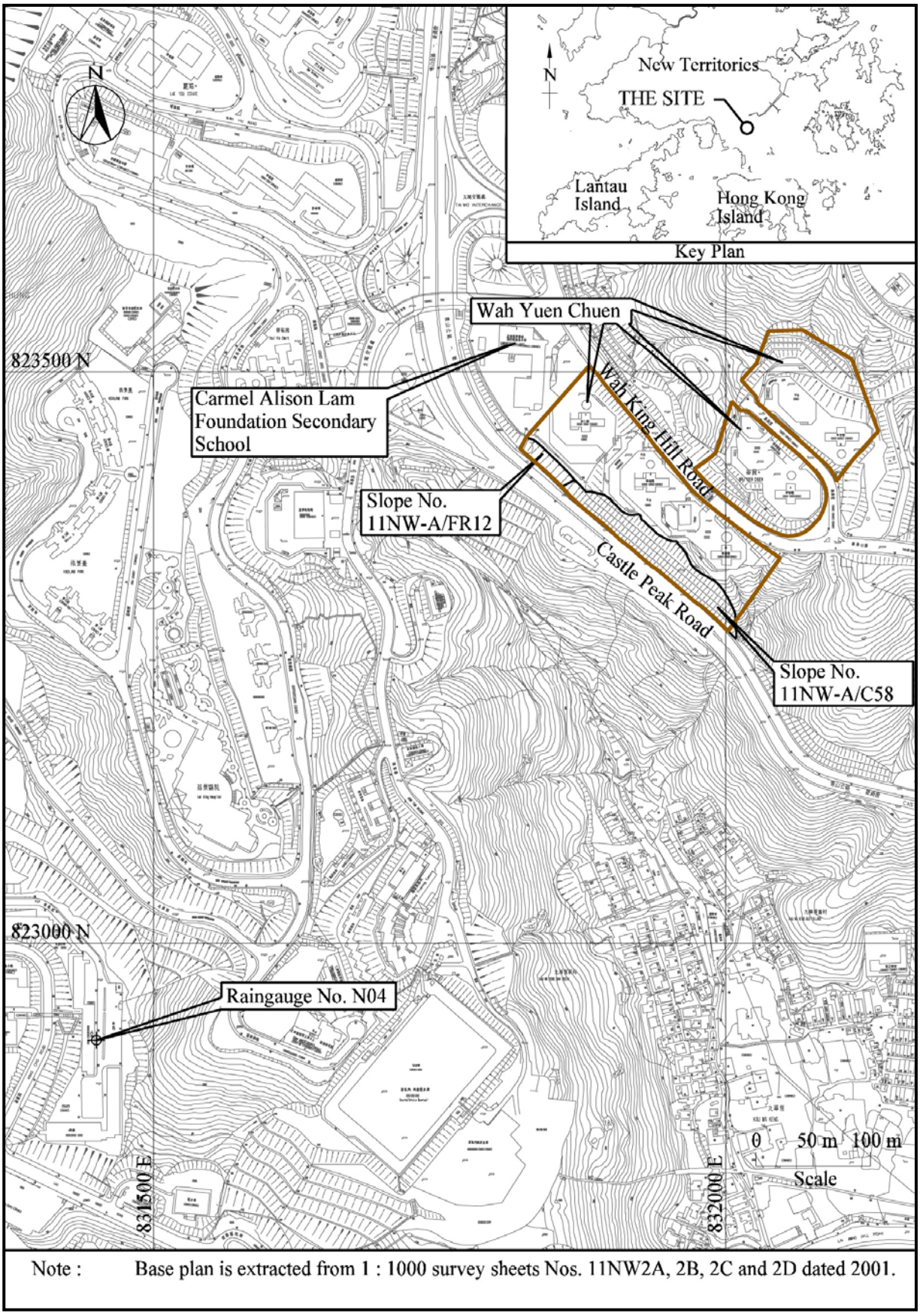

Figure 1 - Location Plan

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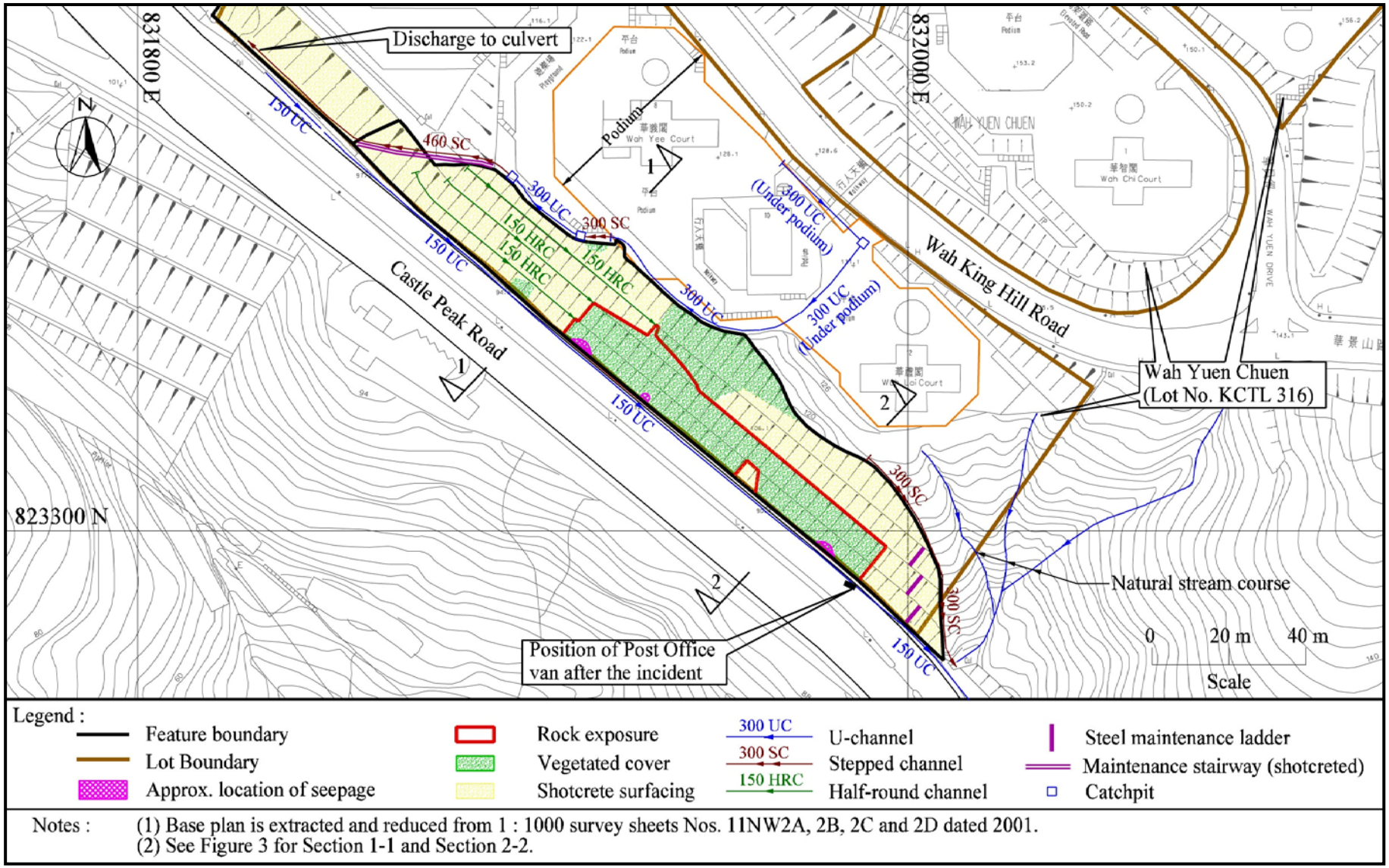

Figure 2 - General Plan Showing Site Observations

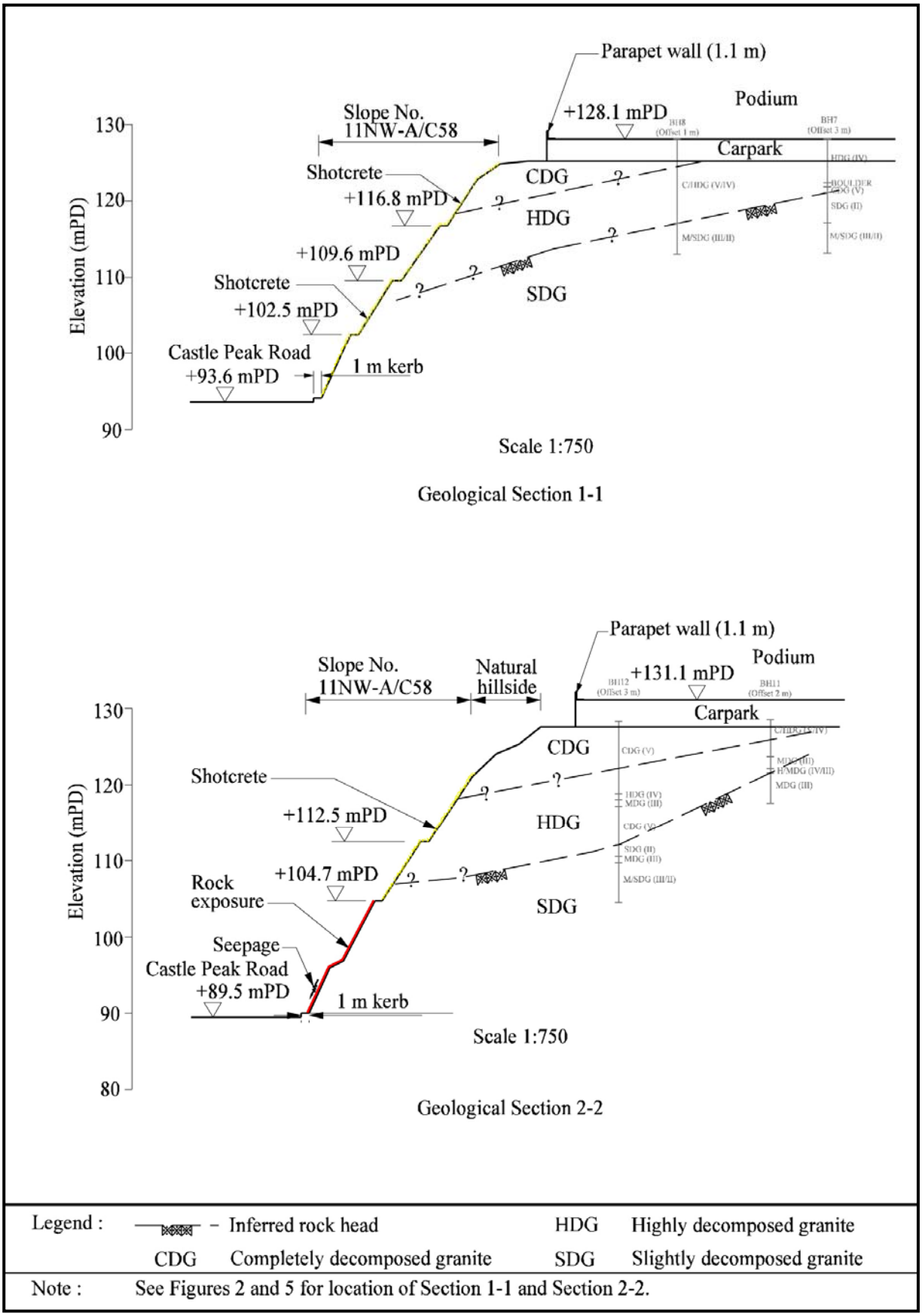

Figure 3 - Geological Section 1-1 and Section 2-2

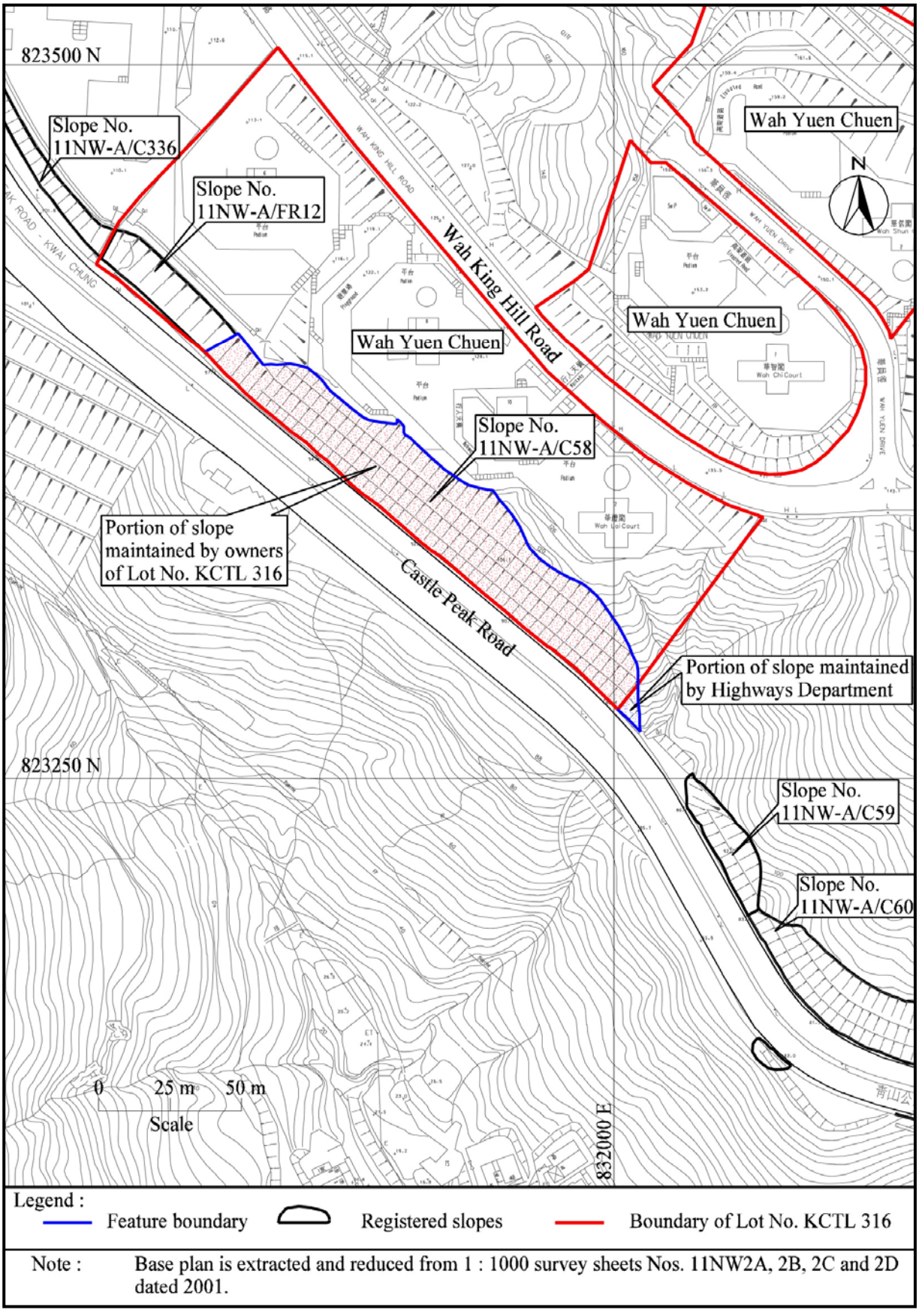

Figure 4 - Boundary of Slope No. 11NW-A/C58 and Land Status

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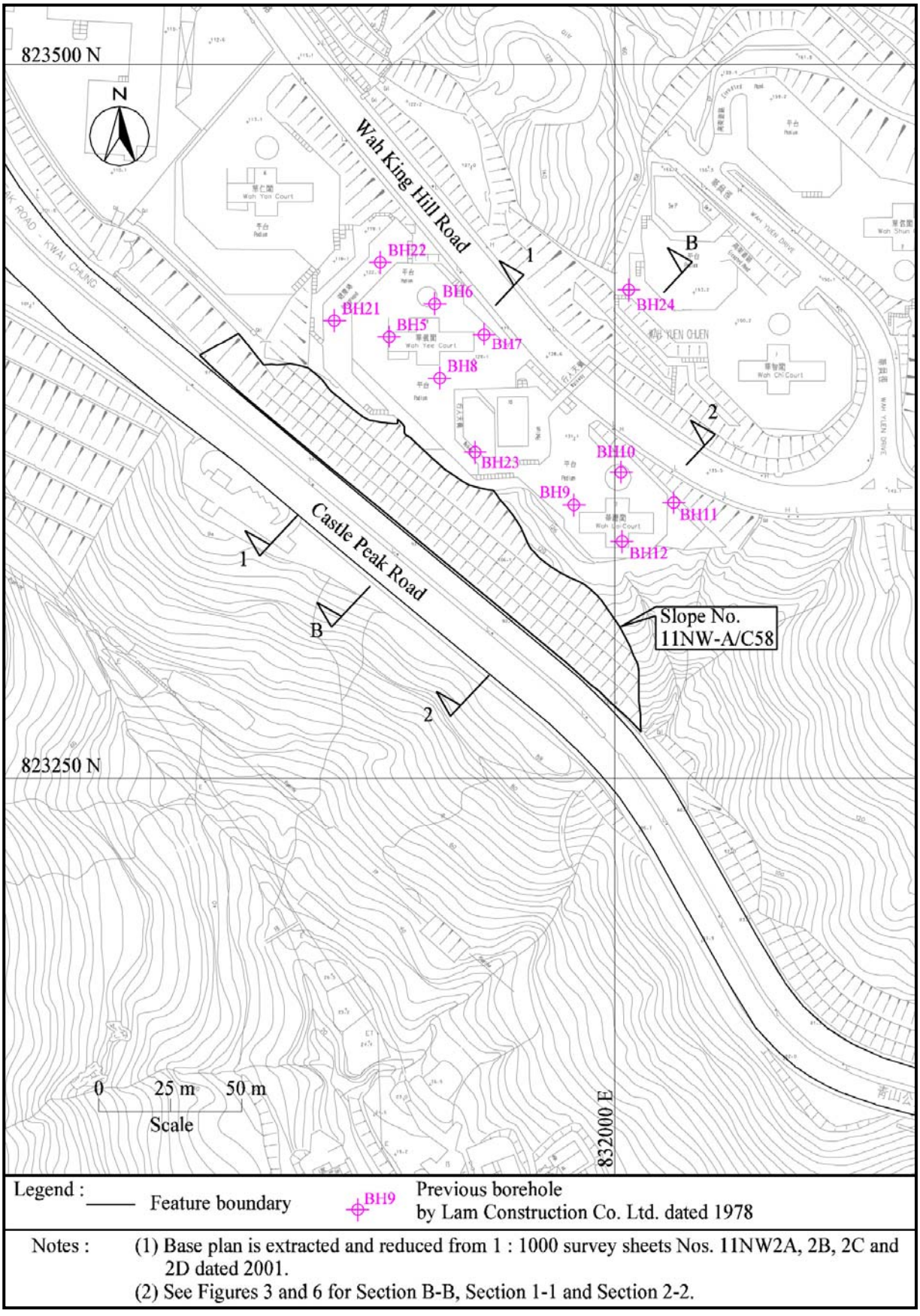

Figure 5 - Previous Ground Investigation

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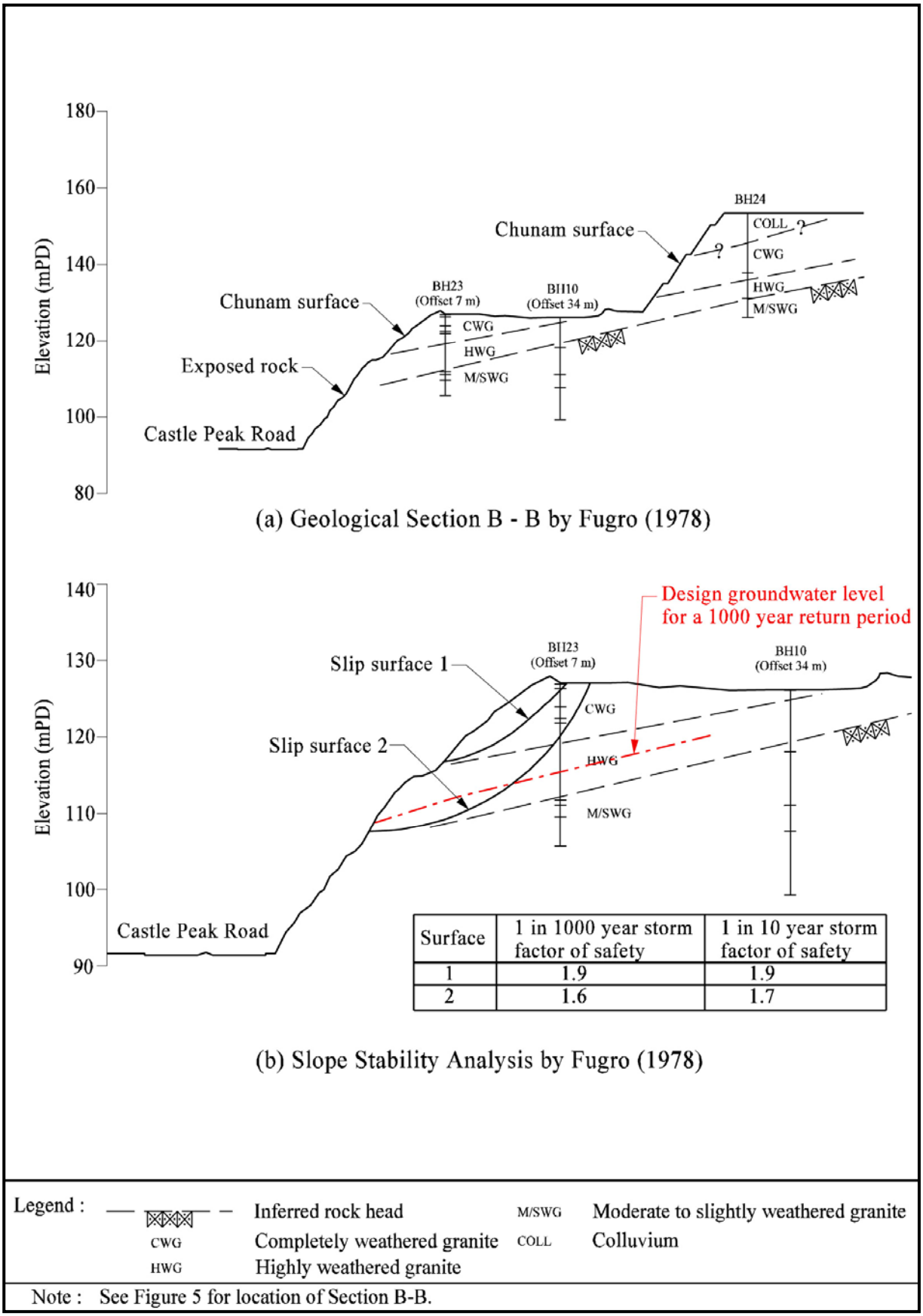

Figure 6 - Geological Section B-B and Slope Stability Analysis Extracted from Geotechnical Report for Wah Yuen Chuen Development by Fugro (1978)

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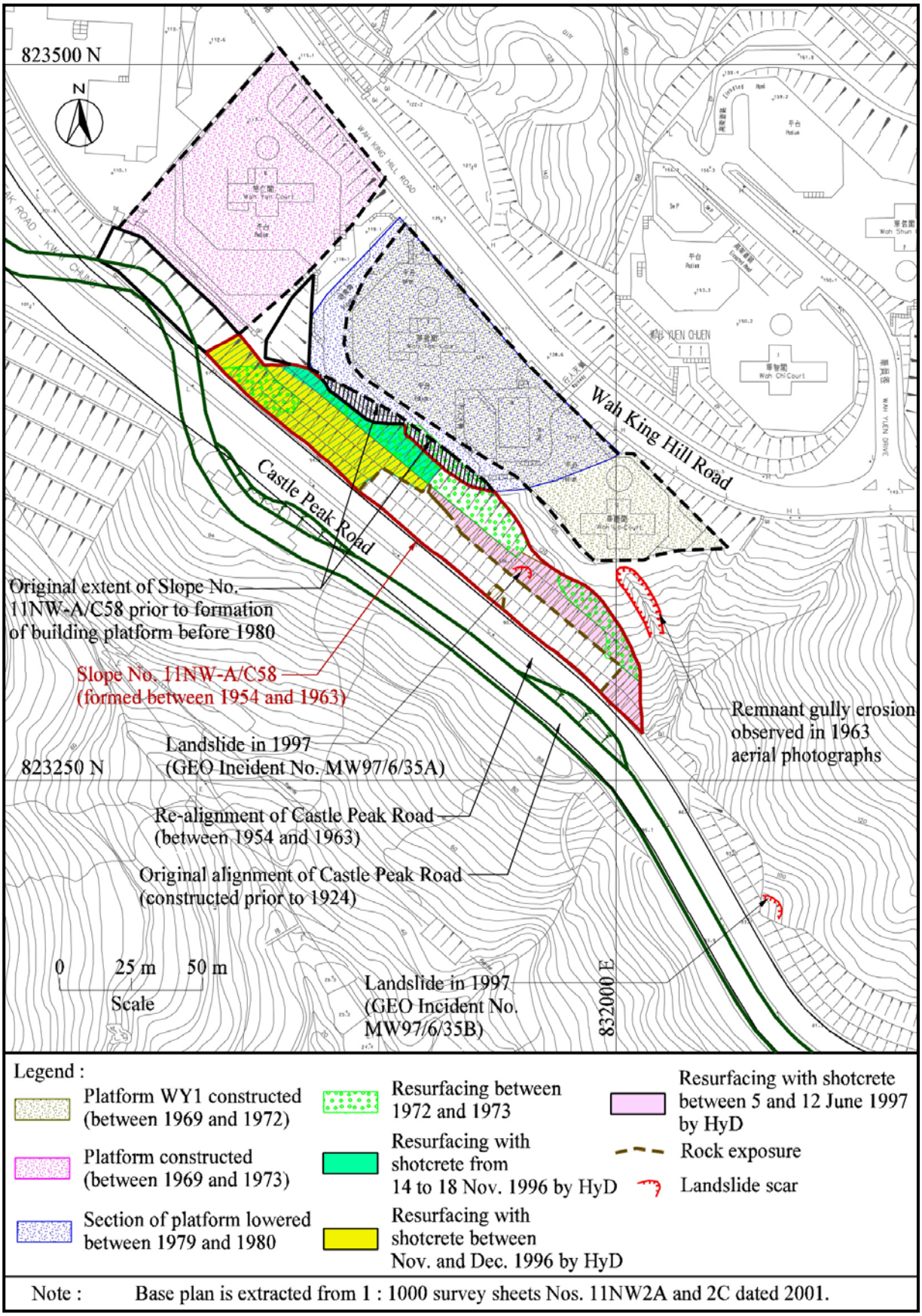

Figure 7 - Site Development History and Previous Instabilities

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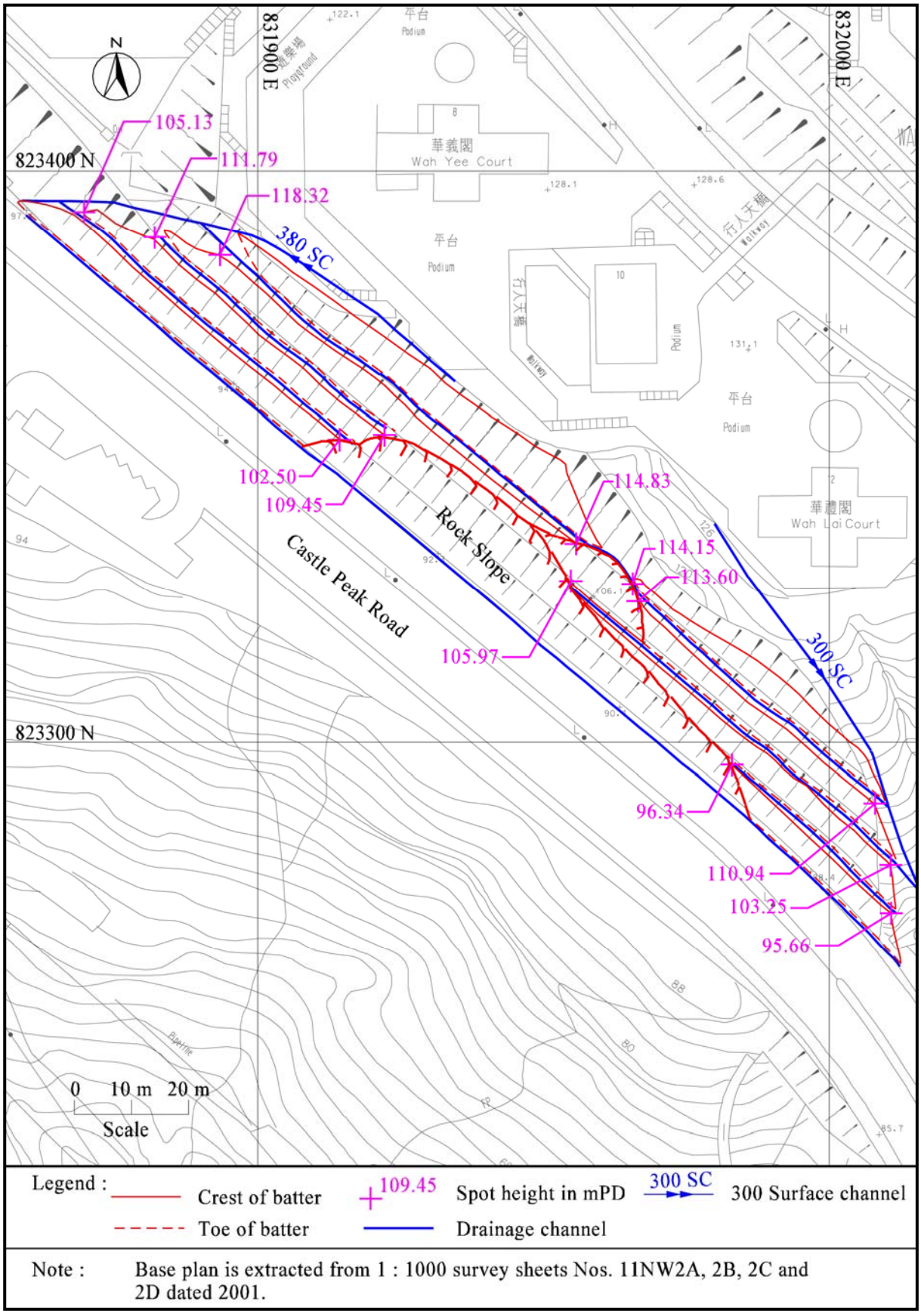

Figure 8 - Slope Drainage Plan Based on Information Extracted from Site Formation Plan Submitted to the BOO by Wong Ouyang & Associates (1978)

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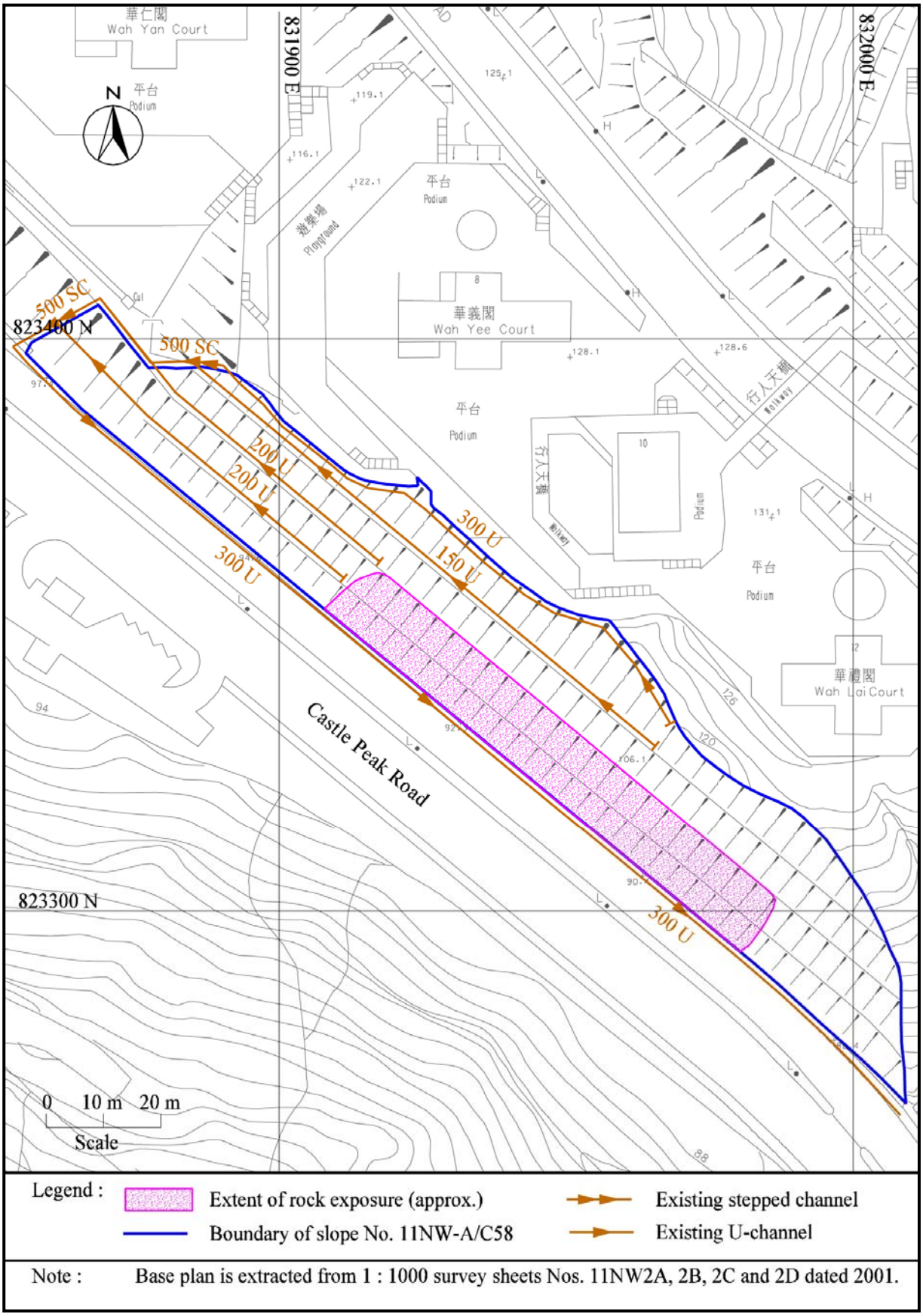

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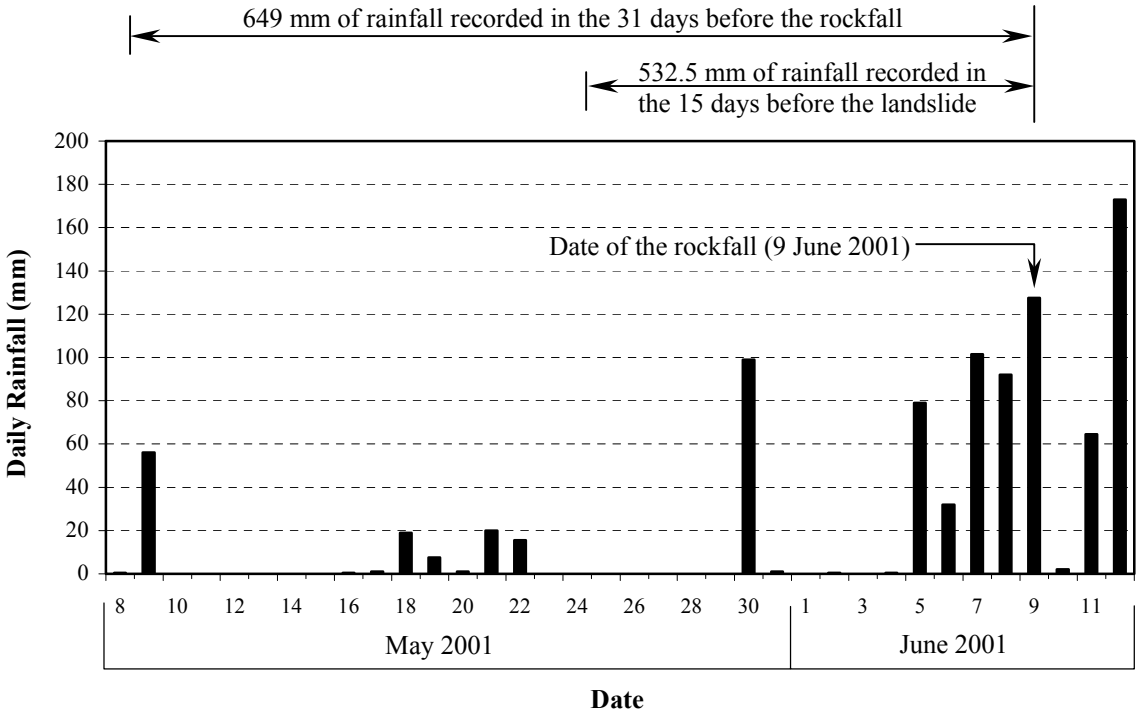
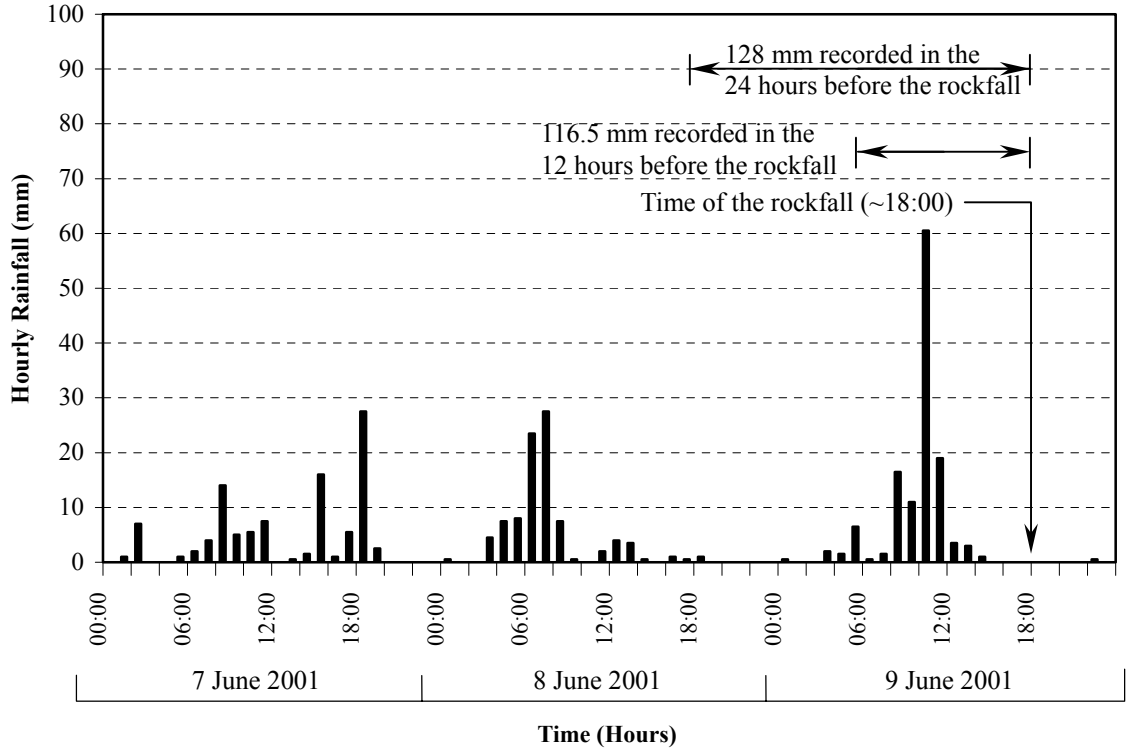
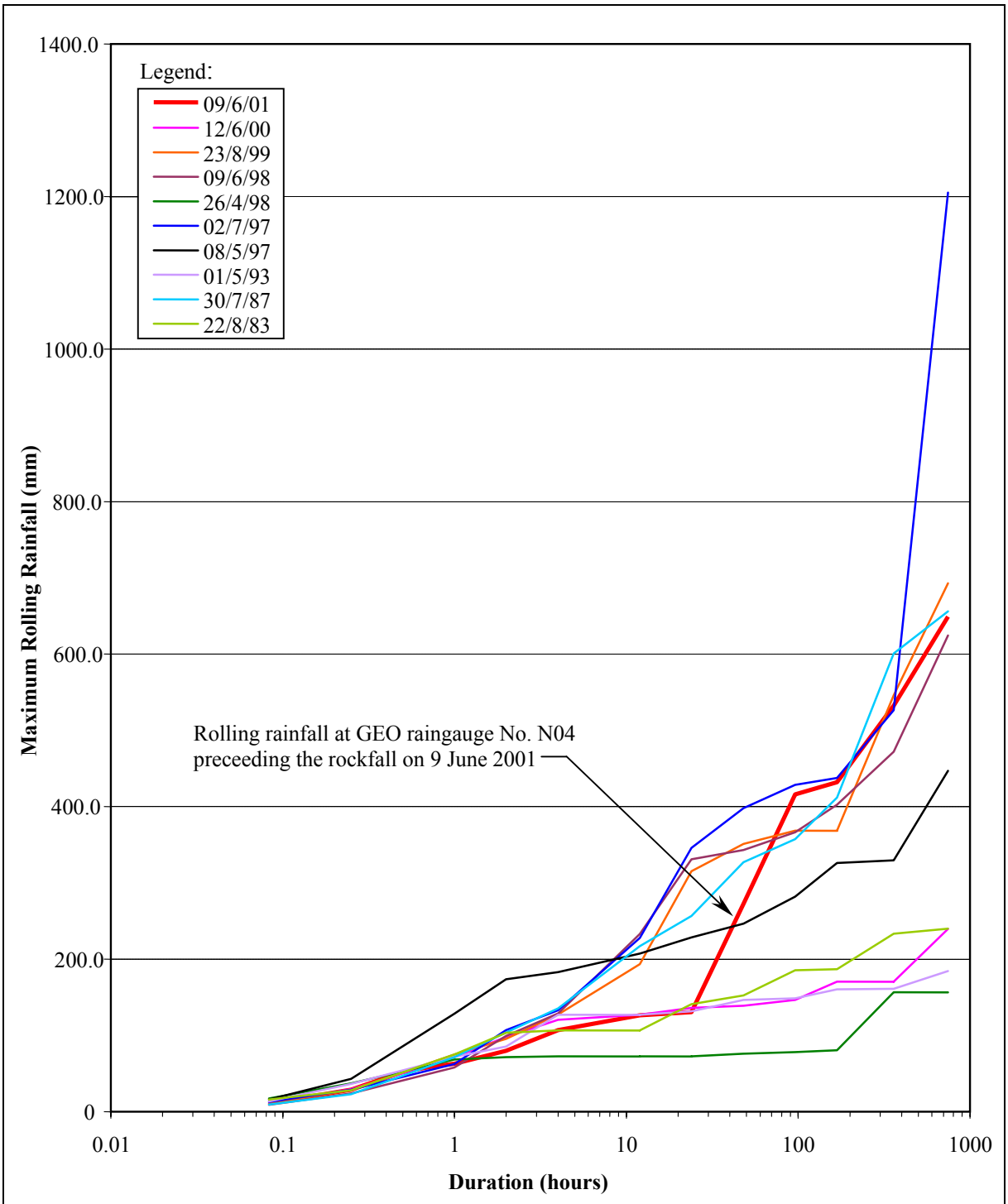


(a) Daily Rainfall Recorded at GEO Raingauge No. N04 from 8 May to 12 June 2001



(b) Hourly Rainfall Recorded at GEO Raingauge No. N04 from 7 to 9 June 2001

Figure 10 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N04 for June 2001



Notes:

(1) Previous rainstorms are selected for GEO raingauge No. N04 given in GEO Report No. 62 - "Areal Extent of Intense Rainfall in Hong Kong 1975 to 1995" (Malone, 1997) and selected rainstorms from 1996 to 2000.

(2) Rainfall data evaluated from 5-minute readings from GEO raingauge No. N04 (about 0.7 km southwest to the site).

(3) Rolling rainfall of previous rainstorm calculated at GEO raingauge No. N04 since September 1979 when the raingauge began operation.

Figure 11 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. N04

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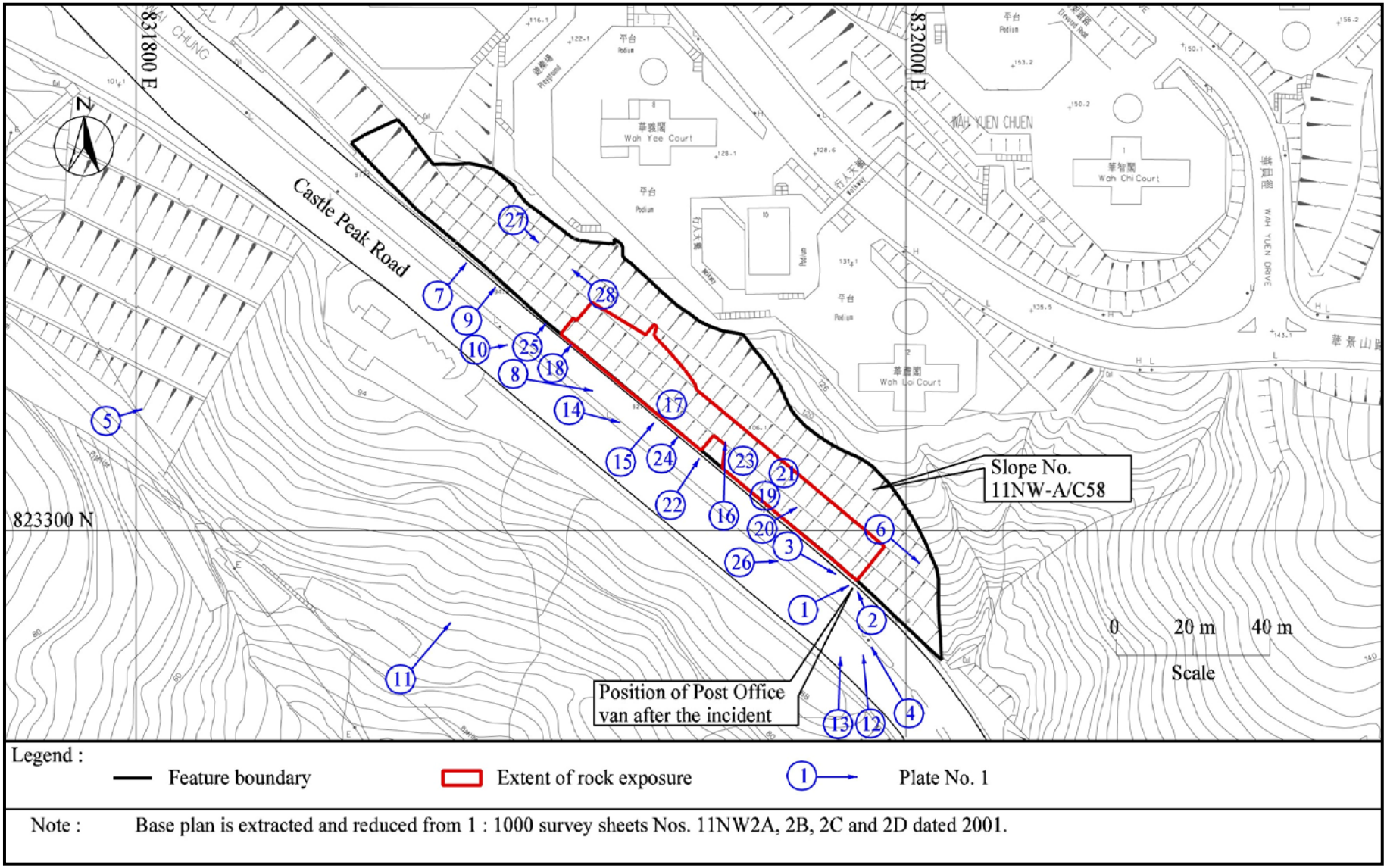

Figure 12 - Location and Directions of Photographs

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Plate 1 - View of Damage to Windscreen and Steering Wheel Caused by Falling Rock Fragment
(GEO Incident No. MW2001/06/007) (Photograph taken by Police on 9 June 2001)

Note: See Figure 12 for location and direction of photograph.

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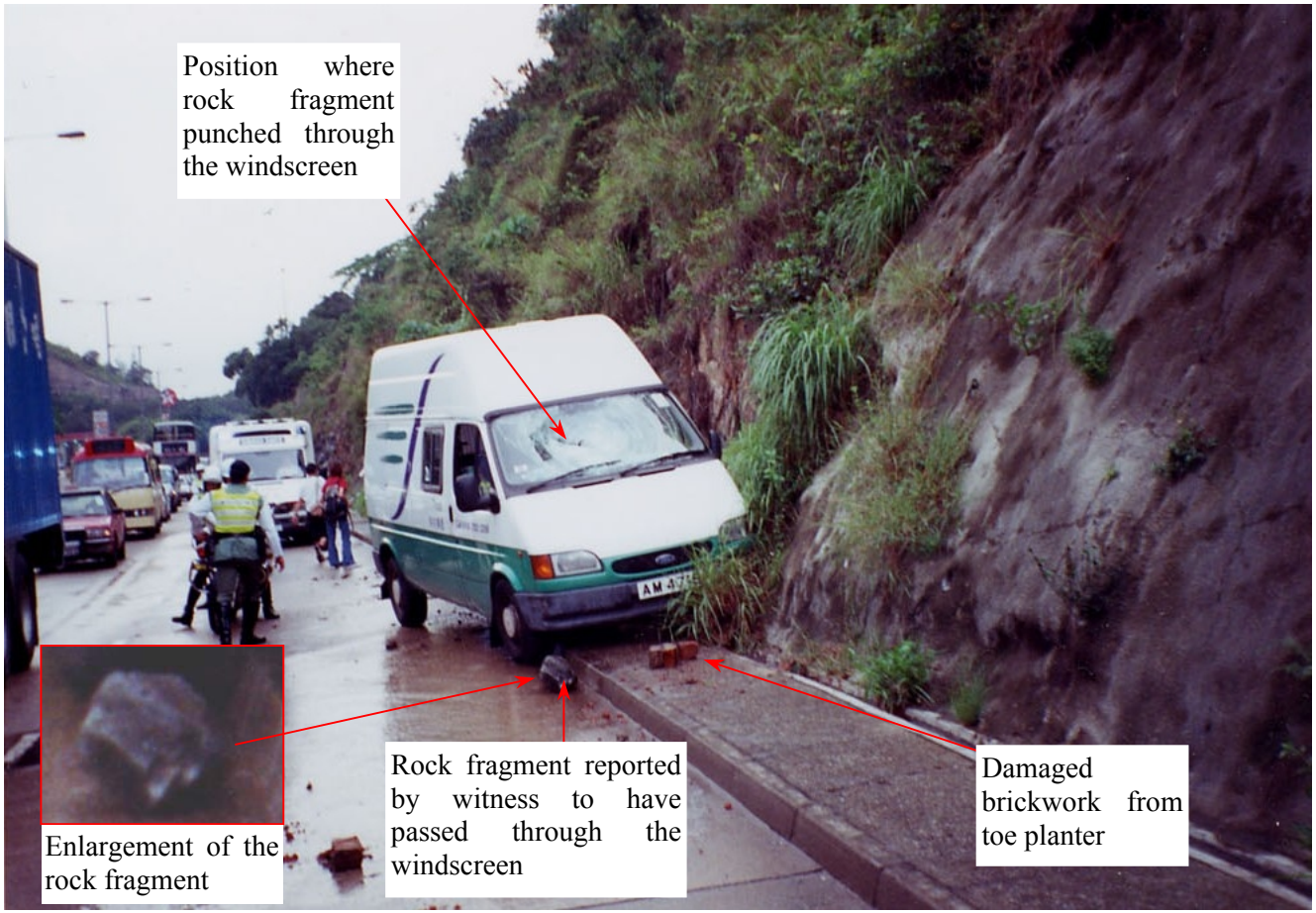

Plate 2 - View from Front of Post Office Van after Rockfall Incident (GEO Incident No. MW2001/06/007)
(Photograph taken by Police on 9 June 2001)

Note: See Figure 12 for location and direction of photograph.

Plate 3 - View from Rear of Post Office Van after Rockfall Incident (GEO Incident No. MW2001/06/007)
(Note skid marks at toe of slope shows the van travelled at least 10 m after the incident.
Photograph taken by Police on 9 June 2001)

Note: See Figure 12 for location and direction of photograph.

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Plate 4 - General View of Slope No. 11NW-A/C58 in 2001 (Photograph taken on 22 August 2001)

Note: See Figure 12 for location and direction of photograph.

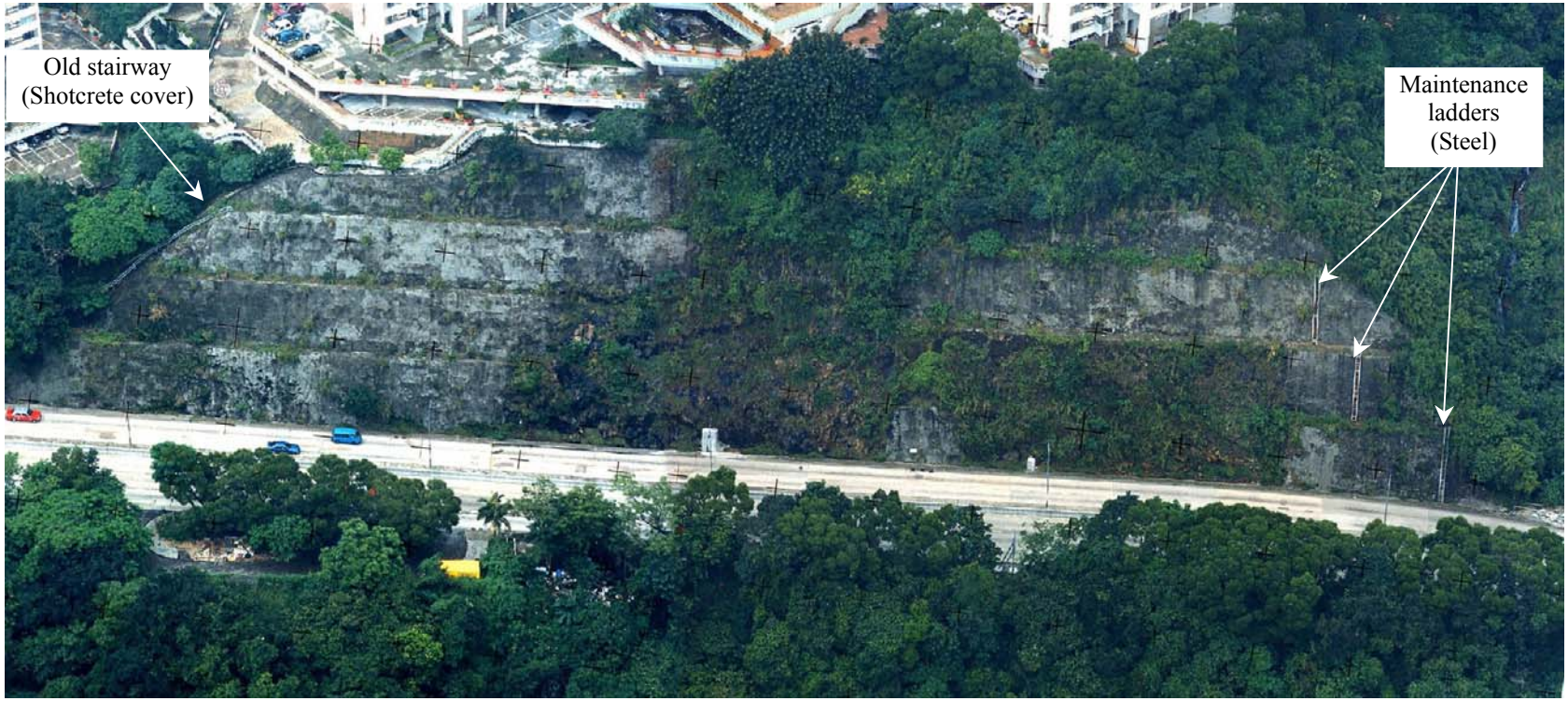

Plate 5 - General View of Slope No. 11NW-A/C58 in 2001 showing Development of Wah Yuen Chuen at Crest (Photograph taken on 7 September 2001)

Note: See Figure 12 for location and direction of photograph.

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Plate 6 - View of Second Berm on Slope No. 11NW-A/C58 (Note there is no drainage provision on the berm near the southeastern end. Photograph taken on 14 August 2001)

Plate 7 - View of Northwest Portion of Slope No. 11NW-A/C58 in 1977 (Photograph taken by B&P in June 1977)

Note: See Figure 12 for location and direction of photographs.

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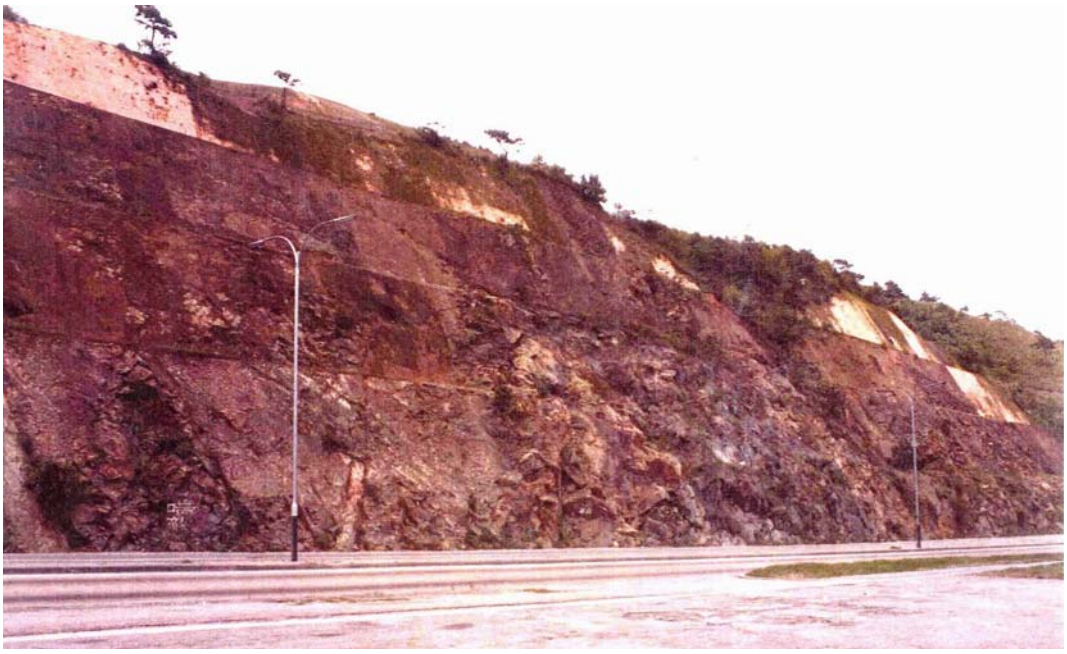

Plate 8 - View of Central and Southeast Portion of Slope No. 11NW-A/C58 in 1977 (Photograph taken by B&P in June 1977)

Plate 9 - General View of New Shotcrete at Fourth Batter at Northwest Portion of Slope No. 11NW-A/C 58 within the Private Portion in 1996 (Photograph taken by GEO on 18 November 1996)

Note: See Figure 12 for location and direction of photographs.

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Plate 10 - General View of Slope No. 11NW-A/C 58 in 1996 showing Unplanned Vegetation on Exposed Rock Portion (Photograph taken by GEO on 18 November 1996)

Note: See Figure 12 for location and direction of photograph.

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Plate 11 - General View of Slope No. 11NW-A/C58 showing Date and Extent of New Shotcreting Based on API and Site Inspection Record (Photograph taken by HAP on 14 July 1997)

Note: See Figure 12 for location and direction of photograph.

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Plate 12 - General View of Slope No. 11NW-A/C58 in 1997
(Photograph taken by HAP on 14 July 1997)

Plate 13 - General View of Slope No. 11NW-A/C58 in 1998
(Photograph taken by HyD on 21 December 1998)

Note: See Figure 12 for location and direction of photographs.

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Plate 14 - General View of Slope No. 11NW-A/C58 in 1999
(Photograph taken by GEO on 20 July 1999)

Plate 15 - Failure Scar on Slope No. 11NW-A/C58 of the GEO Incident No. MW97/6/35A (Photograph taken by GEO on 5 June 1997)

Note: See Figure 12 for location and direction of photographs.

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Plate 16 - Slight to Moderate Seepage at Mid-height on Slope No. 11NW-A/C58
(Photograph taken by GEO on 20 July 1999)

Note: See Figure 12 for location and direction of photograph.

Plate 17 - View of Adverse Sheeting Joint near Centre of Rock Portion of Slope No. 11NW-A/C 58 (Photograph taken on 20 March 2002)

Note: See Figure 12 for location and direction of photograph.

Plate 18 - View of Wedge Failure at the Rock Portion of Slope No. 11NW-A/C 58 (Photograph taken on 20 March 2002)

Note: See Figure 12 for location and direction of photograph.

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Plate 19 - View of Very Closely Spaced Joints Being Exploited by Vegetation to Permit Rock Fragments to Detach (Photograph taken on 21 June 2001)

Plate 20 - View of Loose Rock Fragments with Vegetation Growing in the Joints (Photograph taken on 14 June 2001)

Note: See Figure 12 for location and direction of photographs.

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Plate 21 - View of Loose Rock Fragments on the Surface of the Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 14 June 2001)

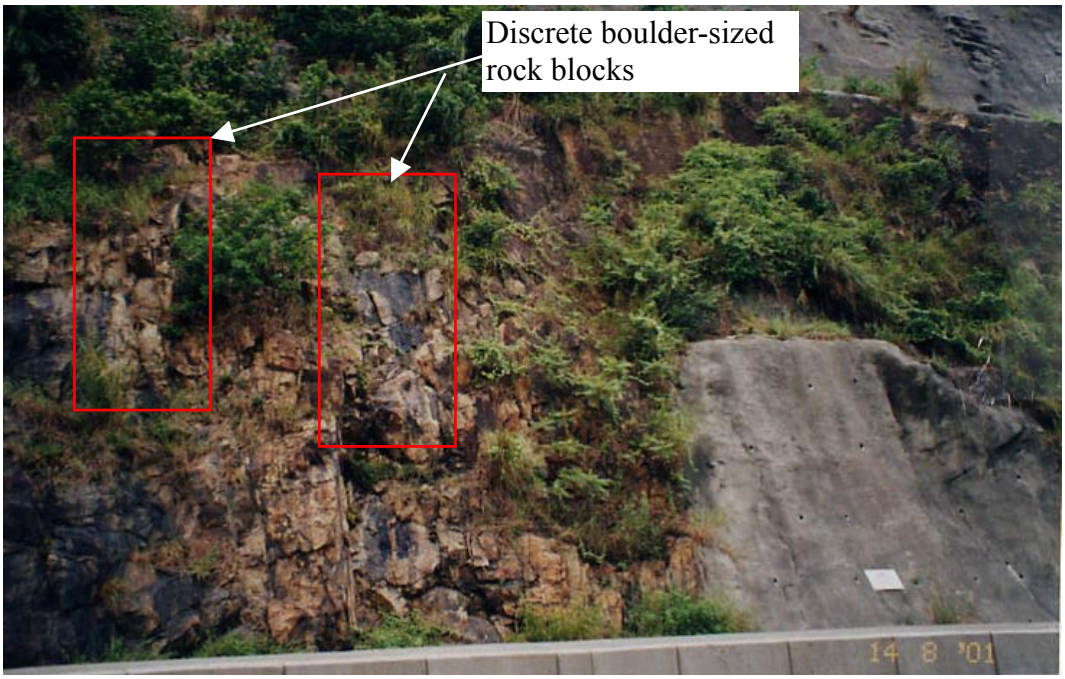

Plate 22 - View of Discrete Boulder-sized Rock Blocks near the Middle of the Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 14 August 2001)

Note: See Figure 12 for location and direction of photographs.

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Plate 23 - Heavy Growth of Vegetation on the Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 21 June 2001)

Plate 24 - View of Rock Debris and Seepage at Toe near the Middle of the Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 14 August 2001)

Note: See Figure 12 for location and direction of photographs.

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Plate 25 - View of Northwest End of Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 14 August 2001)

Plate 26 - View of Southeast End of the Exposed Rock Portion of Slope No. 11NW-A/C58 (Photograph taken on 14 August 2001)

Note: See Figure 12 for location and direction of photographs.

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Plate 27 - View Looking Southeast along Second Berm showing Berm Drainage Partly Blocked by Unplanned Vegetation (Photograph taken on 14 August 2001)

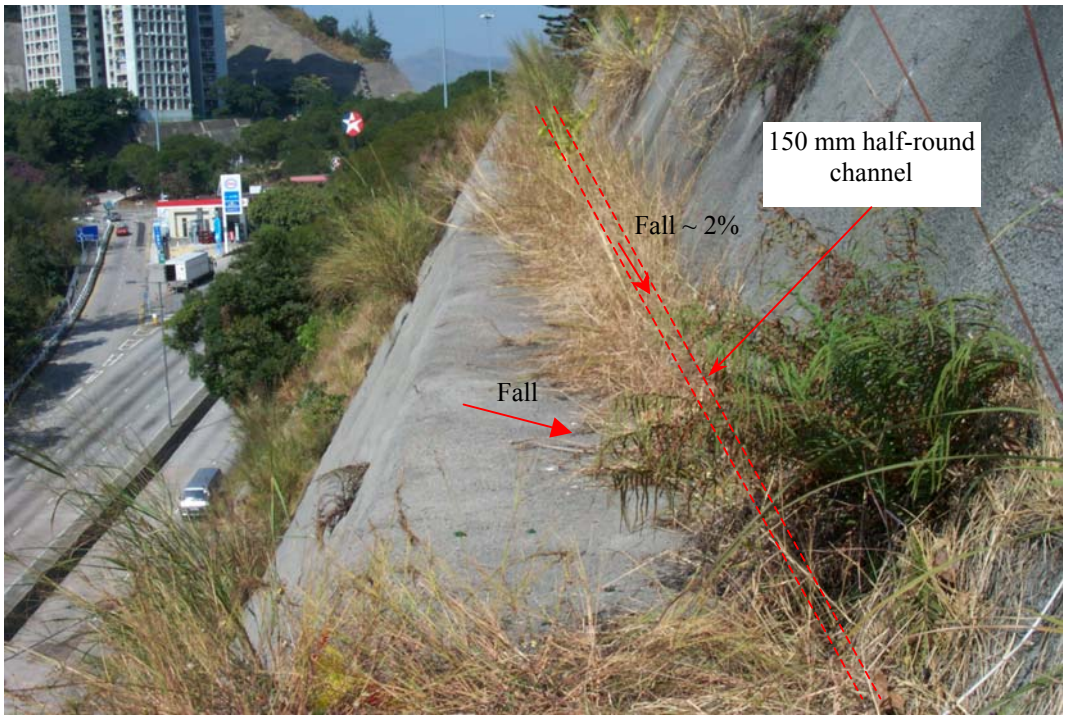

Plate 28 - View Looking Northwest along Second Berm near Location of Discharge onto Exposed Rock Face (Photograph taken on 14 August 2001)

Note: See Figure 12 for location and direction of photographs.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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DETAILED OBSERVATIONS

The following observations were made from the available aerial photographs (see Table A1):

Year	Observations
1924	Castle Peak Road traverses the natural hillside approximately half way up the eastern flank of a large floodplain valley (Figure A1). Although difficult to see, the road appears to have two lanes. There is natural terrain on either side of the road. The natural terrain ridge and spurlines above the road all show evidence of severe sheet and gully erosion. The photographs are of poor quality and stereo cover is limited - no further detail was observed.
1949	Castle Peak Road clearly comprises two lanes. Two small cut slopes are visible along the northern side of Castle Peak Road. Well-defined streamcourses (SC1 and SC2) drain the natural terrain hillside (Figure A2).
1954	Localised filling and cutting is modifying the section of streamcourse SC2 above Castle Peak Road. The precise nature and extent of the streamcourse is indeterminable owing to the poor quality of the aerial photographs.
1963	Castle Peak Road now consists of 4 lanes, with the widening having been achieved by cutting into the natural hillside spurline upslope of the road. A cut slope, currently registered as slope No. 11NW-A/C58, has been formed and comprises four batters with three berms of approximately 1 m in width. There is a drainage channel along the slope crest and a large culvert at the southeast end of the slope. The slope comprises sections of both rock and soil cut, with the extent of the rock cut sections shown on Figure A2. Mottled reflectivity on the some sections suggests that they have been surfaced with a hard surface. The natural terrain uphill of slope No. 11NW-A/C58 is generally grass-covered but contains remnant areas of sheet erosion. A large erosion gully extends through the natural terrain immediately adjacent to the southeast end of the slope (Figure A2). A substantial embankment has been constructed across streamcourse SC1 below Castle Peak Road as part of the road realignment. Borrowing is now taking place on this newly formed fill platform, with the upper sections of streamcourse SC1 having been substantially modified.

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Year	Observations
1964	Seepage is visible on the exposed rock outcrop portion of slope No. 11NW-A/C58 during the 'dry season' at two locations (SP1 and SP2, see Figure A2).
1967	The borrowing operation has ceased. The extent of the cultivated area within streamcourse SC2 has expanded. Seepage is no longer visible at location SP1 but continues to be evident at SP2.
1969	Sheet erosion is still present along spurlines and adjacent sideslopes above slope No. 11NW-A/C58. Seepage is visible on the face of slope No. 11NW-A/C58 at both SP1 and SP2.
1972	The natural terrain above the crest of slope No. 11NW-A/C58 has been cut and a large platform area formed (Platform WY1). A small section of natural terrain remains between the crest of slope No. 11NW-A/C58 and the newly formed platform. Fill is being placed within the quarry site to create a platform for Wan Yan Court. Fill has been placed to create the section of Wah King Hill Road leading up to the level of the newly formed platform.
1973	Platform area WY1 remains vacant. Sections of slope No. 11NW-A/C58 have been surfaced (Figure A2). Shrubs have been planted on the natural terrain above the crest of slope No. 11NW-A/C58. Additional platforms have been constructed to the northeast of platform WY1 for the subsequent development of Wah Chi Court. Wah King Hill Road has been extended and the lower section of Wah Yuen Drive constructed. The platform area for Wan Yan Court has now been constructed with slope No. 11NW-A/FR12 at its southwest boundary. A herringbone drainage channel network is visible on the slope face. The extent of the cultivation within the upper reaches of streamcourse SC2 has decreased.
1975	Wah Yuen Drive has been extended upslope to the level of Wah Shun Court.
1976	A U-channel is visible around the outer edge of platform WY1 and connects to a drainage culvert structure at the east end of the platform.

Year	Observations
1977	The face of slope No. 11NW-A/FR12 is covered by dense vegetation.
1978	The dense vegetation growth on the face of slope No. 11NW-A/FR12 has been cleared. The herringbone drainage channel network on the face of the slope can now be clearly observed and appears to have been recently reconstructed, together with the drainage channel along the crest of the slope.
1979	Slope No. 11NW-A/C216 has been formed. The foundations for both Wah Lai and Wah Yee Court buildings on platform WY1 are both under construction. Large-scale sub-surface drainage systems are presently being constructed along both sides of Wah King Hill Road. Slope No. 11NW-A/C34 above Wah King Hill Road has been trimmed and resurfaced, with the foundations for Wai Chi Court formed in the platform area above the crest.
1980	Wah Lai Court and Wah Yee Court buildings have been substantially completed. The western section of the WY1 platform surrounding the base of Wah Yee Court has been excavated and lowered and this has involved the trimming of the crest of slope No. 11NW-A/C58. The drainage channel along the crest of slope No. 11NW-A/C58 has been reconstructed. Scattered shrubs are visible along the berms of slope No. 11NW-A/C58.
1981	An elevated podium area has been constructed above platform WY1. The original platform is no longer visible. Construction of Wah Lai and Wah Yee Court buildings has been completed.
1982	No observable changes.
1983	No observable changes.
1984	No observable changes.
1985	Density of vegetation has now increased along the berms of slope No. 11NW-A/C58.
1986	No observable changes.
1987	No observable changes.

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Year	Observations
1988	Density of vegetation on the remnant natural terrain above the crest of slope No. 11NW-A/C58 now appears high.
1989	No observable changes.
1990	No observable changes.
1991	No observable changes.
1992	No observable changes.
1993	No observable changes.
1994	No observable changes.
1996	A fence has been constructed along the third berm of slope No. 11NW-A/C58 and the uppermost batter above this fence has been cleared of all vegetation. The upper batter at the northwest end of the slope is dark orange in colour suggesting that the slope cover has been stripped in preparation for shotcreting.
1997	26 May Sections of slope No. 11NW-A/C58 have been resurfaced (Figure A2). 1 November Additional sections of slope No. 11NW-A/C58 have been surfaced (Figure A2).
1998	Scattered vegetation is visible on the face and along the berms of slope No. 11NW-A/C58.
1999	No observable changes.
2000	No observable changes.

LIST OF TABLES

Table A1 - List of Aerial Photographs

Date	Altitude (ft)	Photograph Number
1924	Unspecified	Y108-9
2 June 1949	5800	Y2144-5
18 November 1954	29200	Y2683-4
27 January 1963	2700	Y8185-6
11 December 1964	2700	Y10961-2
13 May 1967	3900	Y13442-3
1969	Unspecified	Y14870-1
1972	Unspecified	259-260
23 October 1973	6000	5313-4
19 December 1975	12500	11793-4
16 August 1976	2000	14676-7
4 October 1976	4000	15435-6
21 December 1977	4000	20228-9
7 December 1978	4000	24098-9
28 November 1979	10000	28105-6
12 November 1980	4000	32850-1
19 January 1981	4000	36238/36268
10 October 1982	10000	44560-1
25 January 1983	4000	47352
5 November 1984	4000	57017-8
2 October 1985	4000	67571-2
22 September 1986	4000	A6298-9
4 October 1987	4000	A10556-7
19 January 1988	6000	CN2043-4
16 August 1989	4000	A17903-4
21 March 1990	4000	A20940-1
1 October 1991	4000	A27636-7
13 May 1992	4000	A31233-4
9 July 1993	4000	A35303
8 October 1993	5000	CN4781
5 May 1994	4000	CN6784
6 May 1994	5000	A38201-2
15 May 1996	4000	CN13402
14 November 1996	4000	CN15828-9
26 May 1997	4000	CN17283-4
1 November 1997	10000	CN19028-9
27 July 1998	4000	CN20139
14 August 1998	3500	CN20741
9 February 1999	5500	CN22372-3
11 June 1999	2600	CN23182-3
16 August 2000	4000	CN28166-7

Note: All aerial photographs are in black and white except those denoted with a CN prefix besides the photograph number.

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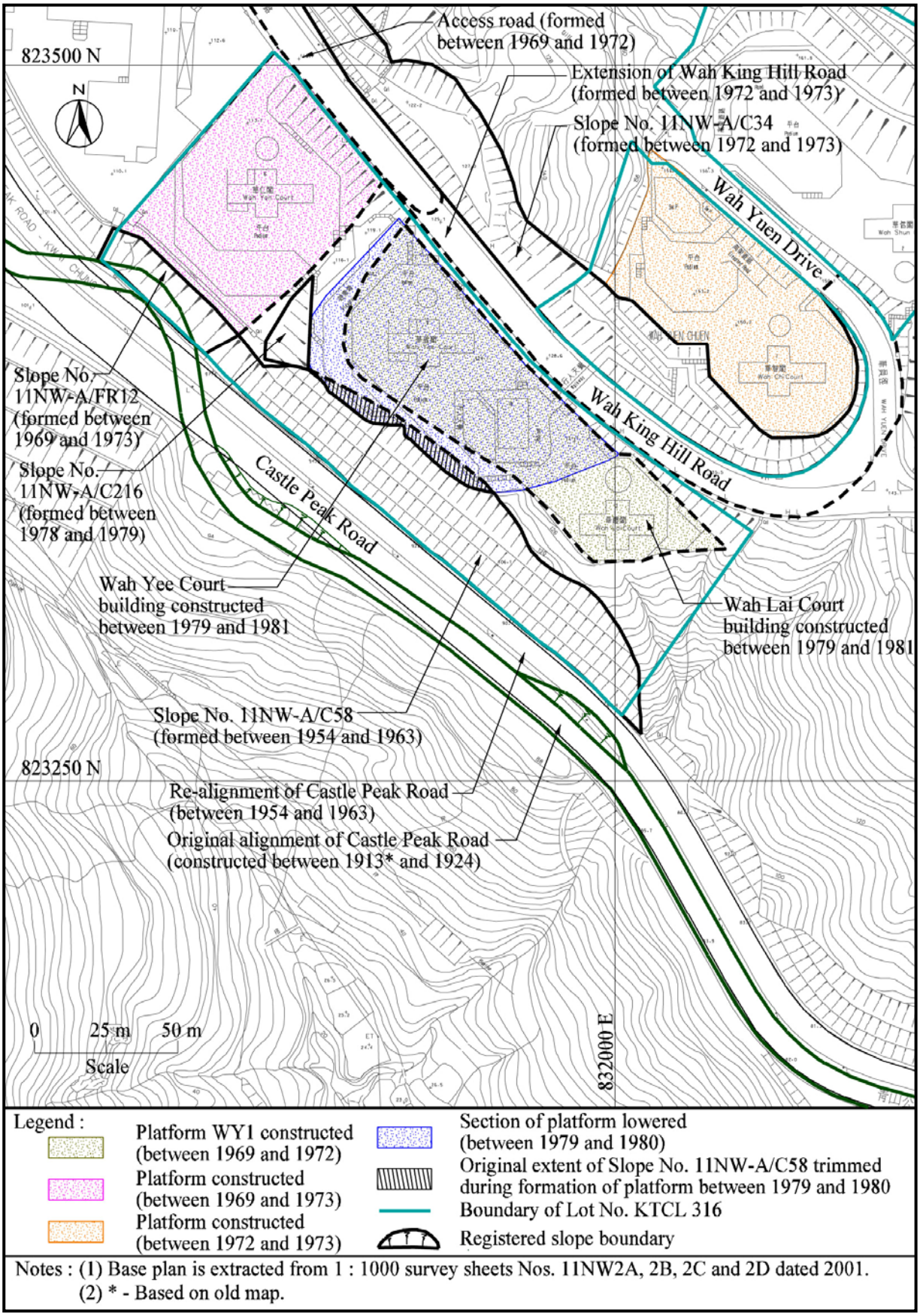

Figure A1 - Site Development History

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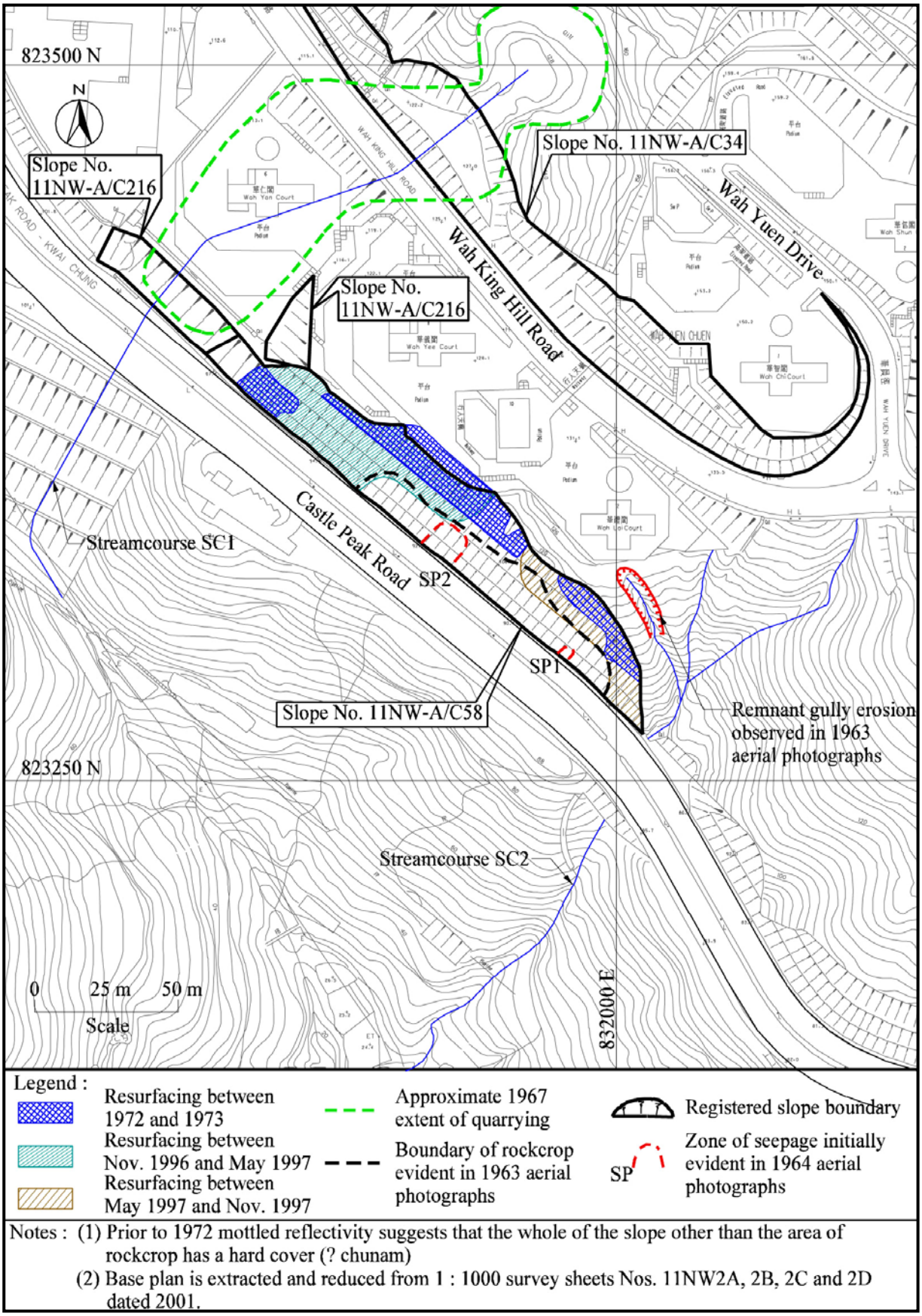

Figure A2 - API Findings

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APPENDIX B

ROCK SLOPE DISCONTINUITY SURVEY

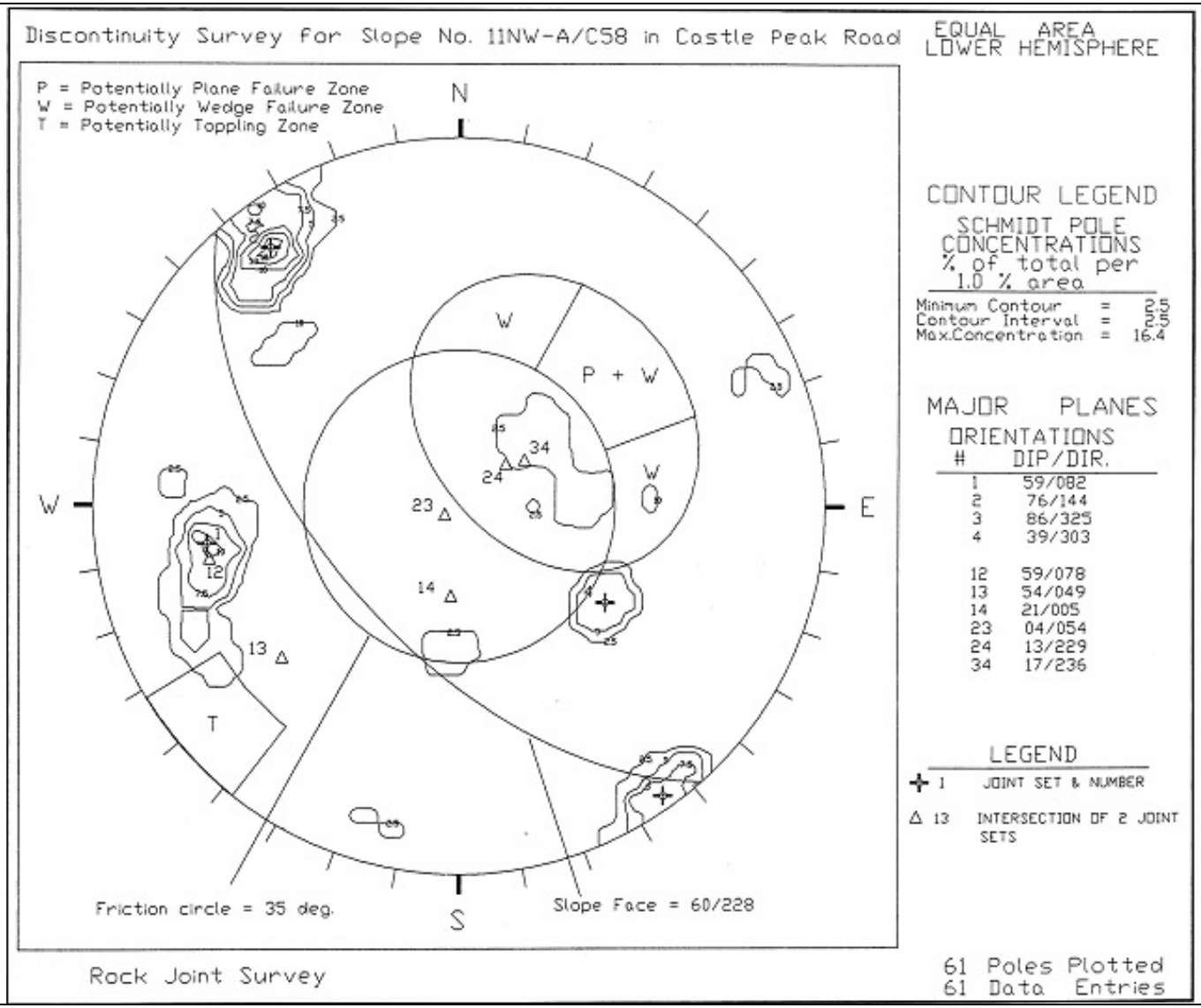

Figure B1 - Stereonet Analysis from the Discontinuity Survey on Slope No. 11NW-A/C58 by MGSL

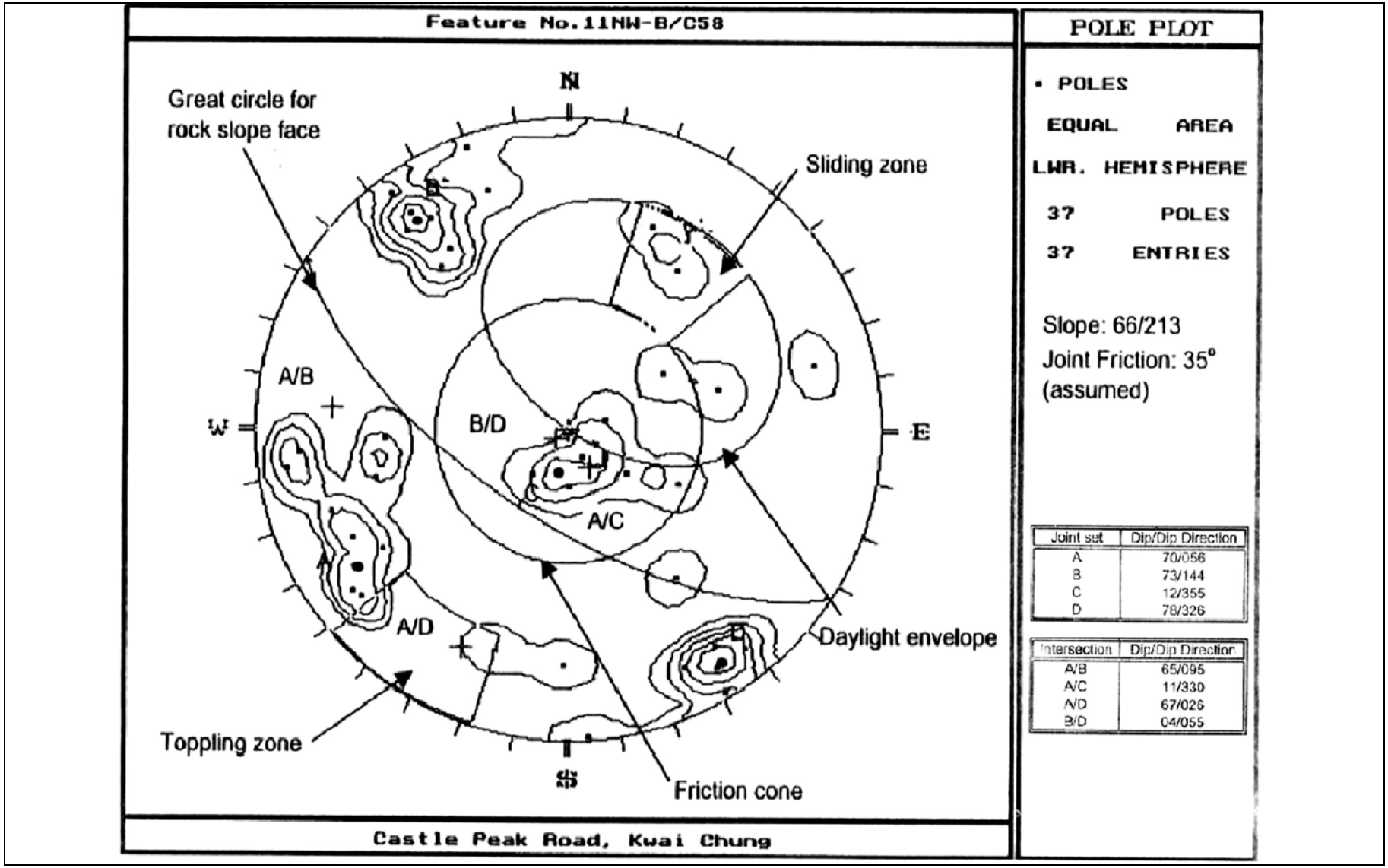

Figure B2 - Stereonet Extract from HAP Stage 2 Study Report on Slope No. 11NW-A/C58

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
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美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

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- 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://bookstore.esdlife.com
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傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports, publications and maps which are free of charge should be sent to:

For Geological Survey Sheet Reports and maps which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
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Fax: (852) 2714 0275
E-mail: ykhui@cedd.gov.hk

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地質調查報告及地質圖:
香港九龍何文田公主道101號
土木工程拓展署大樓
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土力工程處
規劃部總土力工程師
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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, 2000).
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.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 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. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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