DETAILED STUDY OF THE 20 AUGUST 2005 LANDSLIDE ON SLOPE NO. 11SW-D/C543 ABOVE MIDDLE GAP ROAD WANCHAI GAP

GEO REPORT No. 211

FUGRO SCOTT WILSON JOINT VENTURE

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 second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
October 2007

FOREWORD

This report presents the findings of a detailed study of a landslide (Incident No. 2005/8/0326), which occurred on 20 August 2005 on a cut slope above Middle Gap Road, Wanchai Gap. Debris from the landslide, with an estimated volume of 400 m^3, was deposited on Middle Gap Road and Mount Cameron Road below, completely blocking both carriageways, and spilled over into a natural drainage line below Mount Cameron Road. No casualties were reported as a result of the failure.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study comprised site reconnaissance, ground investigation and laboratory testing, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2004/2005 Landslide Investigation Consultancy for Hong Kong Island and Outlying Islands, for the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD), under Agreement No. CE 29/2003 (GE). This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW).

Y C Koo
Project Director
Fugro Scott Wilson Joint Venture

Agreement No. CE 29/2003 (GE)
Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2004 and 2005

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1. INTRODUCTION

On the morning of 20 August 2005, a landslide (Incident No. 2005/8/0326) occurred on slope No. 11SW-D/C543 located above Middle Gap Road, Wanchai Gap, during which time an Amber Rainstorm Warning and a Landslip Warning were in force (Figure 1 and Plate 1). The landslide involved the full height of the cut slope, which had been modified by previous landslides, and extended 2 m to 3 m into the ground above the modified slope crest. Debris from the landslide, with an estimated volume of about 400 m^3, was deposited on Middle Gap Road and Mount Cameron Road below, blocked both carriageways completely, and spilled over into a natural drainage line below Mount Cameron Road. No casualties were reported as a result of the failure.

Following the landslide, Fugro Scott Wilson Joint Venture (FSW), the 2004 and 2005 Landslide Investigation Consultants, carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) under Agreement No. CE 29/2003 (GE).

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

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

(a) a review of relevant documents relating to the history of the site,

(b) detailed interpretation of aerial photographs relating to the site,

(c) topographic survey, geological mapping, and detailed observations and measurements at the landslide site,

(d) limited ground investigation and laboratory testing,

(e) analysis of rainfall records,

(f) engineering analysis of the slope, and

(g) diagnosis of the probable causes of the landslide.

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2. THE SITE

2.1 Site Description

Slope No. 11SW-D/C543 is located on the eastern side of Middle Gap Road about 60 m south of the road intersection of Stubbs Road, Black's Link, Middle Gap Road, Mount Cameron Road, Coombe Road and Peak Road at Wanchai Gap (Figure 1 and Plate 2).

The general landform of this area (Figure 1) comprises two sections of northwest-southeast trending ridgeline separated by the saddle (at an elevation of 240 mPD) forming Wanchai Gap at the road intersection. The southeastern flank of the saddle is inclined at about 30º to 35º and rises from road level to meet the ridge line at an elevation of about 300 mPD. The ridgeline slopes up to the southeast at an overall angle of about 20º. The southeastern flank is traversed by Black's Link to the north and Middle Gap Road to the south, with the latter rising from the road intersection at a gradient of about 1 in 10 (i.e. 6º). The ground above Middle Gap Road generally comprises heavily vegetated natural hillside.

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Middle Gap Road is a single-lane dual carriageway about 6 m wide with kerbing but without footpaths. In the vicinity of slope No. 11SW-D/C543, the carriageway has been formed entirely in cut, with slope No. 11SW-D/C543 above the carriageway level (elevations 246 mPD to 254 mPD) to the east and small cuttings up to 1 m in height above the carriageway to the west. Below the northern portion of slope No. 11SW-D/C543, the small cuttings are absent and the ground to the west falls directly from the edge of the carriageway to Mount Cameron Road (elevation 242 mPD) at an angle of about 30º. Immediately below Mount Cameron Road at this location, a well-defined drainage line extends to the southwest towards the Aberdeen Upper Service Reservoir at an angle of about 35º immediately below the carriageway, reducing to 25º further downslope.

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Slope No. 11SW-D/C543 (Figure 2) is adjoined to the north by cut slope No. 11SW-D/C542 and to the south by tennis courts associated with the residential development at No. 3 Middle Gap Road ('Highclere'). 'Rockery Nook' at No. 4 Middle Gap Road is located on the western side of the carriageway to the south, and Mount Cameron Road Electricity Sub-station is located on the western side of Mount Cameron Road below the northern end to the subject slope.

Slope No. 11SW-D/C543 is approximately 65 m in length. The slope face had a shotcrete surface cover with 75 mm diameter weepholes at 1.5 m centres. It had previously been altered by past landslide events (see Section 3.2), which created a non-uniform sectional geometry along the length of the feature and had resulted in the crest line progressively extending upslope from the original location at about 6 m to 7 m above the road level. The slope had an estimated maximum height of about 16 m prior to the 20 August 2005 landslide.

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A review of the available photographic records (Plate 3) indicates that the cut slope geometry prior to the 20 August 2005 landslide comprised the original cutting up to 3 m high rising above Middle Gap Road at between 60º and 70º, above which the face angle reduced within the existing landslide scars to angles of between 30º and 50º before meeting with the hillside at the slope crest. The local topography immediately above the cut slope crest comprises a small southwesterly trending spur ridge and adjacent ephemeral natural drainage lines to the northwest and southeast that define the northern and southern extent of the cut slope respectively.

The surface drainage system comprised a 300 mm crest U-channel discharging to the north and south into catchpits at road level, as well as a 150 mm U-channel traversing the slope face at mid-height and discharging into a 300 mm stepped U-channel feeding a catchpit at the slope toe. The three catchpits are connected by cross-road drains passing beneath Middle Gap Road. For the catchpit receiving the runoff collected from the on-slope drainage, the cross-road drain discharges into a 450 mm stepped U-channel extending over the sloping ground below Middle Gap Road to a catchpit at the Mount Cameron Road level, which is then connected by a cross-road drain that discharges into the drainage line below Mount Cameron Road.

Maintenance access stairs oriented approximately parallel to Middle Gap Road had been constructed above the crest of slope No. 11SW-D/C543 over the northern and southern thirds of the slope length, terminating at the intersection with the slope face. A tubular steel handrail extended along the upslope edge of the access stairs and followed the crest line of the slope between.

2.2 Buried Water-carrying Services

The locations of buried water-carrying services in the vicinity of slope No. 11SW-D/C543 are shown in Figure 3.

According to the Water Supplies Department (WSD), a 100 mm diameter freshwater main is situated along the western edge of Middle Gap Road, opposite slope No. 11SW-D/C543.

Records of the Drainage Services Department (DSD) indicate that there are no buried drainage works or foulwater sewers in the immediate vicinity of slope No. 11SW-D/C543.

2.3 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System of the Lands Department, the maintenance responsibility of slope No. 11SW-D/C543 rests with the Highways Department (HyD).

3. SITE HISTORY AND PREVIOUS INSTABILITIES

3.1 Site History

The site development history, which is summarised in Figure 4 and Appendix A, has been established from the aerial photographs taken between 1949 and 2003 together with a review of the relevant documentary information.

The earliest available aerial photographs were taken in 1949 and show that most of the present-day development at Wanchai Gap have been completed. These include Middle Gap Road, Stubbs Road, Peak Road, Coombe Road, Black’s Link and Aberdeen Reservoir Road, which generally conform to the respective present-day alignments, together with the developments ‘Highclere’ at No. 3 Middle Gap Road and ‘Rockery Nook’ at No. 4 Middle

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Gap Road. Slope No. 11SW-D/C543 was probably formed in association with the construction of Middle Gap Road to an original geometry similar to that of the adjacent slope No. 11SW-D/C542, comprising a slope inclined at about 60^o to the horizontal and about 6 m to 7 m in height. Slope No. 11SW-D/C543 is situated above the head of the drainage line that extends below Mount Cameron Road.

The hillside above Middle Gap Road has remained largely undisturbed, apart from the presence of a footpath extending upslope from the present location of the tennis courts associated with No. 3 Middle Gap Road to approximately the 283 mPD contour, and a linear feature (possibly a military trench) following the contour to the north, about 25 m in elevation above the crest of slope No. 11SW-D/C543. This feature was visible in the 1949 aerial photographs, but was apparently disused in the 1963 aerial photographs and became progressively overgrown in the subsequent years.

The sloping ground between Middle Gap Road and Mount Cameron Road has also remained largely unchanged, slope No. 11SW-D/C1888 above Mount Cameron Road (Figure 2) being visible in the 1949 aerial photographs.

No major changes are observed in slope No. 11SW-D/C543 between the 1949 and the 1968 aerial photographs, apart from the addition of surface drainage channels above the crest lines of slopes No. 11SW-D/C542 and 11SW-D/C543 at some time prior to the 1963 aerial photographs.

The January 1976 aerial photographs indicate possible landslide remedial works comprising the provision of hard surfacing at two locations in the central portion of slope No. 11SW-D/C543. The December 1977 aerial photographs indicate a significant extension of the crest line upslope above the locations of remedial works visible in the 1976 aerial photographs, and above the mid-southern portion of the slope, and the application of hard surfacing to the majority of the slope face, excluding the northern and southern extents. Middle Gap Road was also re-paved along the length of slope No. 11SW-D/C543 and a short distance to the north during this time.

No major changes are observed between 1977 and 1992, apart from the growth and partial loss of unplanned vegetation on the slope face, and the addition of surface drainage measures on the slope face, which are first visible in the 1984 aerial photographs. The 1993 aerial photographs indicate a further extension of the crest line of slope No. 11SW-D/C543 upslope, coincident with two depressions at the locations of the repairs and the extended crest line visible in the 1976 and 1977 aerial photographs respectively. Slope re-surfacing works also appear to have been carried out at this time.

From 1993 to 2003 there are no major changes evident in the slope geometry. Evidence of minor repair works is visible in the 2001 aerial photographs.

3.2 Previous Slope Instability

According to the GEO's landslide database, one landslide incident has affected slope No. 11SW-D/C543. Incident No. HK92/5/68 occurred on 9 May 1992 and involved detachment of about 3 m^3 of material from the southern extent of the slope. Debris from the

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landslide was deposited on Middle Gap Road. This incident is not visible in the 1993 aerial photographs.

Further evidence of recent instability affecting slope No. 11SW-D/C543 has been established from aerial photograph interpretation (see Appendix A), which indicates two possible instabilities affecting adjacent areas in the central portion of the slope between 1968 and 1976, another instability resulting in the upslope extension of the slope crest between 1976 and 1977, and further upslope extension of the slope crest between 1992 and 1993. The volumes of these previous instabilities are estimated to lie in the range of 10 m^3 to 100 m^3. The observations based on the 1976 and 1977 aerial photographs are supported by the field sheet and record photograph (Plate 4) from an inspection of slope No. 11SW-D/C543 by Binnie & Partners (B&P) in April 1978 (see Section 4.1), the field sheet noting the observation of an existing landslide scar, and the photograph showing two spoon-shaped depressions within the area covered by chunam inclined at a flatter angle than the remaining portion of the original slope face immediately above road level.

The Stage 1 Study report completed by the Design Division of the GEO in October 1992 also made the observation of an "old landslide scar covered with chunam" (see Section 4.2).

Highways Department records (see Section 4.4) also indicate a small detachment involving about 0.5 m^3 of debris at the toe of the slope in the central portion of the feature in August/September 1995 (Plate 5).

Evidence of recent and relict instability in the general area surrounding slope No. 11SW-D/C543 has also been identified in the aerial photographic record (Appendix A). Evidence of relict instability has been identified from the 1963 aerial photographs, which show a total of nine relict scars at the heads of drainage lines in the hillside above Middle Gap Road, three of which are located above slope No. 11SW-D/C543 (Figure 5). Recent instability in the hillside above slope No. 11SW-D/C543 is evident in the 1949 and 1963 aerial photographs, which show probable scars and debris associated with instabilities affecting the abandoned trench (see Section 3.1).

4. PAST SLOPE ASSESSMENT AND UPGRADING WORKS

4.1 Study by Binnie & Partners in 1977

In April 1978, slope No. 11SW-D/C543 was inspected by B&P under the "Phase 1 Re-appraisal of Cut & Natural Slopes & Retaining Walls Study" and was subsequently registered in the 1977/78 Catalogue of Slopes. The field sheet for this feature recorded signs of distress in the form of "cracked chunam" and previous instability in the form of "Slip scar covered with chunam". The record photograph (Plate 4) shows two spoon-shaped depressions in the chunam-covered slope face, as noted in Section 3.1.

Actions recommended included repair and extension of the chunam surface cover to the top of the slope, clearance and repair of U-channels, and clearance of weepholes.

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4.2 Stage 1 Study

In October 1992, the Design Division of the GEO completed a Stage 1 Study report for slope No. 11SW-D/C543, which noted signs of distress and the presence of an old landslide scar covered with chunam. No further action was recommended in the study.

4.3 SIFT and SIRST Studies

In January 1996, under GEO's "Systematic Inspection of Features in the Territory" (SIFT) project, slope No. 11SW-D/C543 was categorised as a Class "C1" feature, i.e. slopes that "Have been formed or substantially modified before 30.6.78 or to have been illegally formed after 30.6.78".

In November 1997, slope No. 11SW-D/C543 was inspected under the "Systematic Identification and Registration of Slopes in the Territory" (SIRST) project initiated by the GEO. The SIRST field sheet notes that the shotcrete surface was in a fair condition and that no seepage was observed. The slope was recorded as having "Multiple minor" inferred past instability and signs of distress were recorded as "Reasonable". The consequence-to-life category of the subject slope was rated as '3'.

4.4 Slope Maintenance Inspections

Routine Maintenance Inspections (RMI) of slope No. 11SW-D/C543 were carried out by HyD in June 1994, October 1995, August 1998, August 1999, November 2000, November 2001, February 2003, December 2003 and October 2004. An inspection was carried out by HyD's consultants, Fugro Mouchel Rendell Joint Venture (FMR) in June 1995. Engineer Inspections (EI) were undertaken by Maunsell Geotechnical Services Ltd. (MGS) in February 1999 and February 2004.

The inspection records for the 1994 RMI indicated that the condition of slope No. 11SW-D/C543 was satisfactory (Plate 6), and no maintenance works were required.

The June 1995 inspection completed by FMR identified evidence of a past failure at the northern end of the slope (Plate 7), an upslope extension of the crest line from the location shown on the record plan, which was possibly a result of slope failure, and chunam cover over an old failure scar at the southern end of the slope, which appear to be broadly consistent with the observations made by FSW from aerial photographs (Section 3.2). FMR also observed that the northern 7 m of the feature had no hard surface cover. The inspection records noted that "Failures have occurred on the slope up to 6 m long and 3 m deep resulting in steep (> 70º) back scarps which are > 2 m high, now covered with shotcrete". However, the locations of these failures were not provided in the records. Routine maintenance works comprising the removal of vegetation from surface drainage channels, weepholes, catchpits and sandtraps, were recommended. A stability assessment and "Major Works", which were not elaborated, were recommended in view of the slope failures.

HyD records indicate that a Works Order was issued in September 1995 to repair the defective slope surface, involving a small landslide at the toe of the central portion of the

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slope in August/September 1995 (Plate 5 and Section 3.2). The inspection records for the subsequent RMI in October 1995 indicated that no maintenance works were necessary (Plate 8).

The inspection records for the August 1998 RMI indicated that action was required in respect of repair of cracked/damaged surface cover, removal of debris and vegetation from the slope surface and clearance of weepholes (Plate 9). These works were reported to have been completed in October 1998. Another Works Order was issued in December 1998 for repair of the slope with about 100 m^2 of 75 mm thick reinforced shotcrete.

Records from the February 1999 EI completed by MGS indicated that the rigid surface cover was in fair condition (Plate 10), and that weepholes, U-channels and catchpits were partially blocked with vegetation. Erosion and washout was reported at the northwestern end of the slope. Minor works were recommended in relation to the clearance of surface channels, catchpits and weepholes, the repair of cracked/damaged surface channels and rigid surface cover, and the regrading and repair of eroded areas. A recommendation was also made for a revision to the feature boundary shown on the record plans, as well as a stability assessment on the basis that the same recommendation made by FMR in 1995 had not been implemented.

The August 1999 RMI recorded recommendations for clearance of surface drainage and weepholes, removal of surface debris and vegetation from the slope face and repair of cracked surface cover (Plate 11). The November 2000 RMI recorded similar recommendations, with the addition recommendation of repair of cracked drainage channels. HyD Records indicate that a Works Order for routine maintenance works was issued in January 2001, which included removal of unplanned vegetation from the slope face, clearance of debris from surface channels and catchpits, removal of defective surface cover (approximately 2 m^2), application of cement rendering to the slope surface (about 22 m^2), and clearance of weepholes.

The inspection records for the November 2001 RMI indicated that no action was required in respect of maintenance works (Plate 12).

The RMI completed in February 2003 recorded that action was required in respect of removal of surface debris and vegetation from the slope face and clearance of weepholes (Plate 13). HyD records indicate that these works were completed on 17 December 2003. Records for the subsequent December 2003 RMI recorded that action was required in respect of clearance of drainage channels and repair of cracked/damaged surface cover (Plate 14).

Records from the February 2004 EI completed by MGS indicated that minor works were required in respect of clearance of surface drainage channels, catchpits and weepholes, the clearance of debris and vegetation from the slope face, repair of the rigid surface cover, and regrading and repair of eroded areas. HyD records indicate that a Works Order was subsequently issued in July 2004 specifying clearance of surface channels and application of 25 mm thick cement rendering to defective surfacing.

The slope records updated as part of the 2004 EI included calculation of the priority ranking score (known as CNPCS score) for the slope, which was based on the slope height and face angle at the critical section of 11 m and 60^o respectively, a consequence-to-life

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category of ‘3’ and evidence of ‘Multiple minor’ past instabilities. The calculated CNPCS score was 3.242.

The October 2004 RMI recorded recommendations for clearance of surface drainage and weepholes, removal of surface debris and vegetation from the slope face, together with repair of cracked drainage channels and surface cover (Plate 15). HyD records indicate that these works were completed in October 2004.

4.5 Provision of Safe Access to HyD Slopes

On 23 September 2003, Fugro (Hong Kong) Ltd., consultants to the HyD under Agreement No. CE 41/2002 (GE), inspected slope No. 11SW-D/C543 for the purposes of determining the need for additional safe access provisions for slope inspections and maintenance. Records of the inspection indicate that the existing access arrangement was inadequate and permanent safe access was recommended.

The proposed access provisions comprised two sections of concrete stairs with tubular steel handrail extending along the slope crest at the northern and southern ends of the cut slope, and a tubular steel handrail following the slope crest line above the access stairs. These works were completed on 3 June 2005.

5. THE LANDSLIDE

5.1 Description of the Landslide

The landslide (Incident No. 2005/8/0326) with a failure volume of about 400 m^3 occurred during heavy rainfall at around 10:45 a.m. on 20 August 2005 when an Amber Rainstorm Warning and a Landslip Warning were in force. The approximate time of failure was confirmed by FSW from the accounts of the residents at Nos. 4 and 8 Middle Gap Road, who reported having observed the landslide debris on Middle Gap Road at around that time. Middle Gap Road at the slope toe and Mount Cameron Road below were completely blocked by the landslide debris. No casualties were reported as a result of the incident.

The landslide affected the full height of cut slope No. 11SW-D/C543 and extended over the major portion of the slope face (Plate 16). The landslide scar measured approximately 40 m in width at the slope toe and extended an estimated 2 m to 3 m into the hillside above the slope crest that had been modified by previous landslides. Landslide debris comprising soil, cobbles, boulders, trees and broken shotcrete with an estimated volume of about 400 m^3 was deposited on Middle Gap Road and Mount Cameron Road, part of which spilled over into a natural drainage line below Mount Cameron Road.

The integrity of the Middle Gap Road and Mount Cameron Road carriageways was not affected by the landslide.

Based on the results of the post-failure topographic survey of the landslide site, a plan and section of the landslide source area and debris trail are presented in Figures 6 and 7 respectively.

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The determination of the depths of the landslide scar is made difficult by the complex pre-failure slope face geometry as a result of modifications of the original slope face by previous landslides (Section 3.2). The maximum depth has been estimated to be around 2 m, based on the post-failure topographical survey by the Survey Division of CEDD and the available photographic record. The scar was bowl-shaped with a steep main scarp dipping at about 70° to the horizontal. The flanks of the scar were relatively steep and generally well-defined.

The surface of rupture was undulating and slightly blocky in the central portion and inclined at an angle of about 55°, daylighting at or slightly above the slope toe (Plate 17). Material exposed in the scar comprised predominantly highly to completely decomposed fine ash tuff with corestones. Zones of kaolinisation of the parent rock were also observed. The failure partially exploited adversely orientated relict joint surfaces (see Section 7.3).

The travel distance of the landslide debris was about 70 m on plan beyond the original toe of the cut slope (Plate 18). The debris mound deposited on the toe of cut slope No. 11SW-D/C543 and Middle Gap Road (Plate 19) had a maximum depth of about 4 m, while that on Mount Cameron Road (Plate 20) was about 1.5 m to 2 m in depth. The debris predominantly comprised yellowish brown sandy clayey silt with a significant content of sub-angular cobbles and boulders. Tree roots, vegetation, concrete fragments of drainage channels and steel hand railing were also contained in the debris. The debris was wet and largely saturated, without much excess water at Middle Gap Road but with progressively more on Mount Cameron Road and the drainage line below. The travel angle of the landslide debris (Wong & Ho, 1996) was estimated to be about 38°.

5.2 Post-failure Observations by FSW

5.2.1 General

FSW first inspected the landslide site at around 9:30 a.m. on 21 August 2005, at which time the weather was generally overcast and light to heavy rainfall was occurring intermittently. The landslide debris deposited on Middle Gap Road and Mount Cameron Road were being removed by HyD's contractor during the time of inspection (Plates 19 and 20).

The landslide scar (Plate 21) was partially obscured by debris deposited in the lower portion of the source area. The exposed upper portion of the scar was relatively smooth, and was largely devoid of erosion gullies or other signs of concentration of surface runoff above the main scarp. The exposed portion of the scar was similarly devoid of any signs of significant seepage or soil pipes.

The main scarp was about 4 m in height and exposed a thin (about 0.1 m to 0.2 m thick) horizon of greyish brown sandy silt topsoil overlying completely decomposed fine ash vitric tuff.

The landslide debris deposited on Middle Gap Road and Mount Cameron Road was orangish brown in colour, saturated and very loose/very soft, having probably been further wetted up insitu following the continuing heavy rainfall on 20 August 2005 after the failure. The debris mounds on Middle Gap Road and Mount Cameron Road at the time of the

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inspection were 35 m and 16 m wide respectively. The general direction of debris movement across Middle Gap Road appeared to have been oblique to the slope face dip direction and towards the west, which may have been a function of the direction of release of material from the slope as well as the longitudinal fall of Middle Gap Road to the north.

The northern margin of the debris mound on Middle Gap Road had been contained to some extent by the small cutting on the western side of the carriageway (Plate 22). Debris in this area was generally less disturbed than the material observed further downslope and contained a number of agglomerations of a light grey/buff coloured kaolin-like material (Plate 23). The debris on Mount Cameron Road included broken shotcrete from the hard surface cover of slope No. 11SW-D/C543.

The main debris runout path covered the approximately 50 m of ground to the south where the cutting pinched out and extended in a southwestern direction. Scarring on the trees adjacent to the southern margin of the debris runout path (Plate 24) indicated the debris mass that travelled downslope beyond Middle Gap Road was probably of the order of 2 m thick.

The passage of the debris mass over the sloping ground between Middle Gap Road and Mount Cameron Road did not result in any significant entrainment of material from this area, which was probably limited to topsoil and vegetation litter, as evidenced by the presence of intact tree stumps and the upslope side of the surface drainage channel traversing this area (see Section 5.1 and Plate 25), which had remained in place following impact by the debris which carried away the rest of the channel.

Similarly, the passage of landslide debris down the natural drainage line below Mount Cameron Road appeared to have only involved minor entrainment of surface vegetation and to have mostly involved debris deposition. The debris trail in this area (Plate 18) narrowed from about 13 m at the Mount Cameron Road level to about 2 m further downslope. The debris deposited in this area was completely saturated with much excess water, as surface runoff from Mount Cameron Road was diverted directly into the drainage line by the debris mound.

5.2.2 Field Mapping

Initial mapping of the landslide scar was completed by FSW between 21 August 2005 and 23 August 2005 during and following the removal of the landslide debris.

The following pertinent observations were recorded from the field mapping, as presented in Figure 8:

(a) The highly to completely decomposed (PW 0/30) fine ash tuff exposed in the scar comprised a firm yellowish brown, clayey sandy silt with occasional sub-rounded cobble- and boulder-sized corestones of moderately decomposed tuff. The kaolinised tuff identified at the lower portion of the scar comprised firm greyish white to greyish yellow silty clay.

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(b) Relict jointing identified in the scar included joint dip angle/dip directions that coincide with the main scarp and flanks, suggesting the landslide exploited locally adverse joint orientations. These orientations are also coincident with the orientations of the major photogeological lineaments in the local area.

(c) There appears to be a weathering gradient from the portion of slope No. 11SW-D/C543 affected by the landslide to less weathered material on the margins to the north and south (Plate 26), and extending to the north into the adjacent slope No. 11SW-D/C542.

(d) No signs of any developing instability in the form of ground deformations or tension cracks could be identified in the hillside above the landslide scar in the immediate vicinity (Plate 27); however, the dense vegetation in this area precluded further detailed inspection.

5.2.3 Other Observations

A walkover inspection was carried out on the lower 100 m section of Black's Link, situated on the northern side of the local ridge line extending to the east from the saddle. Three salient observations were made during the inspection. These are:

(a) The cuttings along the southern edge of the Black's Link carriageway generally expose less weathered material than that exposed in slopes Nos. 11SW-D/C542 and 11SW-D/C543.

(b) The surface of rupture of previous landslides, as evidenced by the generally shotcreted scars were generally steep (about 60º to 70º), and the landslide source areas were shallow (about 0.5m deep).

(c) Pronounced seepage was observed issuing from joints in the various cuttings. Further inspections between August 2005 and October 2005 confirmed that the seepage was sustained in the absence of any significant rainfall since 21 August 2005.

5.3 Urgent Repair Works

Urgent repair works carried out by the HyD at the recommendation of the GEO included trimming of the main scarp, and removal of loosened material and debris from the scar, Middle Gap Road, Mount Cameron Road and the sloping ground in between. A 75 mm thick reinforced shotcrete surfacing with weepholes was applied to the landslide scar and the

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sloping ground between Middle Gap Road and Mount Cameron Road. Surface drainage channels were reinstated on the sloping ground between Middle Gap Road and Mount Cameron Road, but not within the landslide scar.

Middle Gap Road and Mount Cameron Road were reopened to traffic upon completion of landslide debris removal on 22 August 2005, but remained subject to traffic control until completion of the shotcreting and surface drainage works on 24 August 2005 and 15 December 2005 respectively, as advised by HyD.

6. GROUND INVESTIGATION

6.1 Previous Ground Investigations

A number of previous ground investigations have been undertaken within the general vicinity of Wanchai Gap (Figure 9). However, no site-specific ground investigation data in relation to slope No. 11SW-D/C543 could be located.

6.2 Current Ground Investigation

The ground investigation (GI) that formed part of the present study was carried out between December 2005 and January 2006. The GI works comprised the following:

(a) 6 drillholes advanced using rotary drilling methods,

(b) 12 trial pits excavated to maximum depths of 3 m,

(c) 3 vegetation strips, and

(d) discontinuity survey of the adjacent intact portions of slopes Nos. 11SW-D/C543 and 11SW-D/C542.

The locations of the ground investigation stations are shown in Figure 9.

Insitu testing comprised Standard Penetration Testing (SPT) and constant head permeability tests in drillholes, and insitu density and field infiltrometer tests in trial pits.

Bulk disturbed samples, U100 undisturbed tube samples and block samples were recovered from trial pits and continuous Mazier samples recovered from drillholes for laboratory testing.

7. SUBSURFACE CONDITIONS

7.1 General

The subsurface conditions at the site were assessed using information from desk studies, field mapping and ground investigation.

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7.2 Geological, Geomorphological and Hydrogeological Setting

According to the Hong Kong Geological Survey (HKGS) 1:20,000 scale geological map (GCO, 1986), the solid geology of the subject slope and its surrounding area comprises fine ash vitric tuff from the Ap Lei Chau Formation of the Repulse Bay Volcanics Group (Figure 10). Isolated areas of debris flow deposits are indicated in local depressions and valleys, but not in the vicinity of the subject slope.

The upper reaches of the study area are bounded by a northwest-southeast trending ridge. The ridge incorporates a number of minor spur features defined by drainage lines that characterise the local hillside in the vicinity. The site was originally located at the head of a southwest-trending drainage line (see Figure 4). The area between Middle Gap Road and Mt. Cameron Road has been extensively modified by the residential development since the earliest aerial photographs. The valley extending below Mount Cameron Road is relatively undisturbed in the vicinity of the study area.

A prominent northeast-southwest trending fault aligns with the saddle feature comprising Wanchai Gap and could be considered as the major structural control on the development of the local topography. A northwest-southeast trending photolineament that is parallel with the crown of the August 2005 landslide scar is also indicated by the geological map and has been identified from aerial photographs (Figure 4).

Field reconnaissance along Black's Link identified continued seepage of groundwater from rock joints in various cut slopes (see Section 5.2.3) on the northern side of the ridgeline opposite the landslide site, whilst the landslide scar and the adjacent slopes have been generally devoid of any signs of seepage since the time of the incident. These observations suggest a prevailing preferential flow path of groundwater to the northern side of the ridge may exist.

7.3 Discontinuity Survey

The major joint sets in this area are indicated as dipping to the east, southeast and southwest at 15º, 80º and 70º respectively (GCO, 1986).

The results of the discontinuity survey, presented in Figure 11, indicate that the highly decomposed fine ash tuff incorporates relict structures with scattered orientations. Nevertheless, these have been characterised into three main joint sets with dip/dip direction of 11º/143º (Joint Set 1), 54º/149º (Joint Set 2) and 73º/298º (Joint Set 3). An additional Joint Set 4 (80º/220º) has been included to represent the rest of the fewer and scattered joint data for the kinematic admissibility analysis. The results of kinematic admissibility analyses indicate that a wedge failure along the intersection of Joint Sets 2 and 3 is feasible for a cut slope face orientation of similar dip and dip direction to that of slope No. 11SW-D/C543 (60º/235º). Local daylighting joint orientations form potential planar sliding failures and toppling failures.

Supplementary information provided by acoustic borehole televiewer performed in drillhole No. BH1 from 10.5 m to 16.39 m depth also indicates that structures within the

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slightly to moderately decomposed rock mass are of scattered orientations, similar to the results of the discontinuity survey.

7.4 Ground Profile

The information provided by the current site-specific ground investigation is in general agreement with that from the geological map. The local hillside above the landslide scar is underlain by around 8 m to 9 m of completely to highly decomposed tuff, described as light to dark yellowish brown, firm to stiff, sandy silt with some angular, fine to medium gravel with relict joints stained with limonite and manganese. Bedrock comprising slightly to moderately decomposed tuff is located at about 10 m below ground surface. A thin (about 1 m to 2 m thick) layer of material that has been interpreted as colluvium/residual soil/disturbed insitu material (collectively referred to as colluvium hereinafter), described as firm to stiff, yellowish brown, slightly sandy clayey silt with some angular to sub-angular, medium to coarse gravel, cobbles and boulders of weak to moderately strong tuff, overlies the completely decomposed tuff. This stratum was distinguished from the completely decomposed tuff by the state of weathering of the cobble and boulder-sized corestones, which were completely decomposed, whilst the corestones within the completely decomposed tuff were highly to moderately decomposed. A geological profile is presented in Figure 12.

Within the landslide scar, the colluvium is generally absent except in the vicinity of the main scarp, and the surface of rupture has extended into the completely decomposed tuff.

Notable observations from the drillholes, trial pits and surface strips at slope No. 11SW-D/C543 are as follows:

(a) Soil pipes up to 150 mm diameter were encountered in trial pit TP1 (Figures 9 and 12 and Plate 28) at about 0.8 m depth within the colluvium.

(b) Soil pipes were also identified in colluvium at 0.4 m depth in trial pit TP1 during double-ring infiltrometer test following sudden loss of water placed within the rings (Plate 29).

(c) A tension crack about 100 mm wide and extending to the northwest of the crown of the landslide scar was identified in vegetation strip VS3 (Figure 9 and Plate 30). This feature was traced back to the north flank of the landslide scar, about 1.5 m from the crown, and was interpreted as recent and associated with the August 2005 landslide, representing the upper margin of a displaced, but not completely detached, ground mass.

(d) Drillhole BH1, situated some 10 m above the landslide scar, encountered a significant number of boulder-sized corestones within the regolith, and trial pits TP2, TP9 and

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TP12, all located above the landslide scar, terminated on corestones above the 3 m target depth.

(e) Extensive kaolinisation of the decomposed tuff, described as light grey, slightly sandy clayey silt with occasional fine gravel with limonite and manganese stained in relict joints, was identified in the lower portion of the scar in trial pits TP5 and TP6, being most distinct in TP5 (Plate 31), which was broadly consistent with the locations identified during the field mapping of the scar (Section 5.2.2). Kaolinisation was also observed to some extent in TP4, situated higher in the scar, though to a much lesser extent and in combination with deposition in relict joints (Plate 32). Mazier samples recovered from drillholes BH2 and BH5 in the lower slope portion also indicated localised kaolinisation of the tuff, ranging in thickness from 0.2 m to 0.5 m (Plate 33). White and buff kaolin of up to 5 mm thick and black manganiferous infills were commonly observed in relict joints (Plate 34).

(f) Landslide debris of up to 1 m thick remaining within the landslide scar was identified in TP6 above the surface of rupture (Plate 35).

(g) The ground between Middle Gap Road and Mount Cameron Road indicated a thin (about 1m thick) layer of fill immediately below ground surface underlain by a highly to completely decomposed tuff similar to that encountered above the landslide scar.

Standard Penetration Tests (SPT) conducted in drillholes BH2, BH3, BH5 and BH6 indicate that the SPT 'N' values range from 11 to 99 for the completely decomposed tuff with refusal recorded in the less weathered material.

A review of available ground investigation data from investigation stations in the general vicinity of the landslide site, including drillholes and trial pits completed in and around the adjacent slope No. 11SW-D/C542 as part of the current investigation (Figure 9), was performed in an attempt to identify any other occurrences of kaolinisation similar to that observed in the lower portion of the landslide scar. The results of this review indicated that similar kaolinised material of about 2 m thickness may have been encountered in drillholes associated with previous ground investigations within Wanchai Gap Park located at about 100 m to the west of slope No. 11SW-D/C543 (Figure 9), based on the description given on drillhole logs of a light grey, firm, slightly sandy clayey silt/silty clay. Kaolinised material was, however, not identified in the trial pits and surface strips of the current investigation of slope No. 11SW-D/C542.

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7.5 Material Characteristics

The particle size distribution of the colluvium indicates that this material comprises a clayey, sandy SILT with some gravel to a gravelly SAND/SILT (Figure 13). This material generally falls within the intermediate plasticity range in the plasticity chart with a Plasticity Index of 16% to 18% and a Liquid Limit of 38% to 40% (Figure 14).

The particle size distribution of the completely decomposed tuff samples recovered in the zone above the landslide scar indicates that this material comprises a clayey, sandy SILT with some gravel to a silty, sandy GRAVEL (Figure 15). This material generally falls within the plasticity range from low to high in the plasticity chart with a Plasticity Index of 10% to 19% and a Liquid Limit of 33% to 52% (Figure 14). Samples recovered from the kaolinised material in the lower portion of the landslide scar comprise a sandy SILT with some gravel (Figure 16), with fines falling into the intermediate to high plasticity range in the plasticity chart with a Plasticity Index of 16% to 21% and a Liquid Limit of 40% to 52% (Figure 14).

A summary of the laboratory test results is presented in Table 1.

7.6 Shear Strength

Single stage consolidated undrained triaxial compression tests with pore water pressure measurement were undertaken on 31 specimens prepared from Mazier and block samples recovered from colluvium and completely decomposed tuff, including five samples recovered from the kaolinised material in the lower portion of the landslide scar. The test results are presented in Appendix B.

Tests performed on the colluvium indicate shear strength parameters of $c' = 11$ kPa and $\phi' = 31°$ with a lower bound of $c' = 9$ kPa and $\phi' = 25°$. Tests performed on the completely decomposed tuff indicate shear strength parameters of $c' = 0$ kPa and $\phi' = 42°$ with a lower bound of $c' = 4$ kPa and $\phi' = 31°$. Tests performed on the kaolinised material indicate shear strength parameters of $c' = 0$ kPa and $\phi' = 41°$ with a lower bound of $c' = 1$ kPa and $\phi' = 30°$.

A summary of the laboratory test results is presented in Table 1.

7.7 Permeability

Falling head and constant head permeability tests were carried out within the completely decomposed tuff in drillholes BH2 and BH5 respectively. Additionally, double-ring infiltrometer tests were performed in the colluvium in trial pits TP1 and TP3, in the completely decomposed tuff in trial pits TP6, and in the kaolinised material in trial pits TP4 and TP5. The measured range of permeabilities for the different materials are presented in Table 2 and Figure 17. The limited tests show that the colluvium has a permeability in the range of 1×10^{-5} m/s to 8×10^{-5} m/s, the completely decomposed tuff a permeability in the range of 6×10^{-8} m/s to 3×10^{-6} m/s and the kaolinised material a permeability of 2×10^{-6} m/s to 6×10^{-6} m/s. However, where the test intercepted an erosion pipe or preferential flow paths, the local permeability was much higher (Section 7.2).

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7.8 Groundwater

Instrumentation for groundwater monitoring at the site comprised three piezometers installed in drillholes BH2, BH 3 and BH5 and 10 standpipes installed in drillholes BH1, BH4, BH5 and BH6 and trial pits TP1, TP3, TP4, TP5, TP6 and TP9 from February 2006 to March 2006. The piezometers were all installed within the completely decomposed tuff, while the standpipes extended to bedrock. The 7-day readings for all the installations gave a 'dry' result.

Each of the piezometer and standpipe installations was subsequently fitted with automatic piezometer units (i.e. LevelTroll) in March 2006. Monitoring data obtained from early April to late August 2006 indicate that most of the piezometers and standpipes remained dry throughout the monitoring period. The exceptions comprise the standpipes within BH1, TP1 and TP6. Monitoring results from the standpipe in BH1 indicate a rise in groundwater level of at least 2 m near rock head during rainstorms between June and August 2006. The groundwater level generally dropped below the automatic piezometer unit elevation within approximately 2 weeks following the rainfall events. During the same period, automatic peizometer units in TP1 and TP6 recorded sharp storm responses (within one hour for response in TP1 and one day for response in TP6) of about 0.5 m at shallow depths (within about 3 m of the ground surface), which also dissipated rapidly. It is noted that during which time the rainfall was much less intense as compared with that in August 2005 (see Figures 18 and C8).

The groundwater monitoring data are presented in Appendix C.

8. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No.H17, which is the nearest raingauge to the landslide site and located at No. 25 Borrett Road, about 475 m to the north-west of the landslide (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory and the GEO.

According to the witness accounts, the landslide occurred at about 10:45 a.m. on 20 August 2005. For the purpose of rainfall analysis, the time of the landslide was assumed to be at 10:45 a.m., when the peak hourly rainfall was recorded (Section 5.1). An Amber Rainstorm Warning was hoisted at 8:35 a.m. on 20 August 2005.

The daily rainfall recorded by raingauge No. H17 over the month preceding the landslide, together with the hourly rainfall readings for the period between 10:00 a.m. on 18 August 2005 and 10:00 p.m. on 20 August 2005, are presented in Figure 18. The 24-hour and 12-hour rainfall before the landslide was 375.5 mm and 242 mm respectively. The maximum 1-hour rolling rainfall was recorded as 46 mm between 9:05 a.m. and 10:05 a.m. on 20 August 2005.

Table 3 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. H17 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 31-day rolling rainfall of 1172 mm before the landslide was the most severe, with a

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corresponding return period of about 40 years. The results also show that the 7-day rolling rainfall of 726 mm had a corresponding return period of about 33 years. For rainfall durations of less than 2 hours, the corresponding return periods were less than 2 years.

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by local raingauge No. H17 between 1984 and 1997. The return period of both the 24-hour and 7-day rainfall was about 12 years (Table 4). It is noted that the estimated return periods of the August 2005 rainstorm based on rainfall data at local raingauge are generally less than those estimated by the historical rainfall data at the Hong Kong Observatory.

The maximum rolling rainfall for the rainstorm in August 2005 has been compared with the past major rainstorms between 1992 and 1998 recorded by raingauge No.H17, which came into operation in mid-1980s (Figure 19). This shows that the rainfall preceding the August 2005 landslide is the most severe for the 4-day and 7-day duration. While the maximum rolling rainfall for the rainstorm in August 2005 is comparable to the severe rainstorms recorded between 1992 and 1998 for durations longer than 7 days, it is not particularly severe for short duration rainfalls (< 2 days).

9. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses using the rigorous solution of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the probable causes of the landslide. The analyses examined the likely operative range of shear strength parameters along the surface of rupture for different credible groundwater conditions at the time of failure.

The cross-section through the landslide included in the stability analyses was based on Section A-A presented in Figure 7. The pre-failure slope profile was based on topographic survey plans, photographic records and inference using engineering judgement. The geometry of the surface of rupture and the ground profile was based on site measurements by FSW, post-failure topographic survey by the Survey Division of CEDD and the site-specific ground investigation. The idealised inferred section adopted in the analyses is presented in Figure 20.

The stability analyses were carried out using a range of shear strength parameters which covers the typical ranges of those given for selected Hong Kong soils, as well as the parameters determined from laboratory tests as part of this study (Section 7.6). Various levels of elevated groundwater pressures above the surface of rupture were assumed for the purposes of the stability analyses.

The results of the analyses are presented in Figure 20. For a factor of safety of unity, the analyses suggest that failure could have been brought about by the development of a transient ground water pressure corresponding to a water level of about 1 m above the surface of rupture.

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10. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

10.1 Mode and Sequence of Failure

In the absence of direct eye-witnesses of the landslide, the geometry of the landslide scar and the deposition of the landslide debris constitute the information upon which reconstruction of the mode and sequence of failure is based.

The mode of failure comprised a translational slide along a surface of rupture that extended from the slope crest to the toe, passing through the completely decomposed tuff regolith. Scarring on trees situated on the opposite side of Middle Gap Road which extended to about 2 m above ground level suggests that the failure mostly occurred as a massive singular detachment of material from the hillside that impacted on Middle Gap Road before overspilling onto the sloping ground below, crossing Mount Cameron Road and entering the natural drainage line to the west. The debris that entered the drainage line became channelised and travelled further downslope before coming to rest.

Debris that overspilled from Middle Gap Road onto the sloping ground below may have been partly airborne, as evidenced by the minimal entrainment of material from this area, due to the initial impact on Middle Gap Road.

10.2 Probable Causes of Failure

The major landslide occurred on a steep soil cut slope that had been modified by previous repeated instability. The close correlation between the prolonged rainfall in August 2005 and the timing of the landslide suggests that the failure was probably triggered by rainfall.

The landslide was probably caused by the transient build-up of groundwater pressure within the soil mass due to direct infiltration upslope of the shotcreted cut face and possible subsurface seepage via preferential flowpaths. This postulation is supported, to a certain extent, by the rapid rise in groundwater pressure recorded during July and August 2006 at two standpipes installed at shallow depths, which reflected local perching of transient groundwater or development of seepage pressure associated with non-vertical seepage flow. The current investigation of the landslide site has indicated that the base groundwater table is situated below the soil/rock interface in excess of 10 m below ground surface and observations made in the general vicinity of the site along Black’s Link suggest that the base groundwater flows from the higher ground to the east of the site are generally towards the north, i.e. away from the landslide site.

Theoretical stability analyses indicate that relatively small increases in groundwater pressures above the surface of rupture would have been required to initiate the failure.

The landslide site was originally situated at the head of a southwest trending drainage line, which could be susceptible to concentration of groundwater flow. The formation of a steep cut would have resulted in over-steepening and possible stress relief. The site is also located close to a northwest trending photolineament, which may suggest the possible presence of a fault approximately parallel to the subject slope, which could have allowed

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preferential weathering and kaolin development, resulting in a weaker mass. The contribution of the above may predispose the subject cut slope to failure.

Other factors that probably contributed to the major landslide include the following:

(a) the slope-forming materials of slope No. 11SW-D/C543 was apparently in a more advanced state of weathering as compared with the adjacent areas, which give rise to local adverse hydrogeological conditions,

(b) presence of adverse relict jointing in the weathering profile,

(c) presence of voids, including erosion pipes, in the near-surface soil profile leading to increased infiltration rates in the hillside above the cut face and probably enhanced sub-surface seepage, and

(d) a history of repeated slope instability, which could have contributed to local opening up of the relict structures and/or possible changes in infiltration patterns, promoting progressive deterioration of the slope conditions.

Whether or not the zone of heavy kaolinisation identified in the completely decomposed tuff near the slope toe was a key contributory factor to the August 2005 major landslide remains uncertain, as the vertical extent of the kaolinised zone prior to the August 2005 failure is not known. Nevertheless, the observation of kaolinised material within the landslide debris suggests that the surface of rupture probably extended at least partially into the kaolinised zone. The probable existence of permeability boundaries in and around the kaolinised zone could be expected, which may have contributed to the build-up of transient groundwater pressures during rainstorms at the landslide source area.

10.3 Discussion

The 20 August 2005 landslide above Middle Gap Road occurred on an old slope with a history of major as well as minor failures. The past instability probably contributed to loosening up of the ground mass and making it vulnerable to water ingress. This was likely to lead to progressive deterioration of the slope condition. Slope deterioration was probably manifested by the repeated cracking of the hard surface cover as observed during the past slope maintenance inspections. The above reflect that the slope was probably susceptible to development of major instability given severe rainfall.

Slope No. 11SW-D/C543 was formed by cutting into the hillside during the formation of Middle Gap Road immediately above the head of a natural drainage line, the upper extent of which was probably situated just below Middle Gap Road. In geomorphological terms, the proximity to the head of a natural drainage line means that the site is probably susceptible to concentrated groundwater flow and development of slope instability. The more advanced state of weathering at slope No. 11SW-D/C543 as compared with the adjacent areas probably gives rise to an adverse hydrologeological setting in terms of concentrated subsurface seepage flow. The local hydrogeology is further complicated by the presence of erosion pipes in the near-surface ground mass.

The available ground investigation data suggest that the zone of extensive kaolinisation within the completely decomposed tuff identified within the lower portion of the 20 August 2005 landslide scar is locally confined to slope No. 11SW-D/C543, although other examples of kaolinisation may also have previously been encountered in the general area. The photolineament observed in close proximity to the slope indicates the possible presence of a fault, which could have allowed preferential weathering and kaolin development. Nevertheless, given the proximity of the site to the prominent northeast-southwest trending fault to the west, the possibility that the slope-forming materials have, at some stage, been affected by tectonic activity and hydrothermal processes cannot be ruled out.

11. CONCLUSIONS

It is concluded that the landslide, which occurred on 20 August 2005 and affected cut slope No. 11SW-D/C543, was probably triggered by severe rainfall. The failure affected an old, soil cut slope with a history of repeated instability, which showed possible signs of distress in the years preceding the failure in the form of repeated cracking of the hard surfacing.

The failure was probably caused by the build-up of transient groundwater pressure in the soil mass following severe rainfall. The repeated failures at slope No. 11SW-D/C543 have occurred in an area of more advanced weathering within the regolith, which included a zone of heavy kaolinisiation of the parent weathered rock, as compared with the adjacent areas.

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Table 1 - Summary of Laboratory Test Results (1 of 3)

GI Station No.	Sample Depth (m)	Material	Testing Result													
			Moisture Content (%)	Atterbreg Limits				Particle Size Distribution				Triaxial Compression Test				
				Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour upon Shearing
TP1	1.0	Colluvium	15	39	22	17	0.59	22	41	26	11	-				
			15	-				-				cus	30	100	62	Dilative
			18	Non-plastic				4	43	40	13	-				
	2.0		20	-				-				cus	40	76	49	Dilative
			17	-				-				cus	80	282	154	Dilative
	3.0	CDT	11	33	23	10	-0.97	11	71	7	11	-				
			11	Non-plastic				6	79	13	2	-				
			11	-				-				cus	120	172	103	Dilative
TP2	1.0	Colluvium	14	-				-				cus	45	59	38	Contractive
			15	-				-				cus	90	77	52	Contractive
TP3	0.8	Colluvium	23	-				-				cus	40	77	48	Dilative
			21	-				-				cus	80	167	108	Dilative
	1.0		24	Non-plastic				5	76	16	3	-				
	1.8		27	-				-				cus	120	112	61	Contractive
			25	-				-				cus	200	265	146	Dilative
	2.0		27	Non-plastic				4	74	13	9	-				
	2.8	CDT	23	-				-				cus	160	197	108	Contractive
			21	43	26	17	0.73	25	52	20	3	-				
TP4	1.0	Colluvium	30	Non-plastic				4	75	19	2	-				
			29	-				-				cus	50	103	60	Dilative
			30	-				-				cus	30	119	68	Dilative
	2.0	Kaolinised tuff	31	-				-				cus	60	125	86	Dilative
			28	-				-				cus	120	332	232	Dilative
			30	Non-plastic				5	68	24	3	-				
	3.0		29	48	31	17	1.02	8	56	31	5	-				

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Table 1 - Summary of Laboratory Test Results (2 of 3)

GI Station No.	Sample Depth (m)	Material	Testing Result													
			Moisture Content (%)	Atterbreg Limits				Particle Size Distribution				Triaxial Compression Test				
				Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour upon Shearing
TP5	0.8	Kaolinised tuff	29	-				-				cus	30	94	57	Dilative
			29	-				-				cus	30	208	118	Dilative
	1.0		25	Non-plastic				5	80	14	1	-				
	1.8		29	-				-				cus	90	164	101	Dilative
			29	40	24	16	0.85	7	76	16	1	-				
	2.0		28	Non-plastic				7	76	16	1	-				
	2.8		31	52	31	21	0.39	9	75	15	1	-				
	3.0		26	Non-plastic				4	54	31	11	-				
TP6	3.0	CDT/HDT	27	43	25	18	0.63	10	67	18	5	-				
TP9	1.0	Colluvium	13	40	25	15	-0.2	8	46	30	16	-				
	1.0		14	44	26	18	-0.25	17	41	22	20	-				
TP10	1.0	Colluvium	28	Non-plastic				5	63	21	11	-				
		HDT	28	52	33	19	0.69	24	53	21	2	-				
			29	-				-				cus	50	46	32	Contractive
	2.0	HDT	29	-				-				cus	100	270	194	Dilative
			27	-				-				cus	200	199	124	Contractive
			28	Non-plastic				3	28	28	41	-				
TP11	1.7	HDT	20	-				-				cus	45	138	100	Dilative
	2.8	HDT	17	-				-				cus	90	114	74	Contractive
TP12	0.5	Colluvium	17	-				-				cus	160	162	79	Contractive
	0.5		17	43	25	18	-0.16	25	47	19	9	-				
BH1	2.0	HDT	11	-				-				cus	35	274	205	Dilative
	2.2		12	-				-				cus	70	307	213	Dilative
	2.4		10	-				-				cus	140	421	297	Dilative
	6.4		18	-				-				cus	100	190	118	Dilative

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Table 1 - Summary of Laboratory Test Results (3 of 3)

GI Station No.	Sample Depth (m)	Material	Testing Result													
				Atterbreg Limits				Particle Size Distribution				Triaxial Compression Test				
			Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour upon Shearing
BH1	6.6	HDT	20	-				-				cus	200	302	209	Dilative

Legend:

$s' = (\sigma'_1 + \sigma'_3)/2$ and
$t' = (\sigma'_1 - \sigma'_3)/2$; where σ'_1 and σ'_3 are the major and minor effective Principle Stresses respectively.
cus = Consolidated Undrained Triaxial Compression Test with Pore Pressure Measurement.

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Table 2 - Summary of Field Permeability Test Results

Soil Stratum	Coefficient of Permeability, k (m/s)								
	Double-ring infiltrometer test						Borehole permeability test		Average Permeability (m/s)
	TP1	TP2	TP3	TP4	TP5	TP6	BH2	BH5	
Colluvium/ Residual soil/ Disturbed insitu material	1.35×10^{-5} to 2.41×10^{-5} (0.8 m) (see note 2)	(see note 3)	4.96×10^{-5} to 7.61×10^{-5} (0.5 m) (see note 2)	-	-	-	-	-	4.08×10^{-5}
Completely decomposed tuff	-	-	-	-	-	2.57×10^{-6} (2.0 m)	6.47×10^{-8} (see note 4)	9.56×10^{-7} (see note 5)	9.14×10^{-7}
Kaolinised material	-	-	-	2.05×10^{-6} (0.5 m)	5.75×10^{-6} (1.3 m)	-	-	-	3.90×10^{-6}

Notes:
(1) Bracketed figures indicate depth at which test was performed.
(2) Multiple tests were carried out due to high permeability of the material.
(3) Permeability test has not been carried out as the soil stratum was not of sufficient thickness.
(4) Falling head permeability test has been carried out.
(5) Constant head permeability test has been carried out.

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Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. H17 for Selected Durations Preceding the 20 August 2005 Landslide and the Estimated Return Periods Based on Lam & Leung (1994)

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	7.0	08:40 on 19 August 2005	< 2
15 Minutes	14.0	02:05 on 19 August 2005	< 2
1 Hour	46.0	10:05 on 20 August 2005	< 2
2 Hours	74.5	20:45 on 19 August 2005	< 2
4 Hours	136.0	22:35 on 19 August 2005	3
12 Hours	242.0	05:40 on 20 August 2005	5
24 Hours	375.5	10:45 on 20 August 2005	10
2 Days	479.5	10:45 on 20 August 2005	16
4 Days	556.0	10:45 on 20 August 2005	13
7 Days	726.0	10:45 on 20 August 2005	33
15 Days	836.0	10:45 on 20 August 2005	20
31 Days	1172.0	10:45 on 20 August 2005	40

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data.
(3) The use of 5-minute data for durations between 4 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.

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Table 4 - Maximum Rolling Rainfall at GEO Raingauge No. H17 for Selected Durations Preceding the 20 August 2005 Landslide and the Estimated Return Periods Based on Evans & Yu (2001)

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	7.0	08:40 on 19 August 2005	< 2
15 Minutes	14.0	02:05 on 19 August 2005	< 2
1 Hour	46.0	10:05 on 20 August 2005	< 2
2 Hours	74.5	20:45 on 19 August 2005	< 2
4 Hours	136.0	22:35 on 19 August 2005	3
12 Hours	242.0	05:40 on 20 August 2005	4
24 Hours	375.5	10:45 on 20 August 2005	12
2 Days	479.5	10:45 on 20 August 2005	8
4 Days	556.0	10:45 on 20 August 2005	5
7 Days	726.0	10:45 on 20 August 2005	12
15 Days	836.0	10:45 on 20 August 2005	7
31 Days	1172.0	10:45 on 20 August 2005	10

Notes: (1) Return periods were based on Evans & Yu (2001).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.

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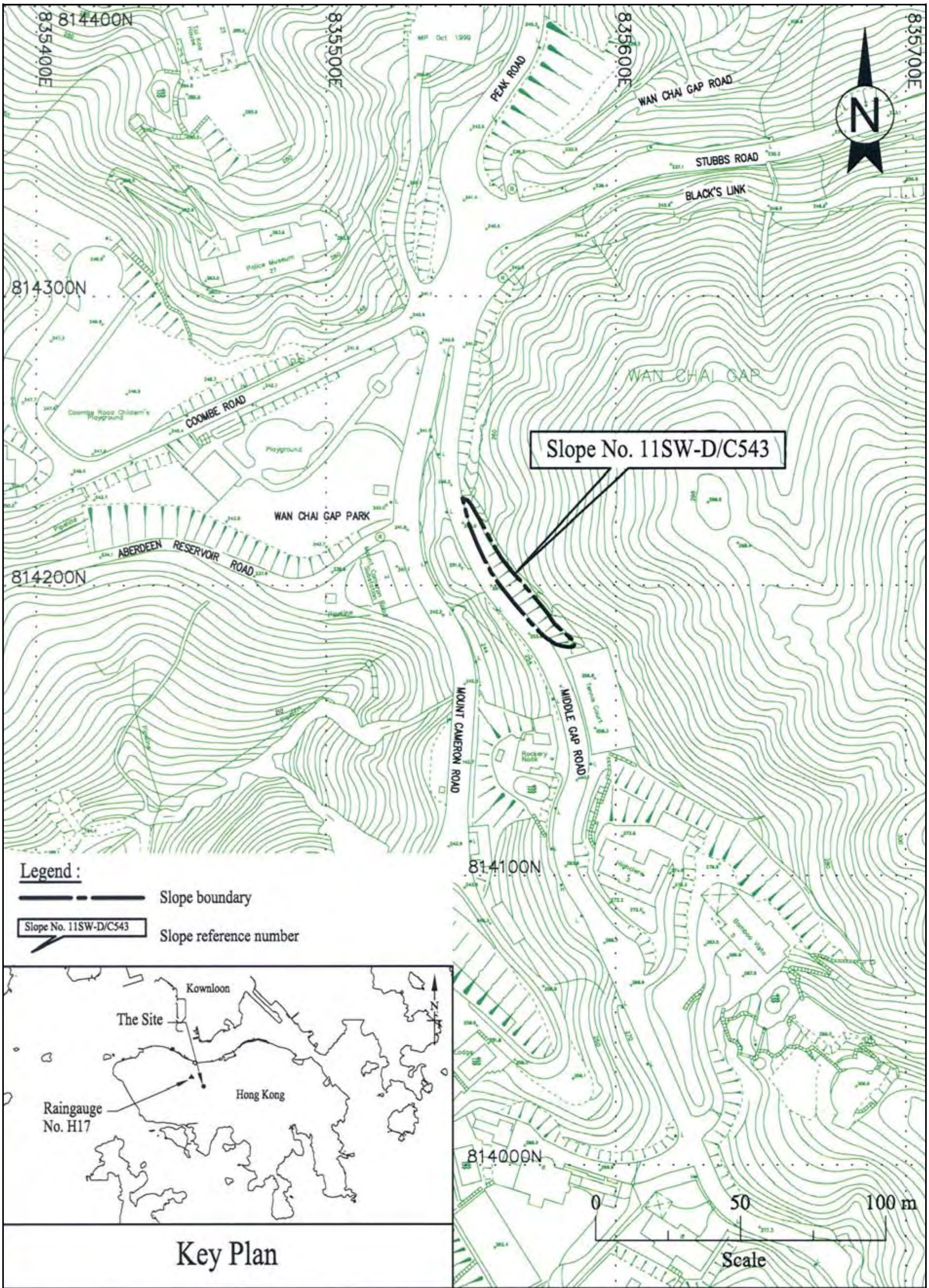

Note : Base map is extracted from Survey Sheet No. 11SW-14D, Scale 1 : 1000, dated 1992

Figure 1 - Site Location Plan

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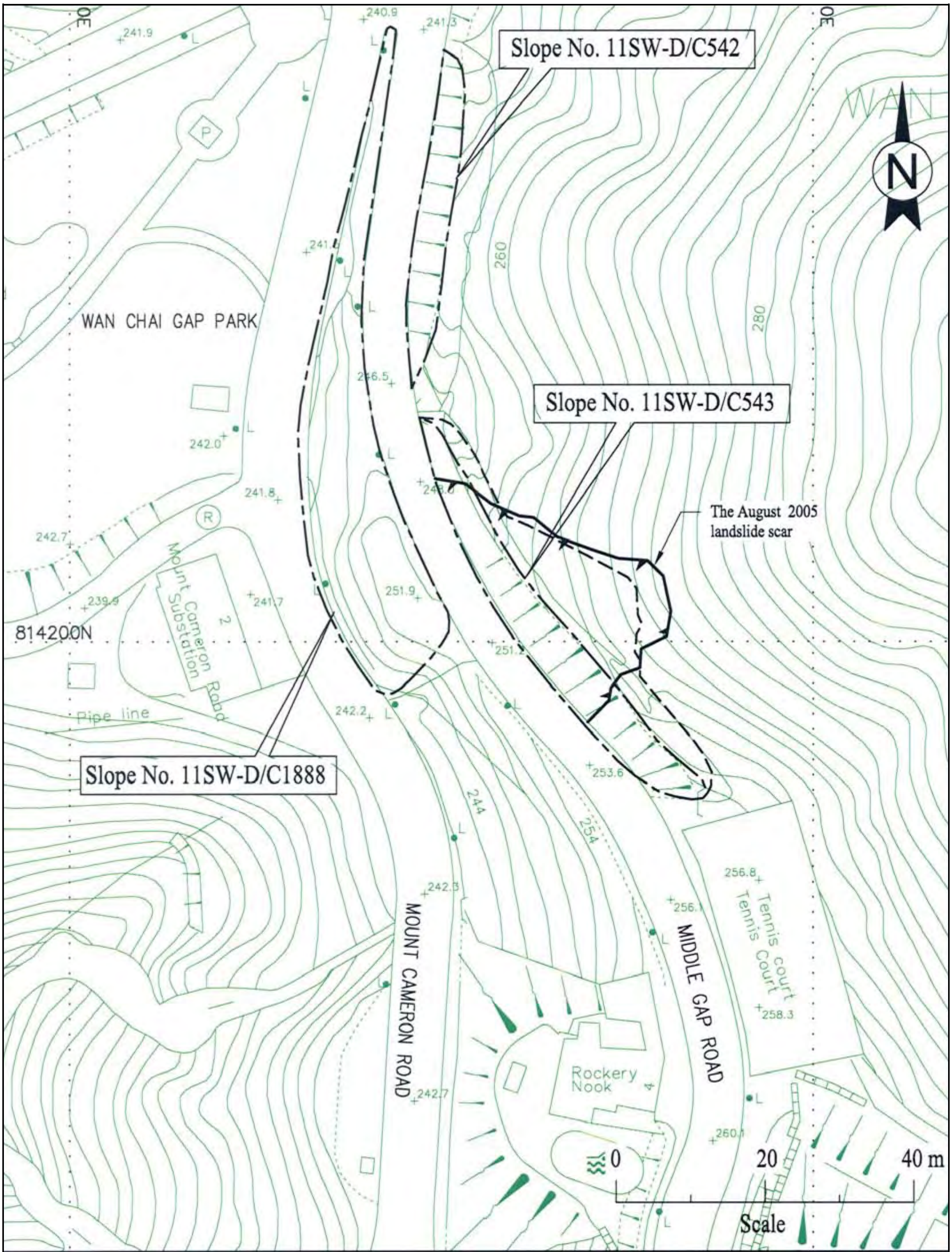

Legend :

Registered feature boundary	Estimated pre-failure alignment of slope crest

Note : Base Map is extracted from Survey Sheet No. 11SW-19D, dated 1999.

Figure 2 - Site Plan

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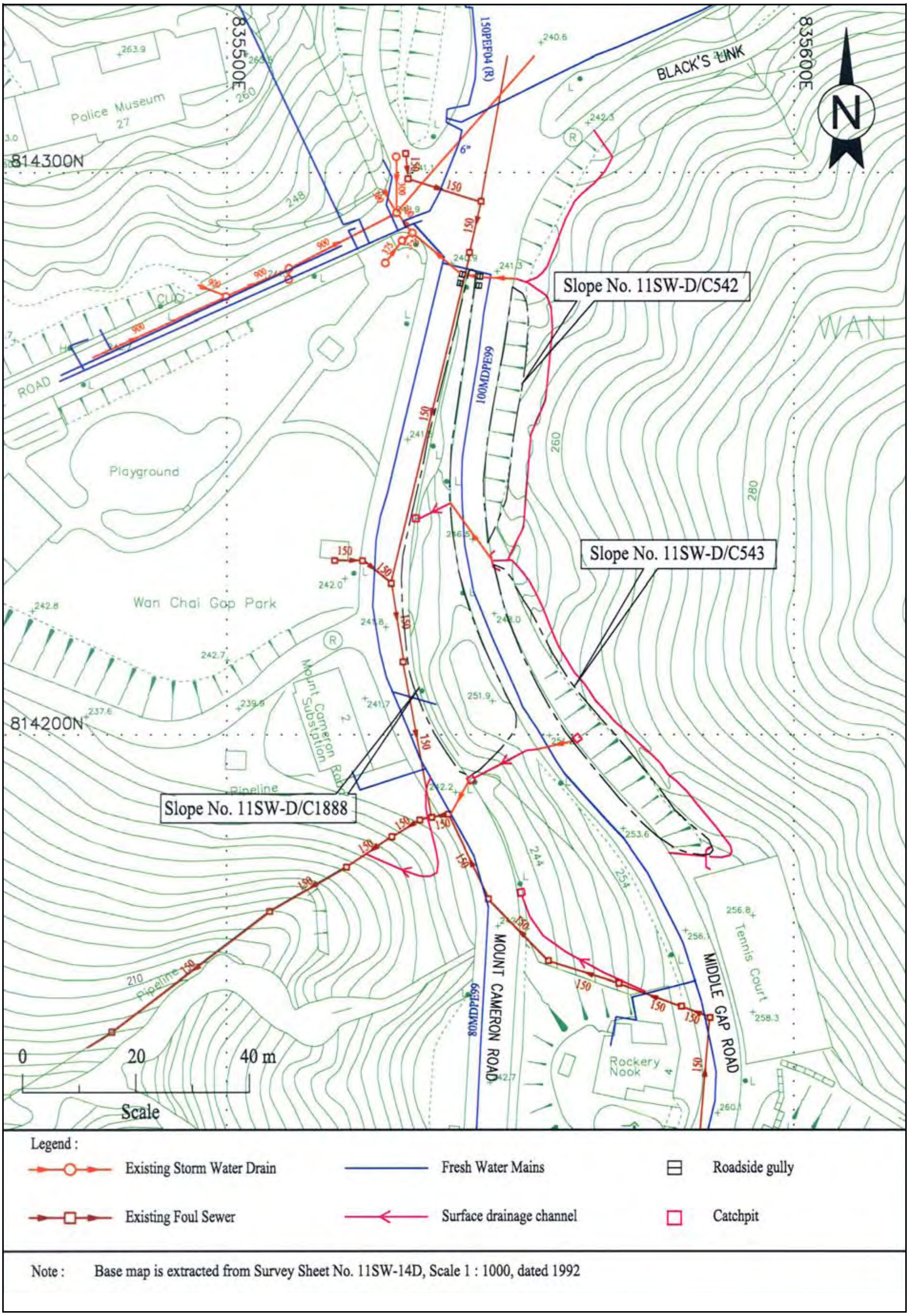

Figure 3 - Buried Water-carrying Services and Surface Drainage Channels

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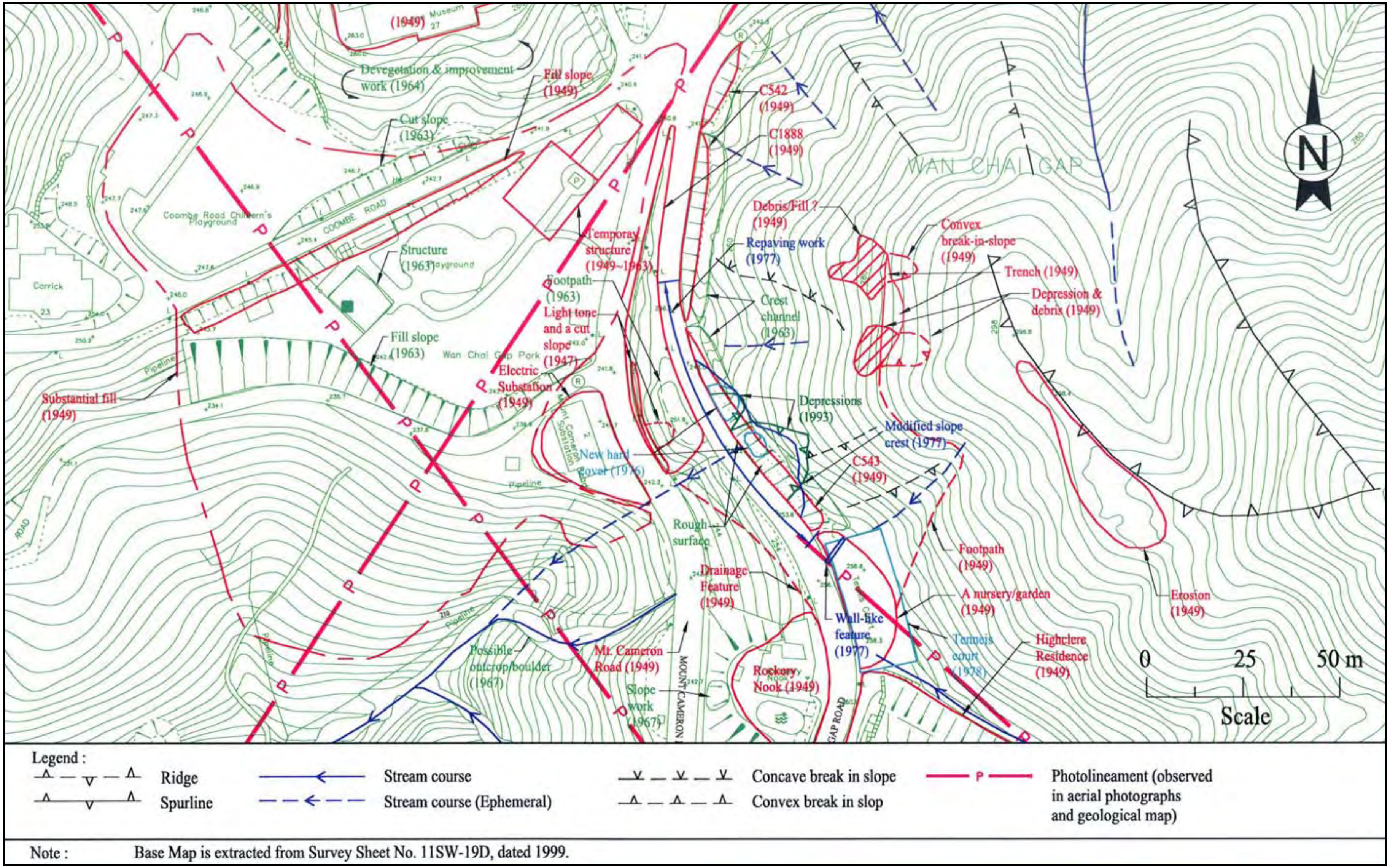

Figure 4 - Site Development History

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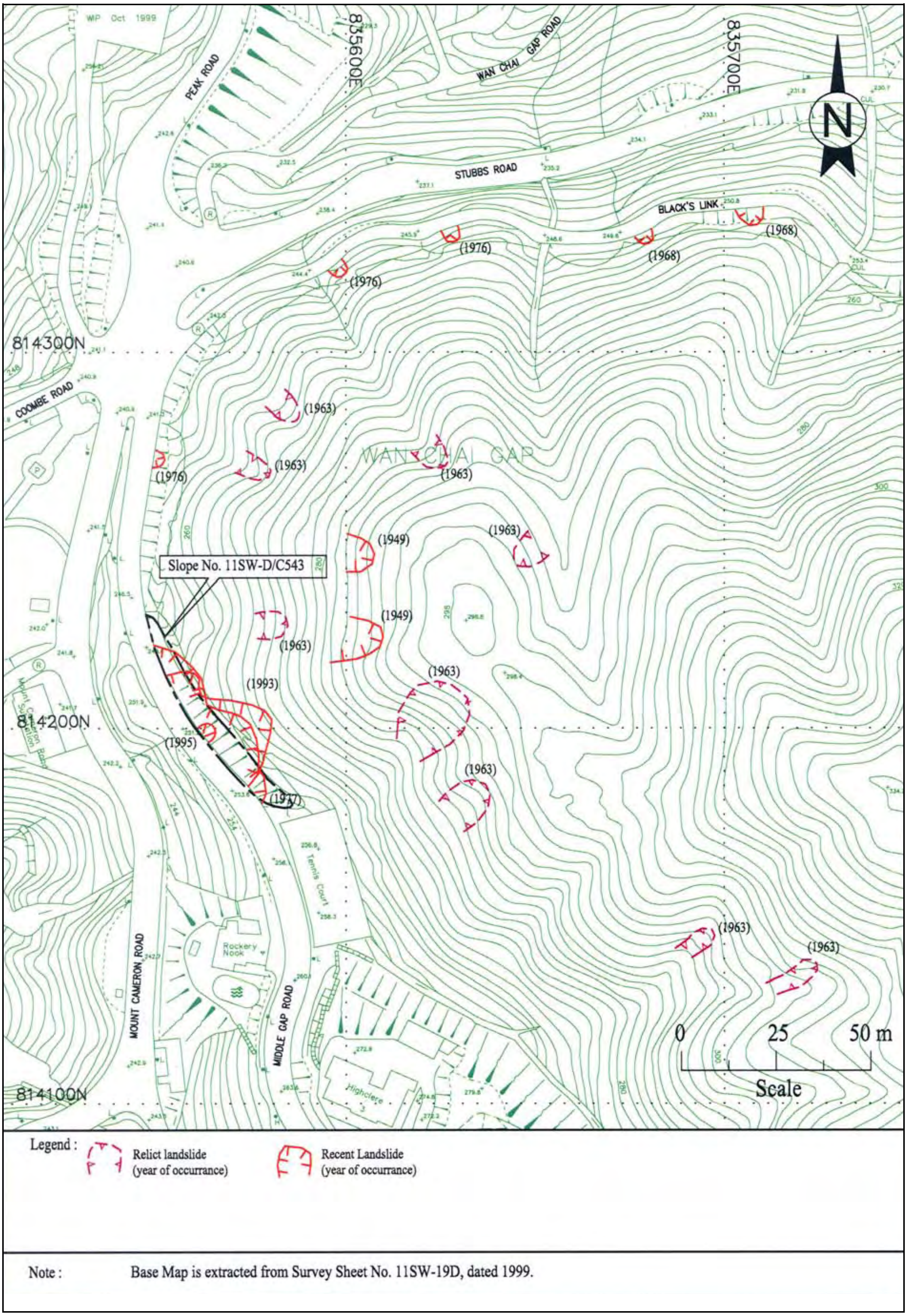

Figure 5 - Previous Instability

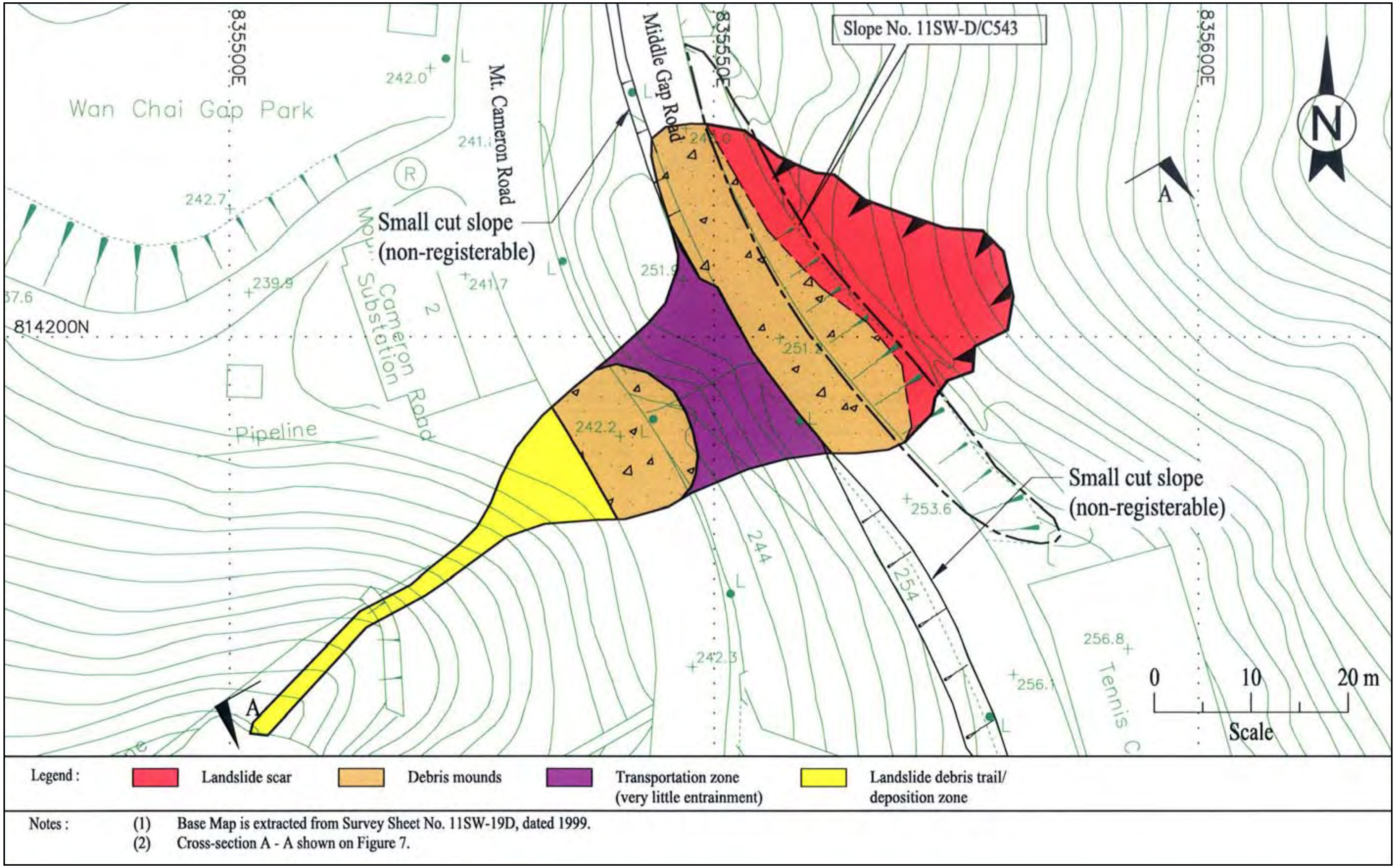

Figure 6 - Plan View of Landslide

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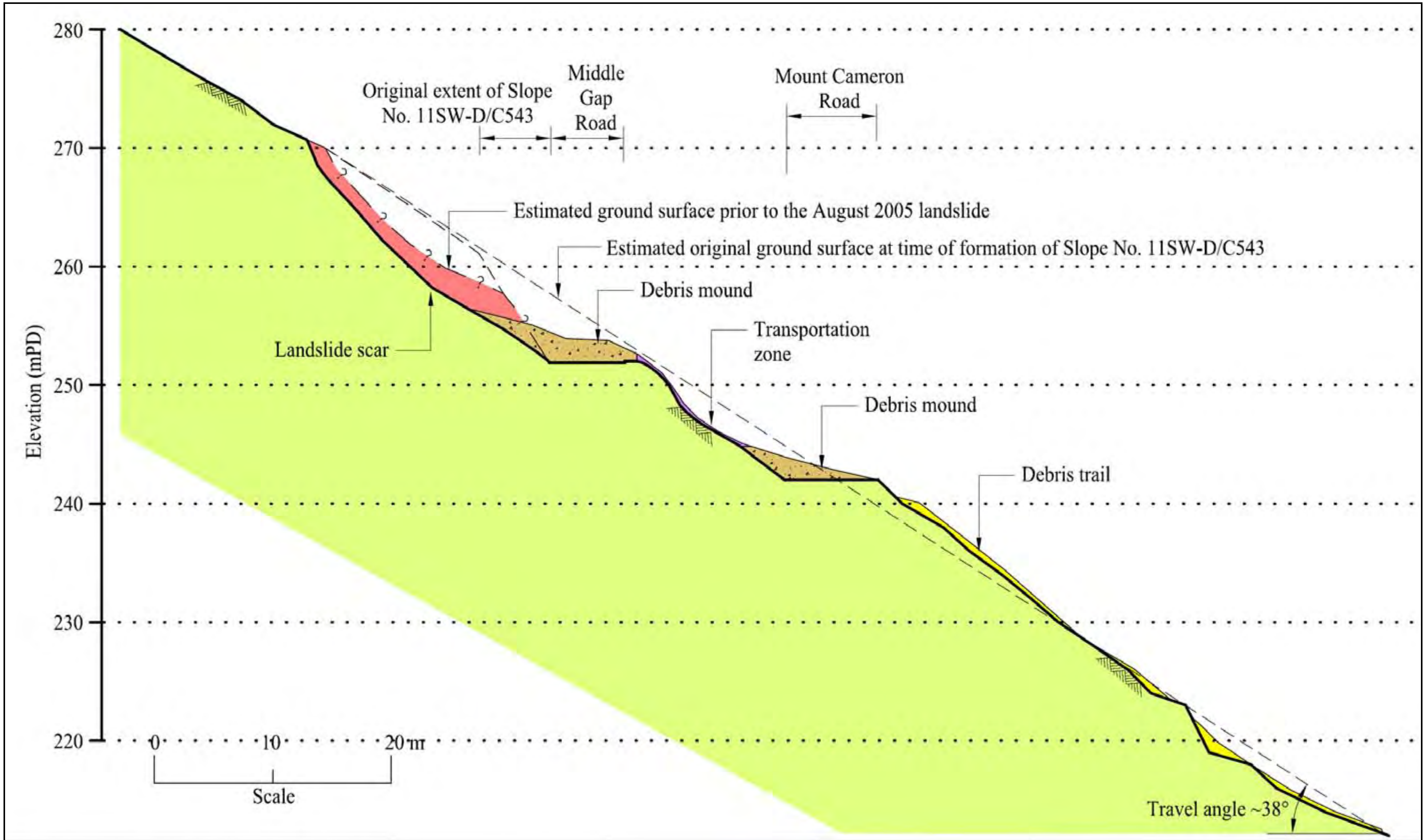

Note : Refer to Figure 6 for section location.

Figure 7 - Section A-A through the Local Hillside Showing Extent of Debris Runout

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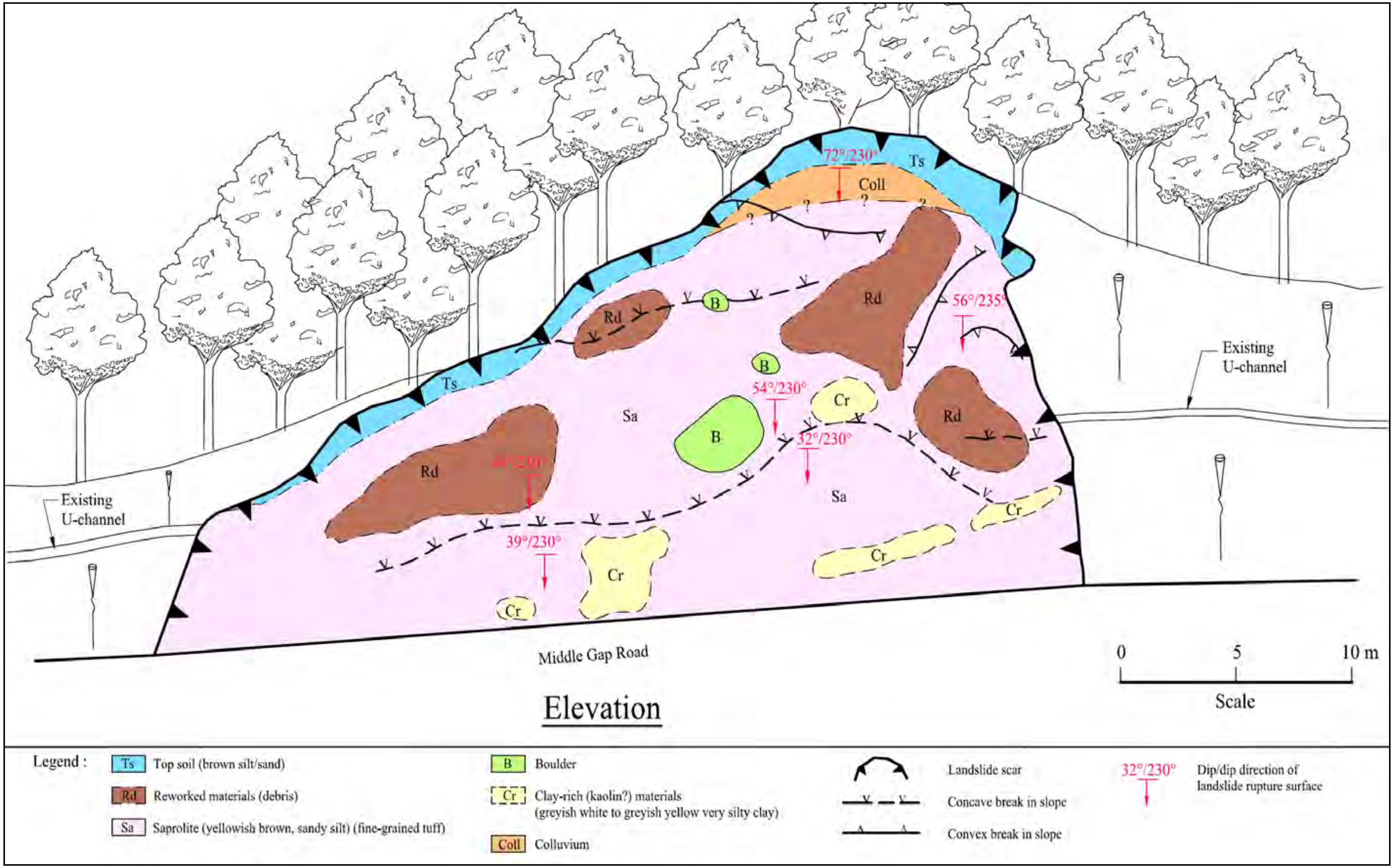

Figure 8 - Mapping of the Landslide Scar

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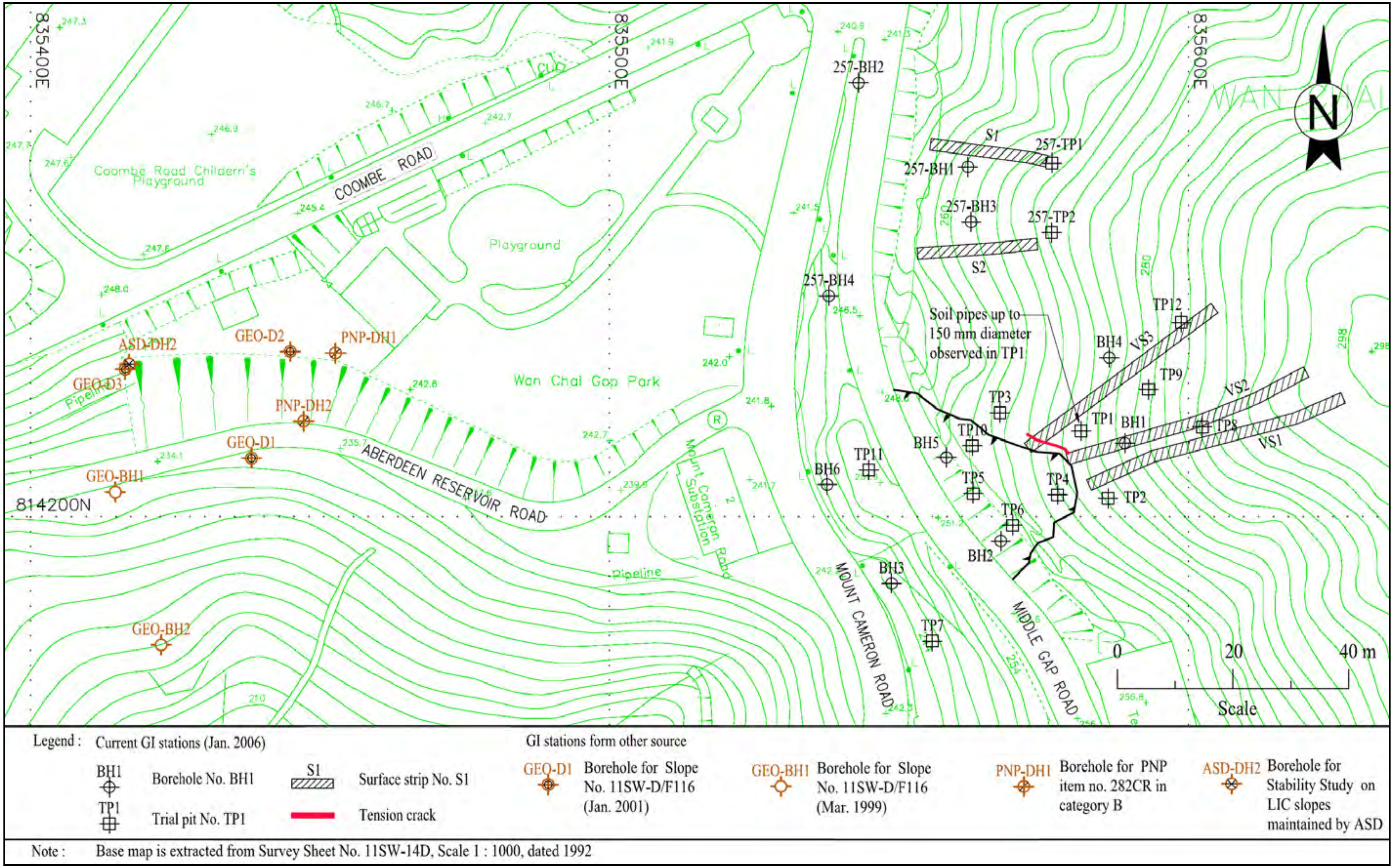

Figure 9 - Ground Investigation Stations

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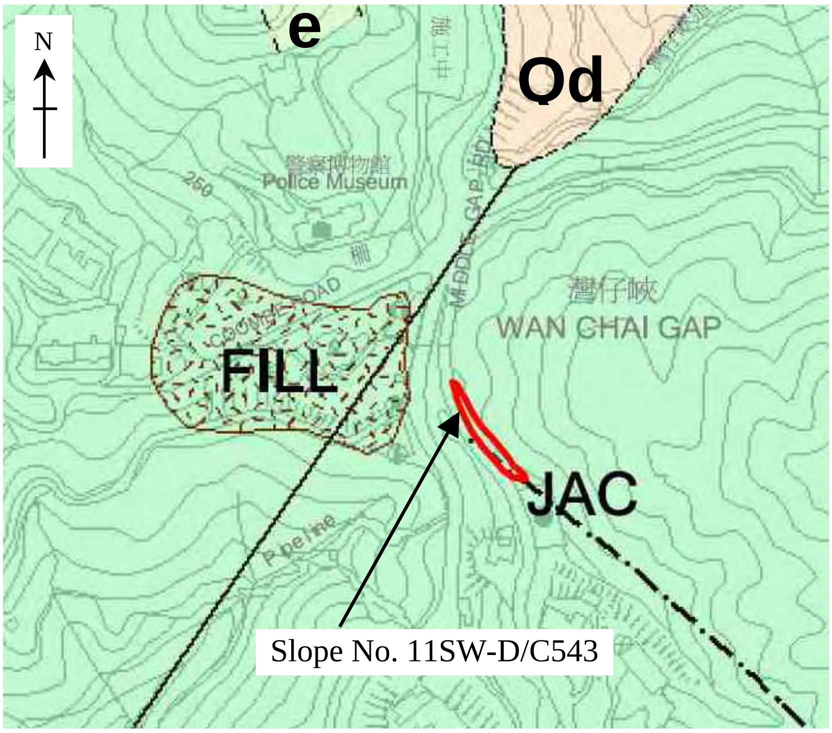

Legend:

Quaternary Superficial Deposits (Onshore)

Fill; Sanitary fill (Qfs) - Natural earth and waste

Qd — Debris flow deposits - Unsorted sand, gravel, cobbles and boulders; Clay/Silt matrix

Solid Geology

JAC — Fine ash vitric tuff

e — Eutaxite

Geological Lines

Geological boundary, superficial deposits

Photogeological lineament

1982 — Fill boundary, with limit of reclamation of date shown

Note: (1) Extract from Sheet 11 of the Hong Kong Geological Survey 1:20,000 scale Map Series HGM20 (GCO,1986).

Figure 10 - Solid and Superficial Geology of the Study Area

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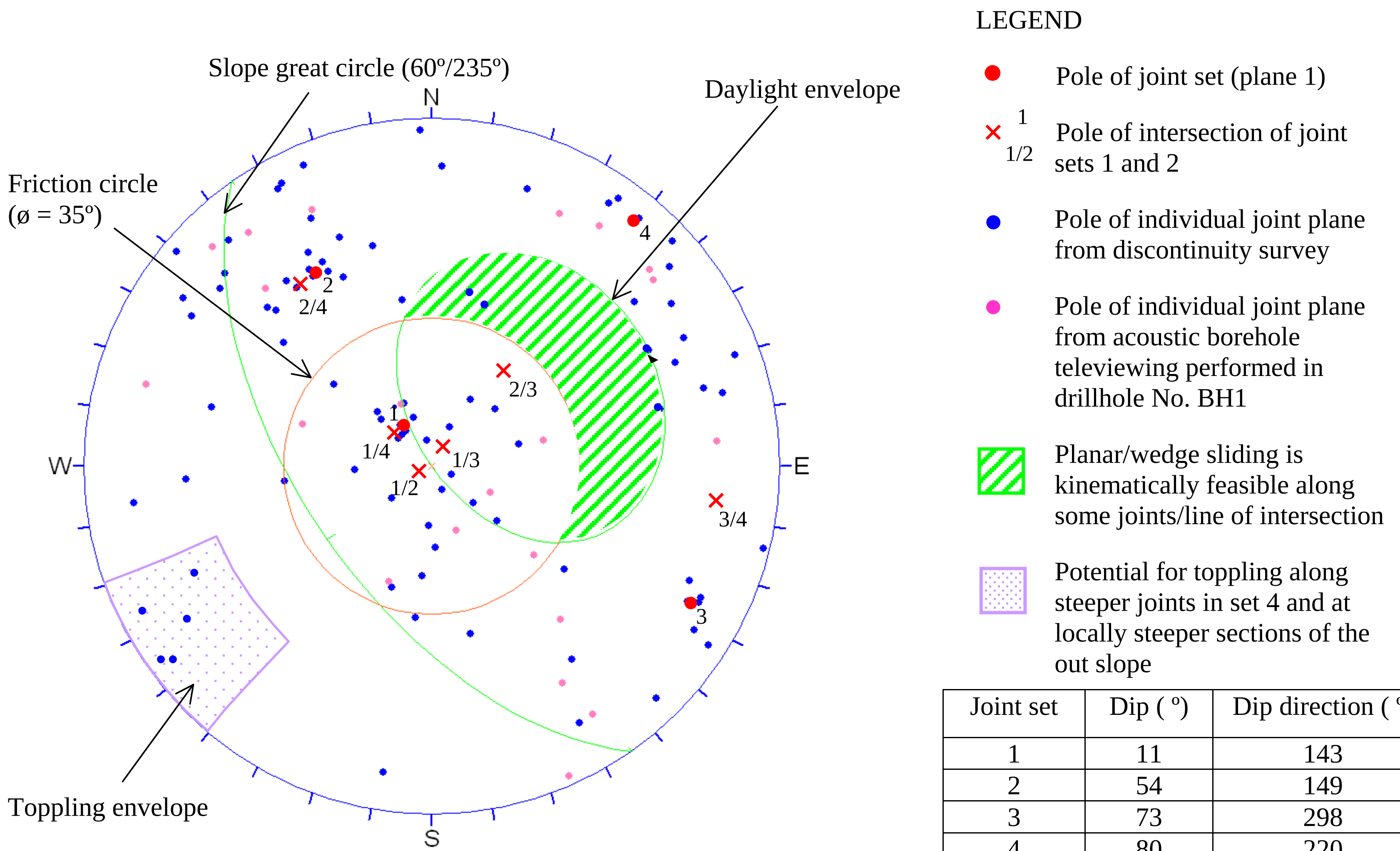

Joint set	Dip (º)	Dip direction (º)
1	11	143
2	54	149
3	73	298
4	80	220

Note: Joint sets interpreted from pole data based on contouring of pole concentrations using Fisher Concentrations Method.

Figure 11 - Stereographic Projection of Discontinuity Survey Data

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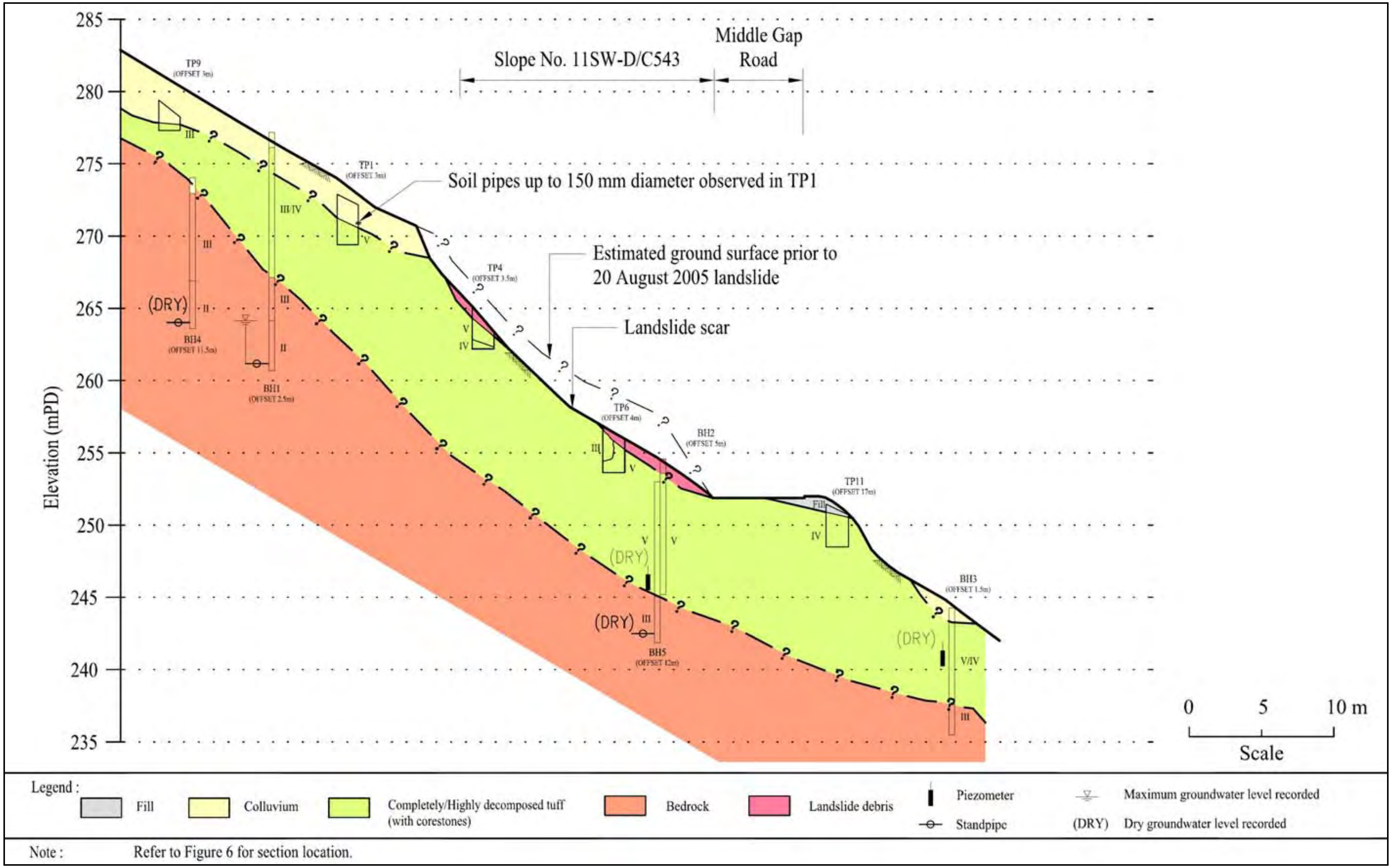

Figure 12 - Geological Profile (Section A - A)

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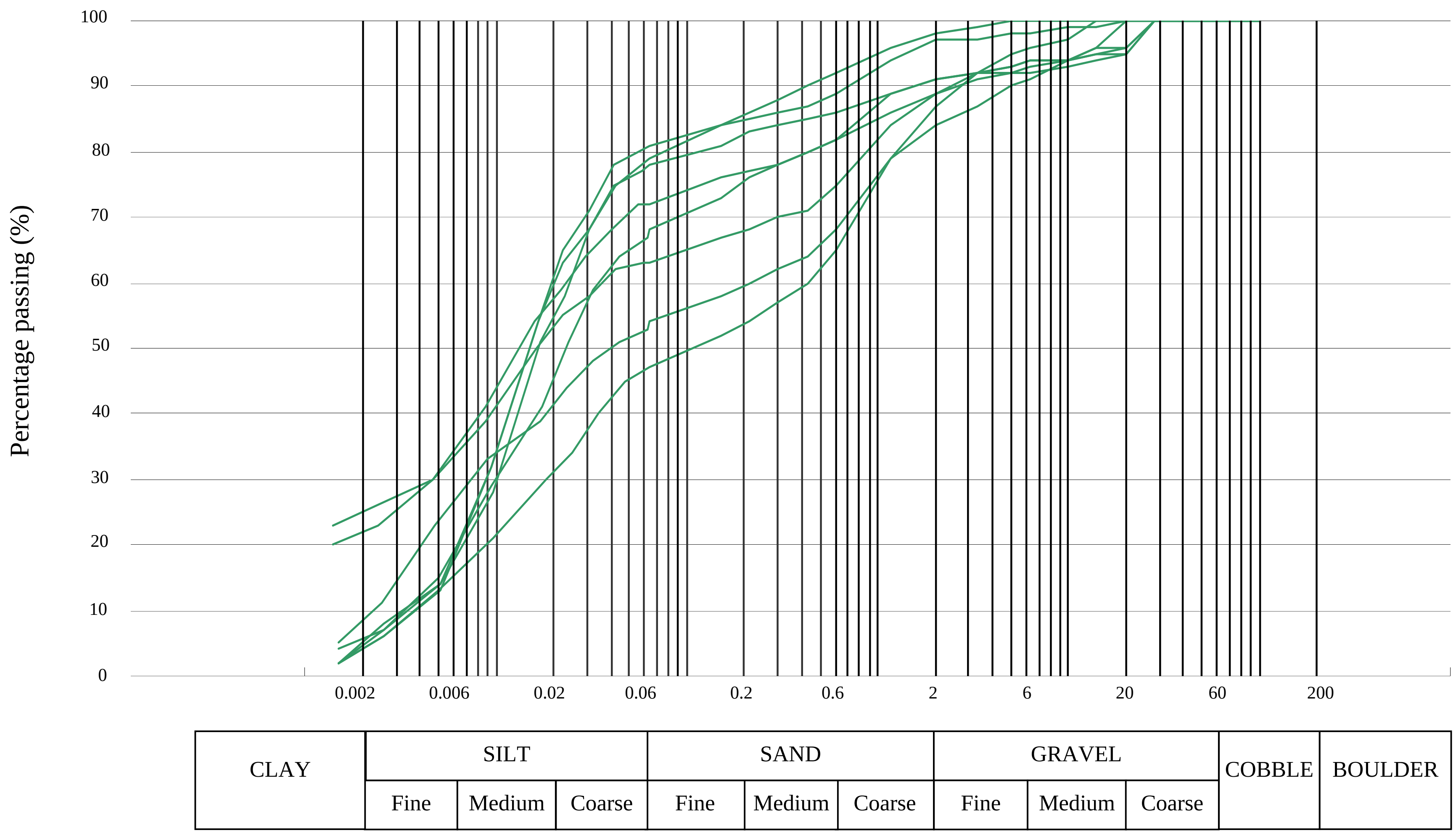

Figure 13 - Particle Size Distribution of Colluvium

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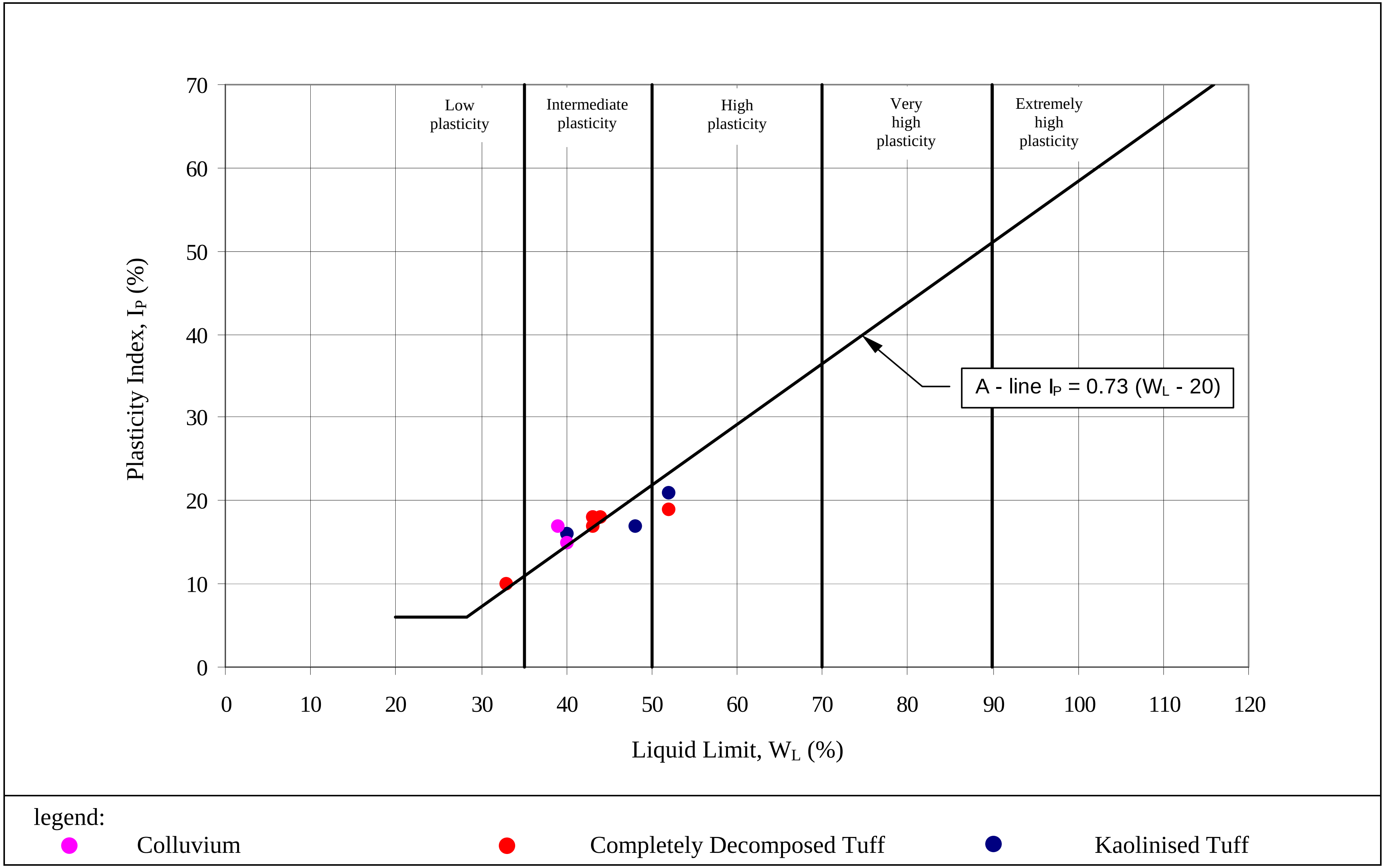

Figure 14 - Plasticity Chart for Colluvium, Completely Decomposed Tuff and Kaolinised Tuff

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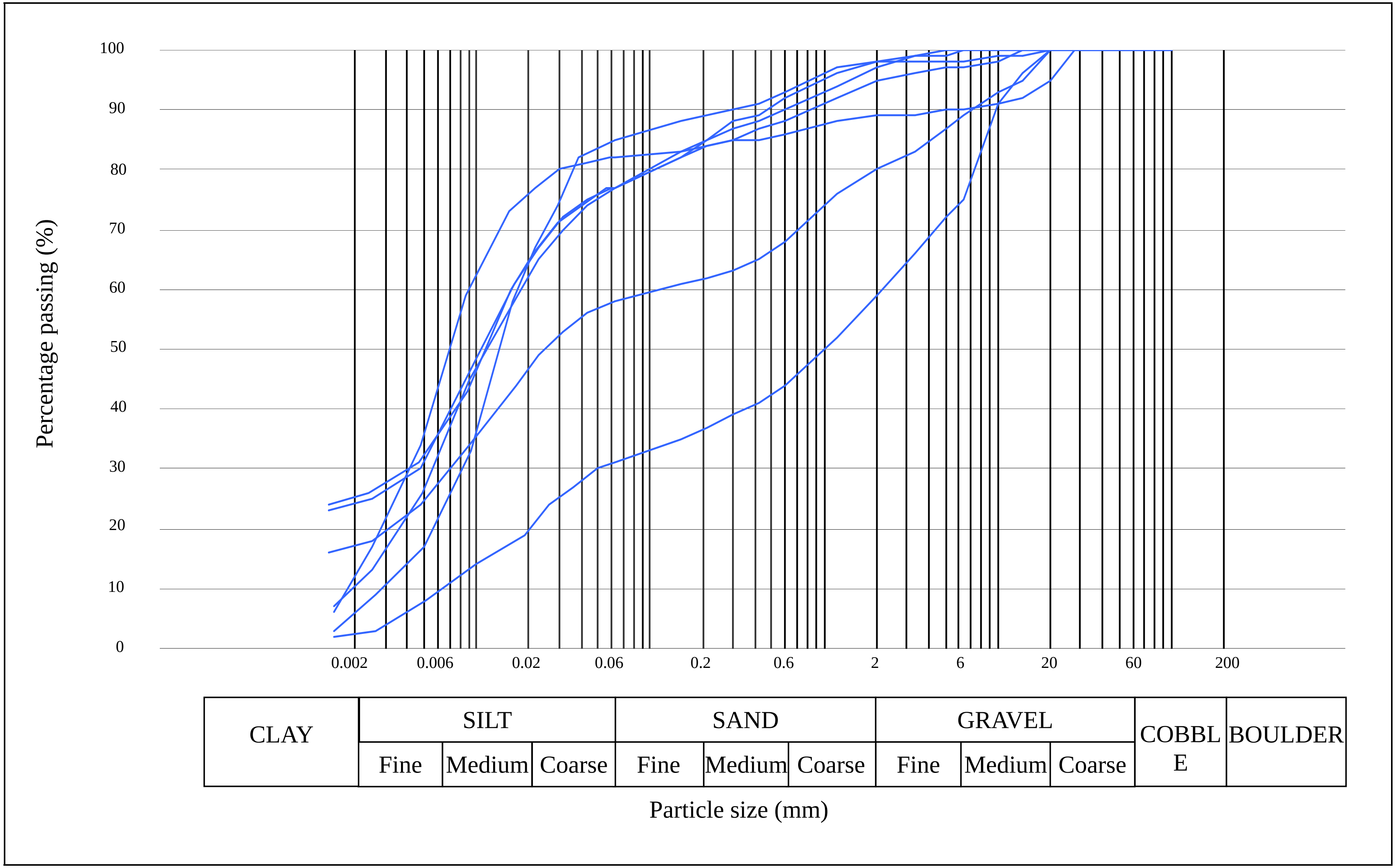

Figure 15 - Particle Size Distribution of Completely Decomposed Tuff

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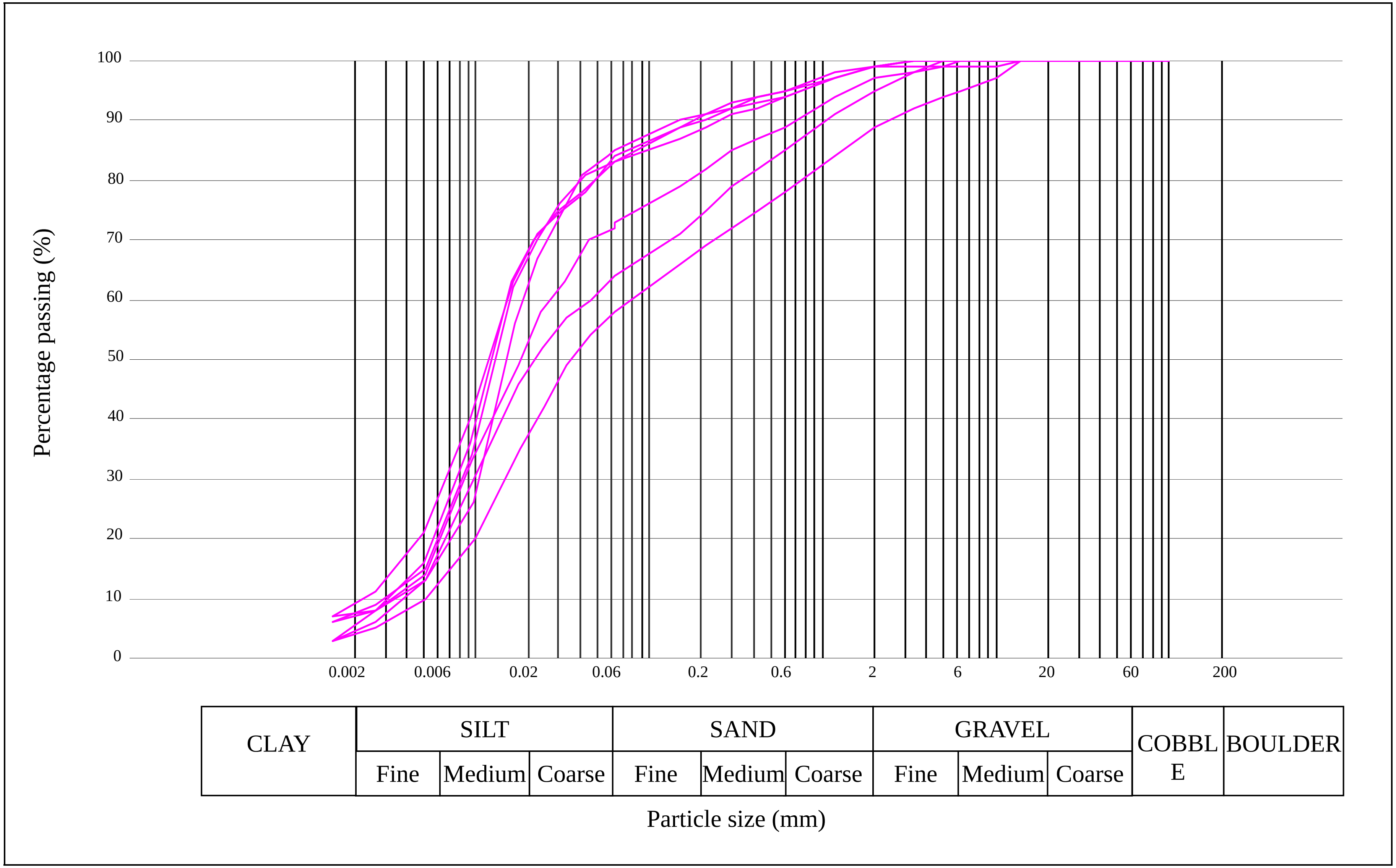

Figure 16 - Particle Size Distribution of Kaolinised Tuff

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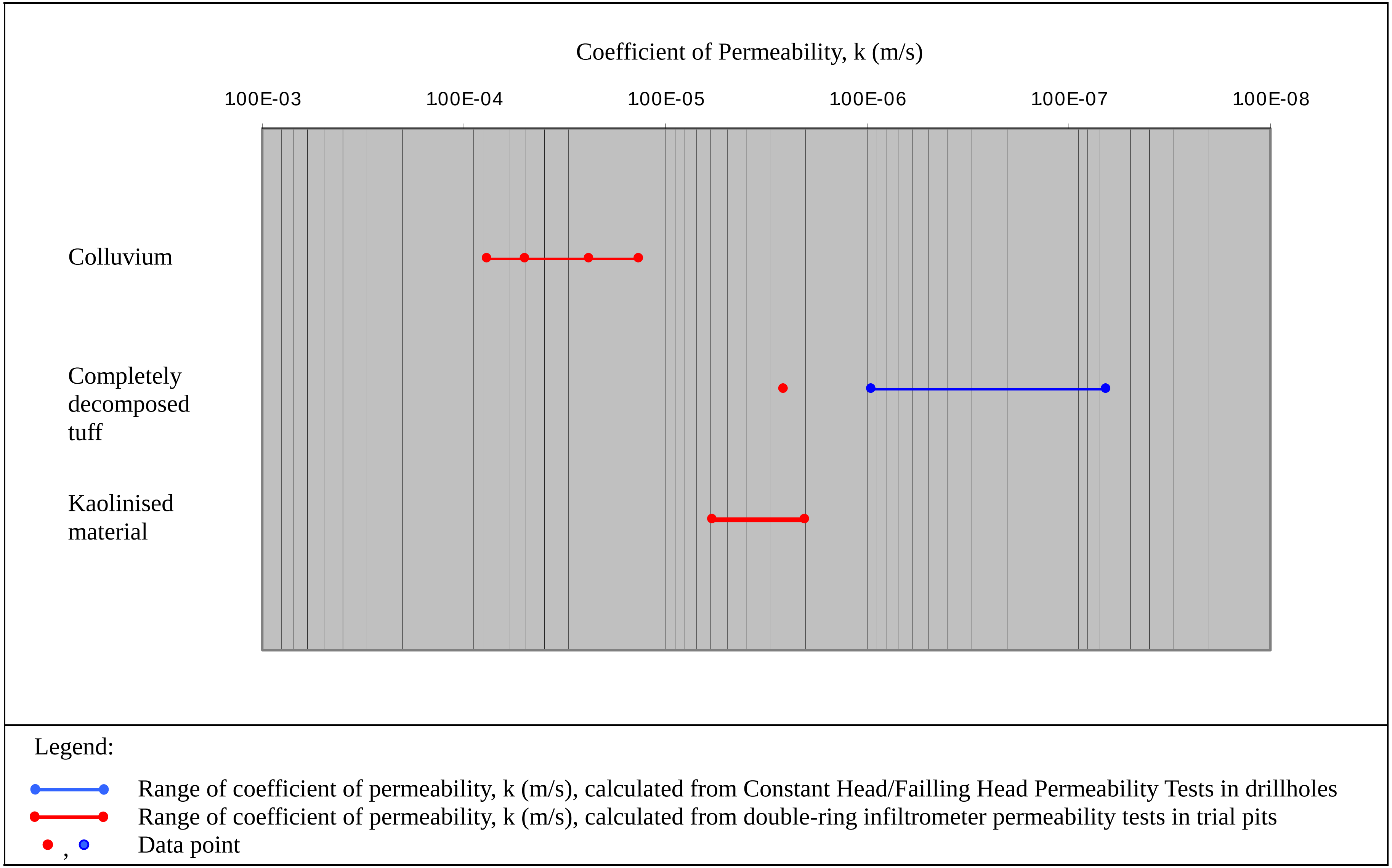

Figure 17 - Results of Permeability Tests

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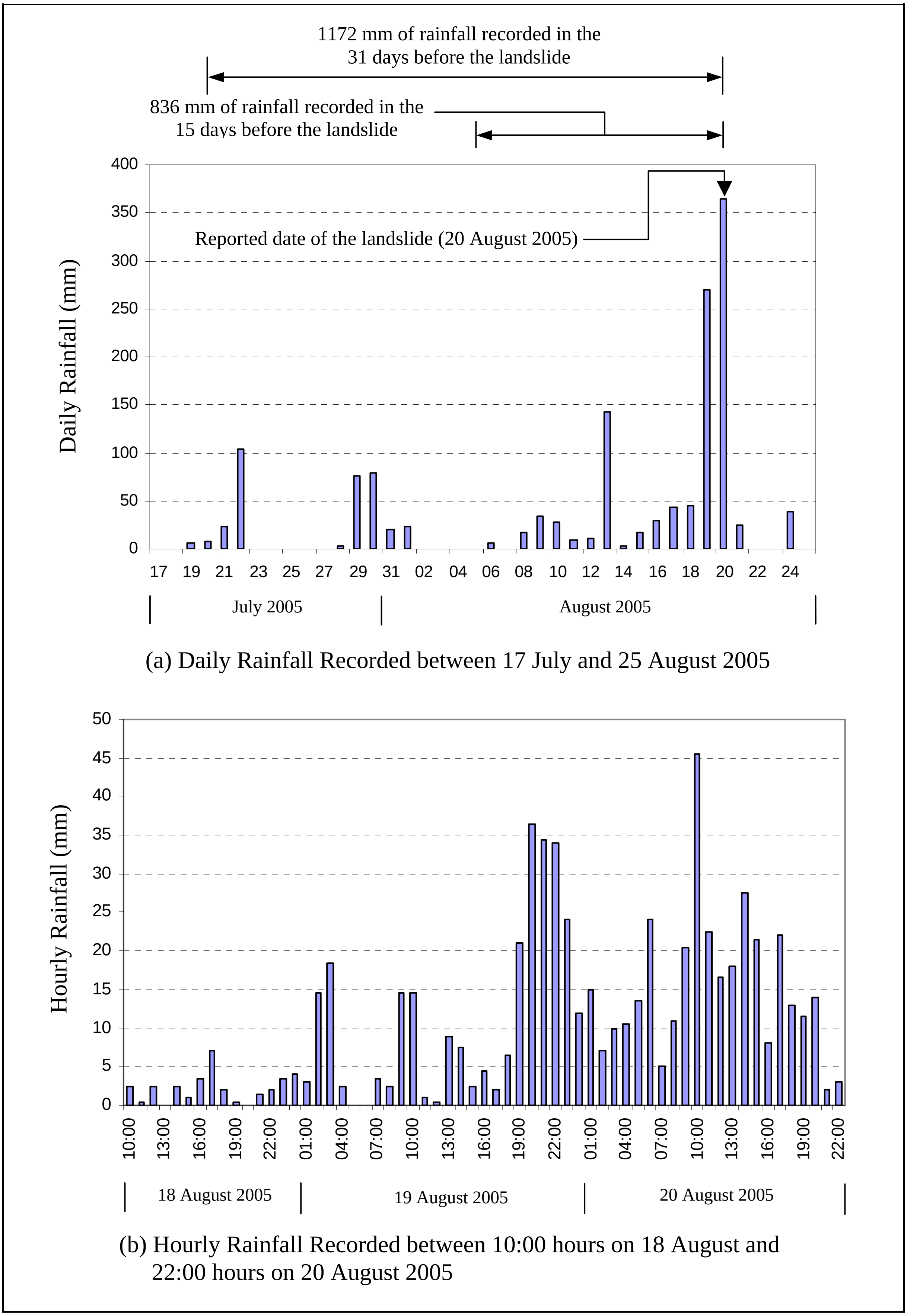

Figure 18 - Rainfall Recorded at GEO Raingauge No. H17

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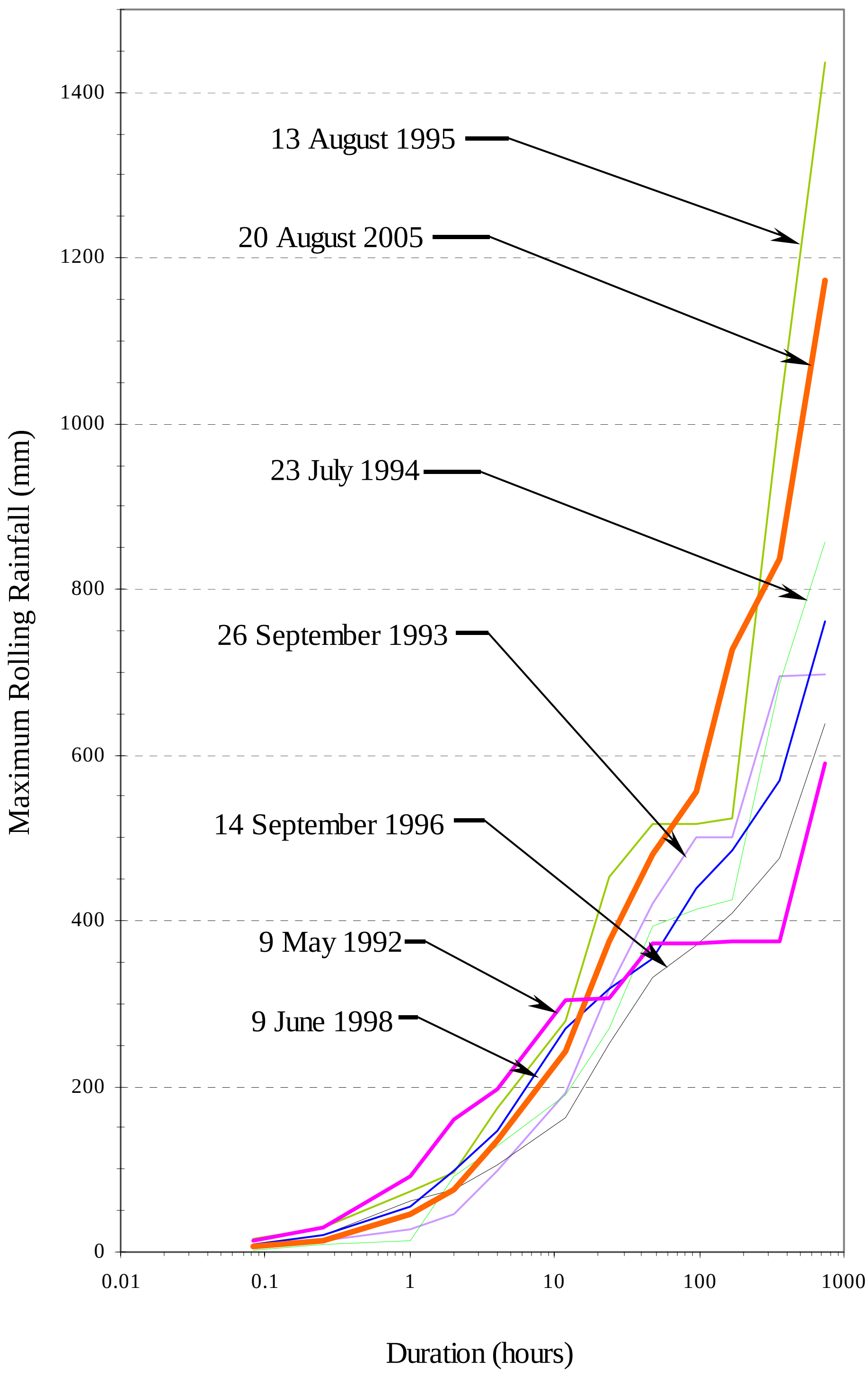

Notes: (1) Rainfall data before September 1995 are 5-minute statistics from GEO raingauge No. H06.
(2) Rainfall data after September 1995 are 5-minute statistics from GEO raingauge No. H17.

Figure 19 - Maximum Rolling Rainfall Preceding the Landslide and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. H17

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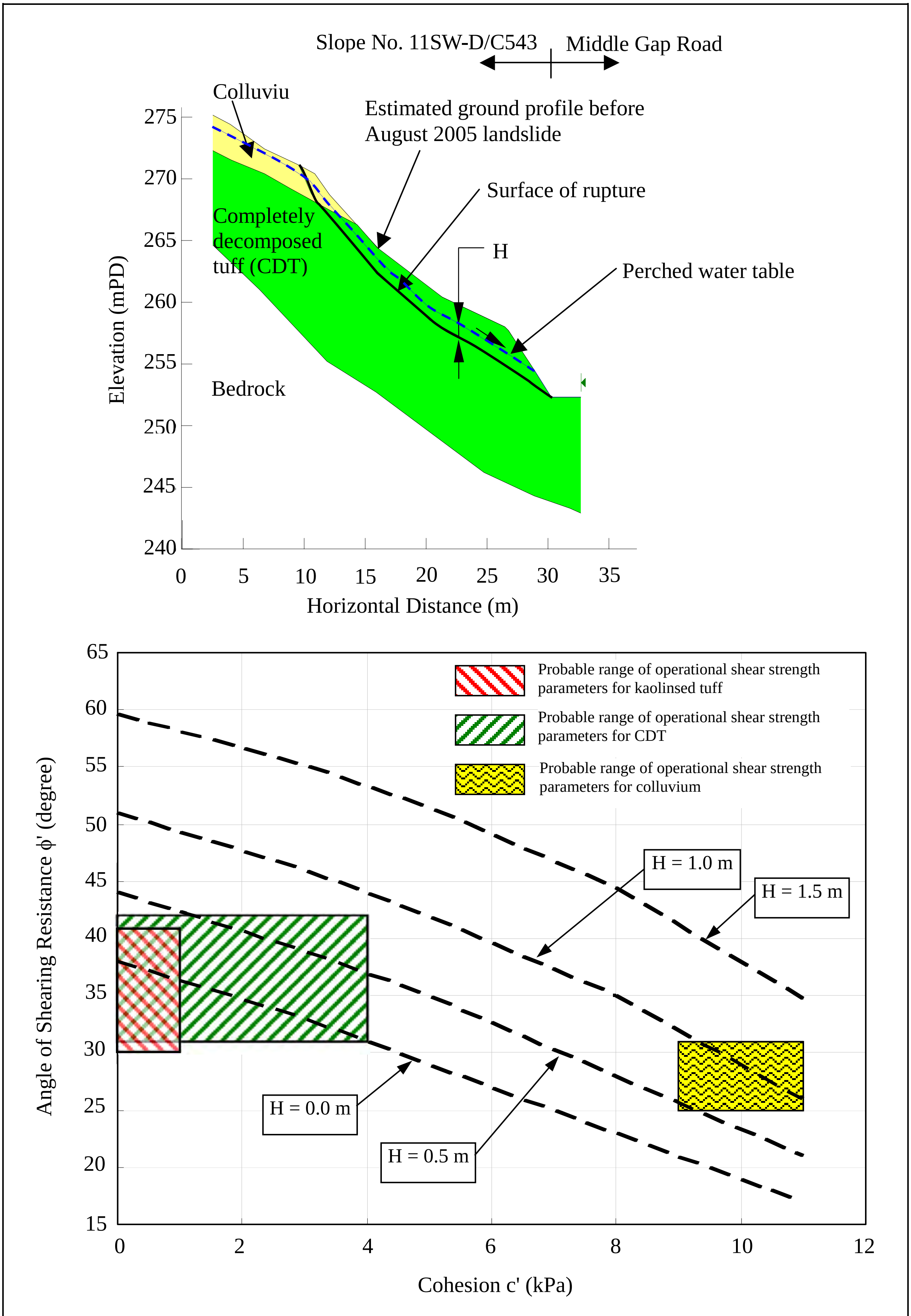

Figure 20 - Results of Theoretical Stability Analysis

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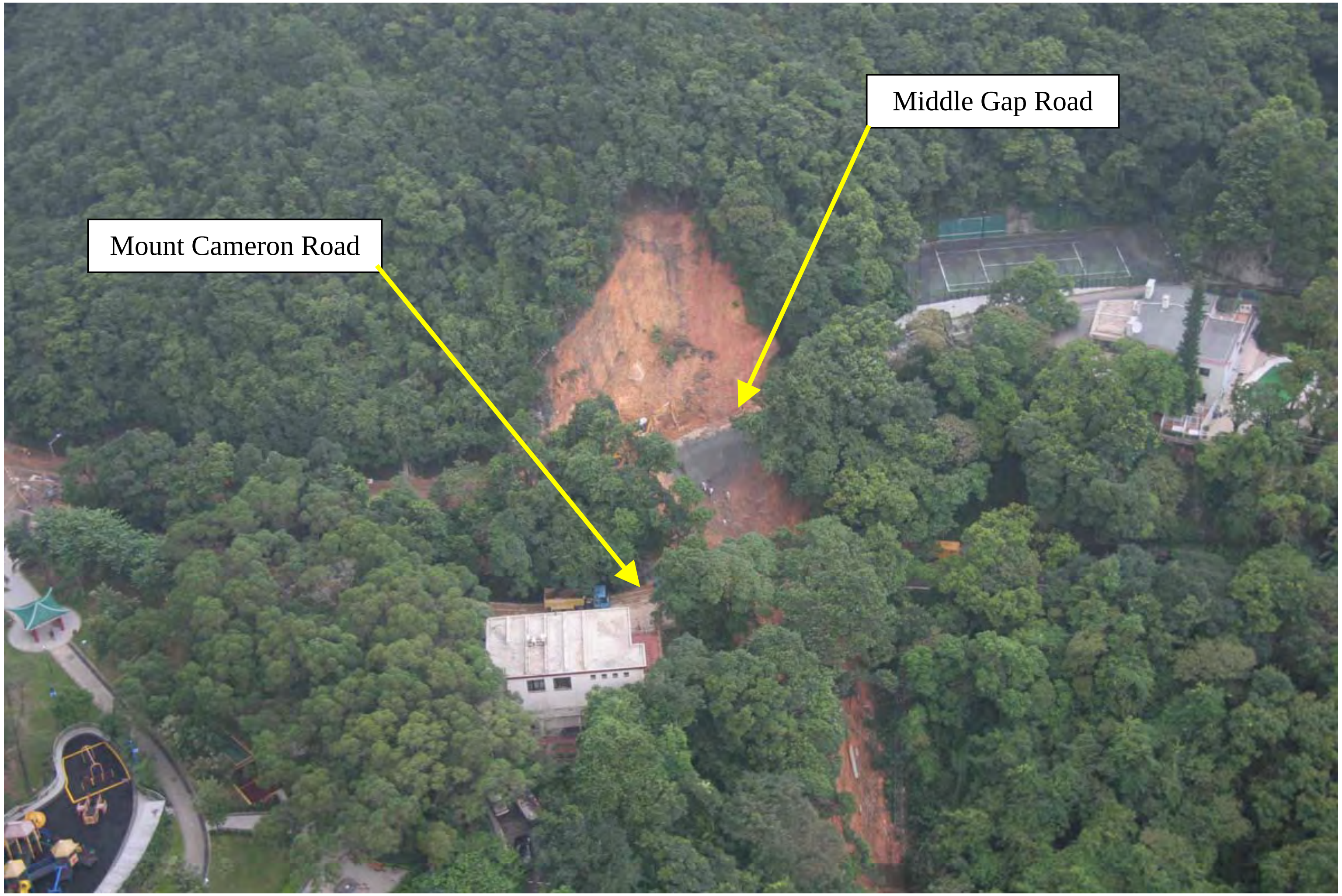

Plate 1 - Oblique Aerial View of the Landslide Site

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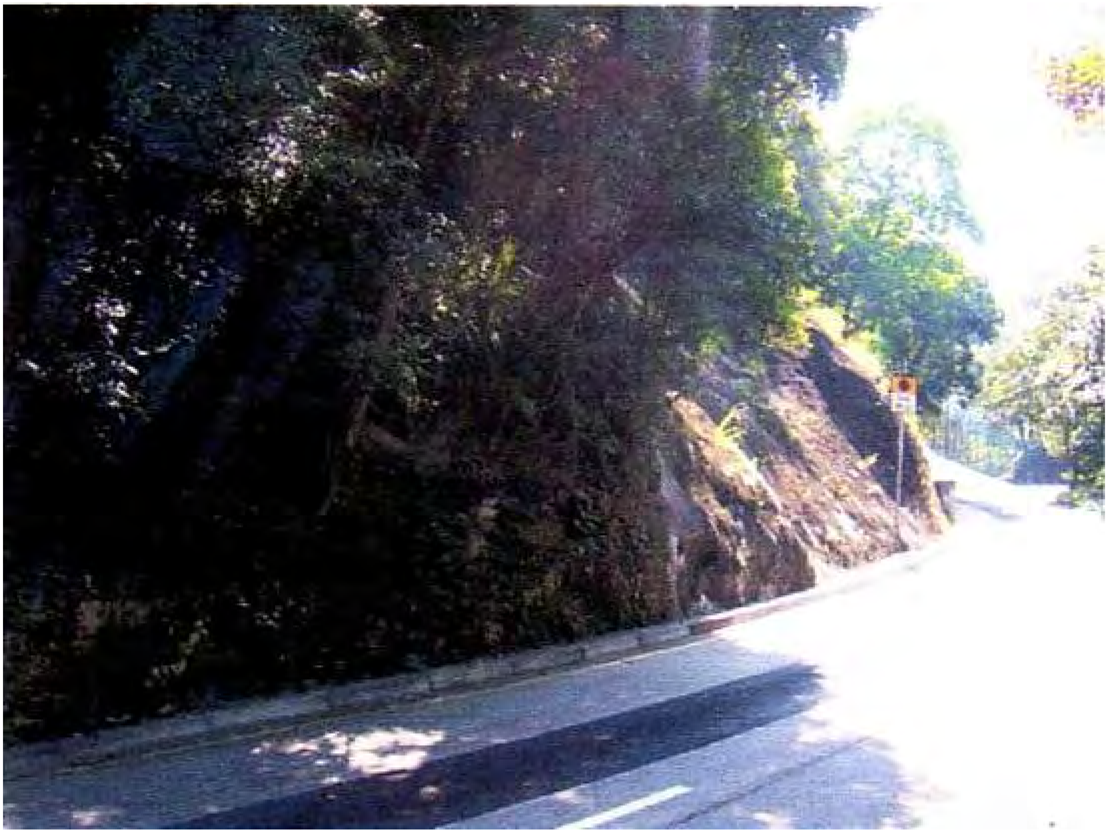

Plate 3 - Record Photograph of Slope No. 11SW-D/C543 Taken in October 2004
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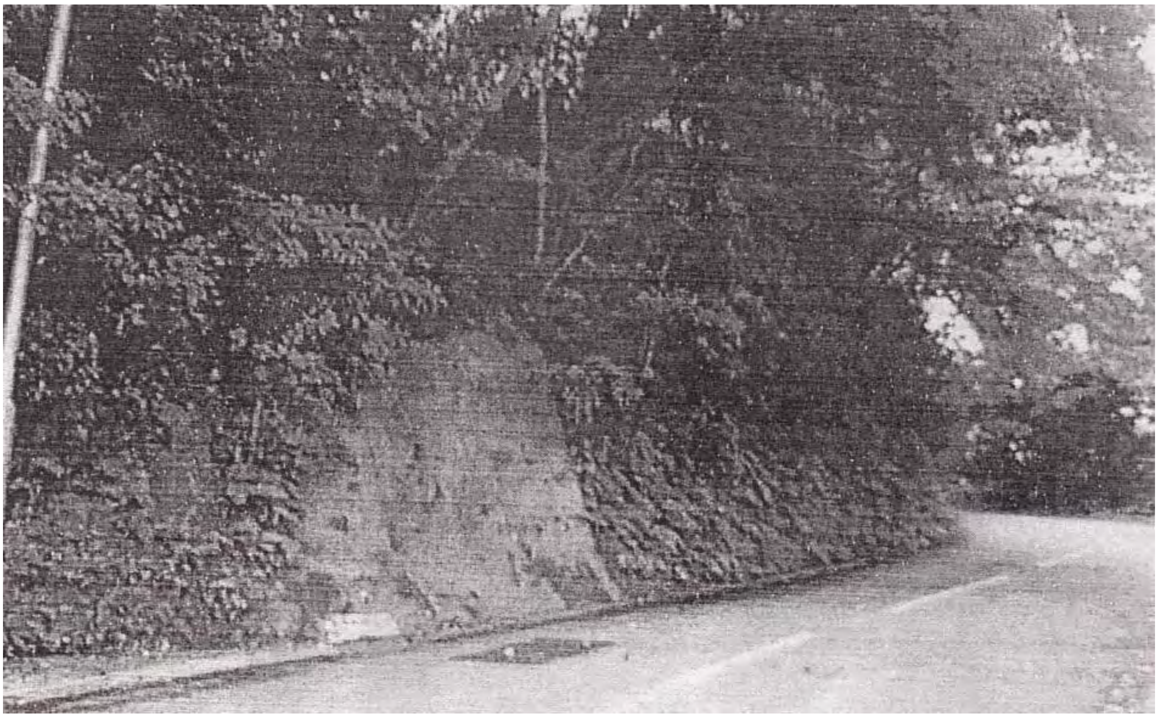

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About 4 m in depth

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Plate 20 - Debris Mound on Mount Cameron Road

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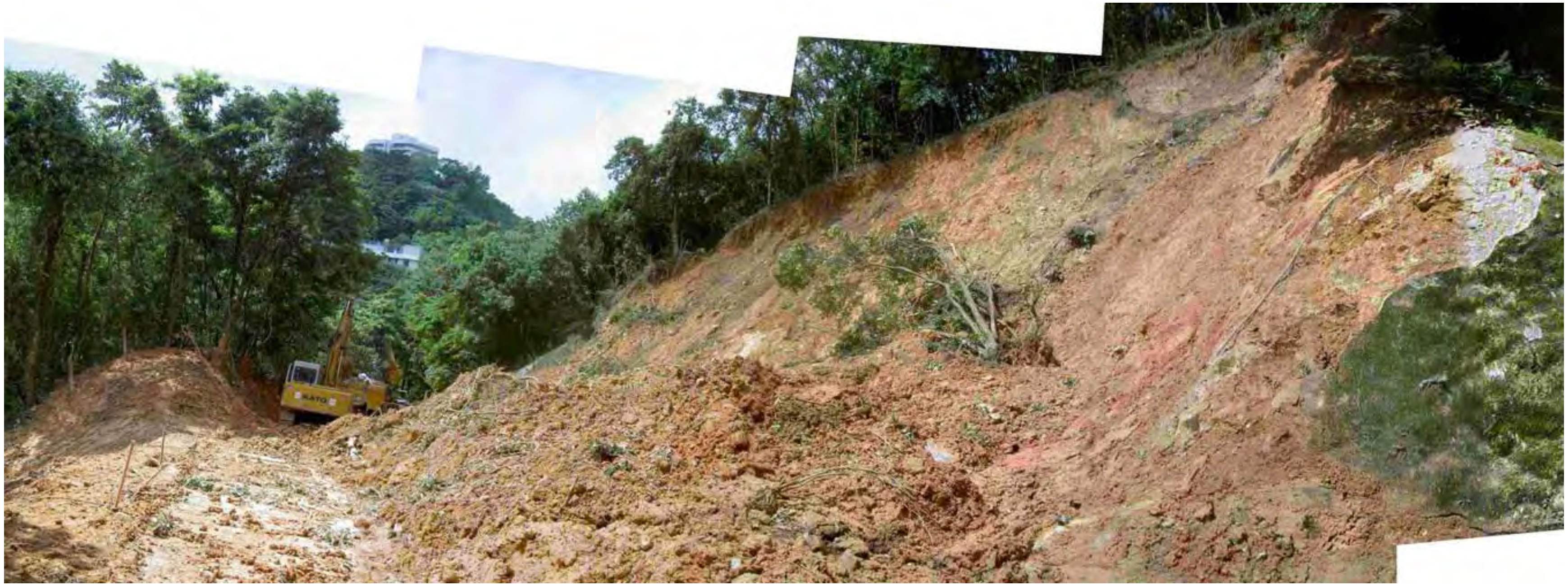

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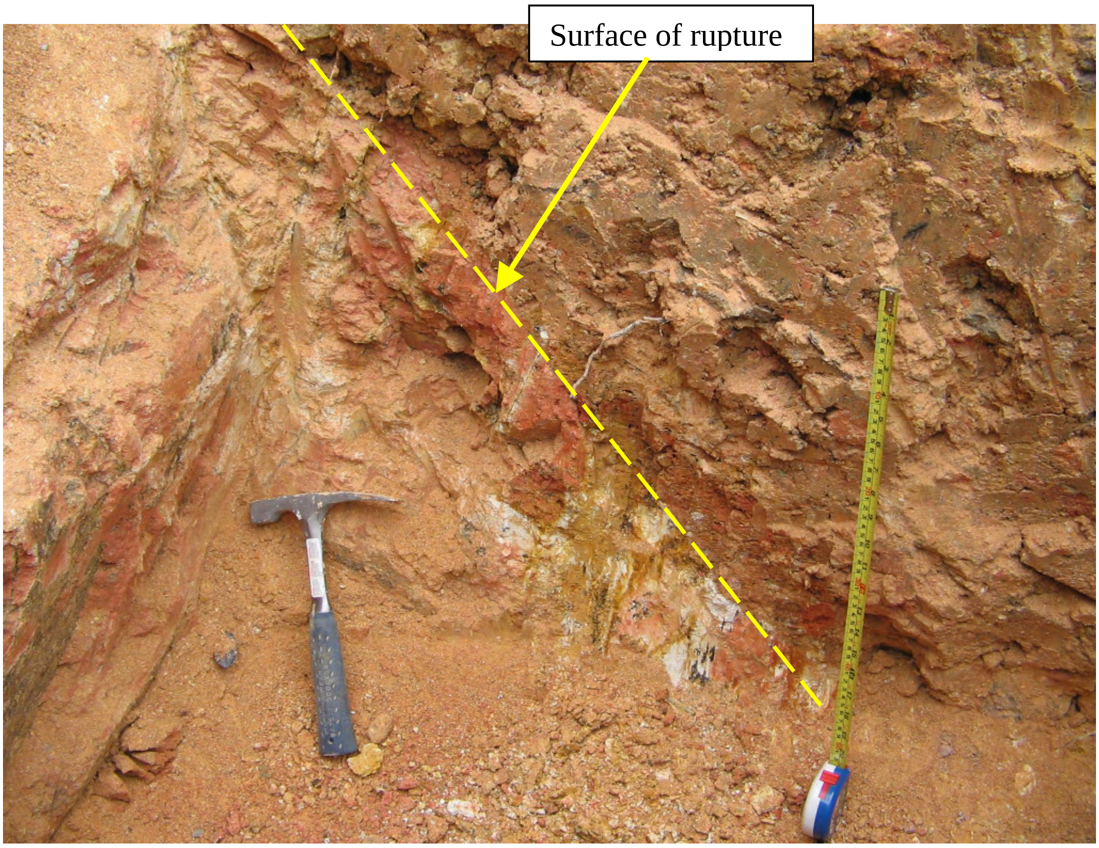

Plate 35 - Landslide Debris above Surface of Rupture in Trial Pit TP6
(Photograph taken on 11 February 2006)

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The following comprise the detailed observations made from the aerial photographs studied (see Figure 4 of main report). A list of aerial photographs used in this study is given in Section A.2.

Year Observations

1949 The aerial photographs are of poor quality. Middle Gap Road, Mount Cameron Road, Stubbs Road, Peak Road, Black's Link, Coombe Road and Aberdeen Reservoir Road are present and generally conform to the respective present day alignments. The carriageways converge at the saddle between two sections of northwest-southeast trending ridgeline forming Wanchai Gap.

The various present-day developments in and around Wanchai Gap are mostly formed, and include the levelled platform presently occupied by Wanchai Gap Park, which involved a significant body of fill extending below Aberdeen Reservoir Road, Coombe Road Children's Playground, for which site formation was underway, the Police Museum above Coombe Road, the Mount Cameron Road Electrical Sub-Station, "Highclere" at No. 3 Middle Gap Road, which was under construction at the time and "Rockery Nook" at No. 4 Middle Gap Road.

Roadside cuttings are present along the eastern side of Middle Gap Road at the present-day locations of slopes Nos. 11SW-D/C542 and 11SW-D/C543. These both appear to be steeply cut (c. 60^{o}) and of similar geometry to the present-day arrangement at slope No. 11SW-D/C542.

The southeastern flank of the saddle, bounded at Wanchai Gap by Middle Gap Road to the south and Black's Link to the North, and into which slopes Nos. 11SW-D/C542 and 11SW-D/C543 have been cut, is heavily vegetated. Some erosion is visible near the ridge line. It contains five natural drainage lines that radiate out from a central point about 80 m on plan from the road alignments. These appear to discharge into culverts passing beneath the carriageways.

A footpath is visible on the hillside above slope No. 11SW-D/C543, rising from an unused platform at the present-day location of the tennis courts at No. 3 Middle Gap Road to the south of slope No. 11SW-D/C543 before following the 283 mPD contour to a point directly above the Wanchai Gap road intersection. A depression (possible landslide scar) is visible above the footpath at a point above the central portion of slope No. 11SW-D/C543, with a possible debris mass extending below the footpath. Some end-tipping of fill was also visible at the northern extent of the footpath.

The sloping ground between Middle Gap Road and Mount Cameron Road below slope No. 11SW-D/C543 appears to comprise much the same arrangement as the present-day geometry, with a steep roadside cutting formed at the location of slope No. 11SW-D/C1888 and the ground extending south to

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Year	Observations
1949 cont'd	No. 4 Middle Gap Road containing the head of the drainage line extending to the southwest below Mount Cameron Road. A drainage feature (channel) traverses this area from Middle Gap Road at the western boundary of No. 4 to Mount Cameron Road level at the drainage line. A light-toned patch is visible on the sloping ground above the southern portion of slope No. 11SW-D/C1888.
1963	Two photolineaments trending NW-SE and NE-SW are evident, the NE-SW set traversing Wanchai Gap Park and the road intersection, and the NW-SE set traversing the Coombe Road Children's Playground, Wanchai Gap Park and the hillside below Mount Cameron Road. A minor photolineament trending WNW-ESE was also evident immediately to the south of slope No. 11SW-D/C543. No major changes to the general development in the local area. Construction at No. 3 Middle Gap Road was complete and the platform at the present location of the tennis courts to the south of slope No. 11SW-D/C543 was occupied by a garden/nursery. A new structure was evident in Wanchai Gap Park and structures visible in the 1949 aerial photographs had been demolished. The fill extending below the park and Aberdeen Reservoir Road was mostly vegetated; however, traces of gully erosion were evident. Nine possible relict landslide scars are evident in the natural hillside extending above Middle Gap Road and Black's Link, most of which are situated at the heads of the natural drainage lines identified in the 1949 aerial photographs. An additional drainage line above the boundary between slopes Nos. 11SW-D/C542 and 11SW-D/C543 extends below one of the relict scars. The footpath extending above slope No. 11SW-D/C543 identified in the 1949 aerial photographs was covered with grass. A sharp convex break-in-slope (possible landslide scar) was evident at the northern end of the footpath. The feature was covered with grass and no associated debris was apparent. The central lower portion of the face of slope No. 11SW-D/C543 appears to be rough in texture, suggesting an outcropping of rock or highly decomposed materials. Possible surface channels, situated a short distance above the crest lines of slopes Nos. 11SW-D/C542 and 11SW-D/C543 are visible. A footpath was evident on the sloping ground between Middle Gap Road and Mount Cameron Road below slope No. 11SW-D/C543, and a number of large trees situated on the natural hillside within the drainage line immediately below Mount Cameron Road were observed to be leaning at various angles. No signs of instability related to these trees were evident.

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Year	Observations
1964	High altitude photographs. Vegetation increased in density over the hillside above slope No. 11SW-D/C543 since 1963. The footpath and the breaks-in-slope observed in 1949 and 1963 were covered with vegetation. Erosion on the ridge line above still evident, but reduced from 1949. No major changes evident in Middle Gap Road or slope No. 11SW-D/C543.
1967	High altitude photographs. No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Traces of gully erosion evident on the fill slopes above Aberdeen Reservoir Road and below Coombe Road. An area of high reflectance, possibly rock outcrop/boulders, was visible on the main stream course in the drainage line extending below Mt Cameron Road, and a recent landslide scar was visible further down the drainage line to the southwest. Evidence of minor slope works were visible on the fill slope below No. 4 Middle Gap Road.
1968	No major changes evident in the general area. Slope No. 11SW-D/C543 in shadow of trees growing on natural hillside above. Two possible recent landslide scars evident on cut slopes above Black's Link to the northeast.
1976	No major changes evident in the general area. The garden/nursery at the present-day location of the tennis courts to the south of slope No. 11SW-D/C543 no longer visible. Two areas of new hard surface cover (chunam?) were evident in the central portion of slope No. 11SW-D/C543, possibly associated with recent instability. Vegetation evident on the remainder of the slope face. Two areas of high reflectance in cut slopes above Black's Link to the north of slope No. 11SW-D/C543 which are possible recent landslide scars covered with chunam.
1977	Change in the geometry of Slope No. 11SW-D/F543 evident, with crest line extending further upslope above locations of repair observed in 1976 aerial photographs and new hard surfacing applied to slope face, excluding northern and southern ends of feature. Middle Gap Road also re-paved over the length of slope no. 11SW-D/C543 and short distance to northwest. A wall-like feature was visible on the abandoned garden/nursery to the south of slope No. 11SW-D/C543.

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Year	Observations
1977 cont'd	The scar observed in the 1967 aerial photographs in the valley below Mount Cameron Road was covered with dense vegetation.
1978	No stereopair. No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Tennis courts constructed at the present-day location to the south of slope No. 11SW-D/C543.
1979	No major changes in the general area. Vegetation evident on the chunam face of slope No. 11SW-D/C543. Some amenity facilities were evident on Wan Chai Gap Park and Coombe Road Children's Playground.
1980	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. An area of high reflectance, possibly indicating a repaired landslide scar, was visible in the central portion of slope No. 11SW-D/C542.
1982	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1984	No stereopair. No major changes observed in general area. Surface drainage works visible on slope No. 11SW-D/C543 and comprise a U-channel traversing the slope at mid-height, connected to a stepped channel extending to a catchpit at the slope toe.
1986	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Sparse cover of vegetation observed on the slope face. Majority of the spur ridge above the slope crest has dense cover of trees and only a minor remnant of the hillside erosion observed in the 1949 aerial photographs is still visible.
1987	No stereopair. No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1988	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Sparse cover of vegetation observed on the cut slope face.
1990	Some of the vegetation on the surface of slope No. 11SW-D/C543 observed in the 1988 photographs had been removed leaving the slope face bare in these areas.

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Year	Observations
1991	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Bare patch on cut slope face observed in 1990 aerial photographs covered by vegetation.
1992	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1993	Two areas of high reflectance were visible on the face of slope No. 11SW-D/C543, which coincide with depressions extending the slope crest further upslope from the extent observed in the 1977 aerial photographs and may represent chunam/shotcrete repairs to recent landslide scars. Some linear features, possibly surface channels, were apparent on the surface of these areas of high reflectance.
1994	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Sparse cover of bushy vegetation observed on the new hard surface of the cut slope.
1995	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1996	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1997	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
1998	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Vegetation cover continued to increase over the general area.
1999	No stereopair. No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
2000	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
2001	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above. Evidence of minor repair works, possibly cement mortar, visible on the hard surface cover of the cut slope.
2002	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.
2003	No major changes observed on slope No. 11SW-D/C543 and the natural hillside above.

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A.2 List of Photographs

Date	Reference No.	Altitude
8/05/1949	Y1371, Y1372, Y1373	8600’
1/02/1963	Y7256, Y7257, Y7258, Y7259	2700’
6/02/1963	Y7311, Y7312, Y7313, Y7314	3700’
13/12/1964	Y12829, Y12830	12500’
15/05/1967	Y13279	6250’
1968	Y14026, Y14027, Y14028	Unknown
28/01/1976	12645, 12646, 12647	4000’
21/12/1977	20461, 20462, 20463	4000’
30/11/1978	23826	4000’
28/9/1979	27145, 27146, 27147	5500’
16/04/1980	29833, 29834, 29835	4000’
28/07/1982	43058, 43059, 43060	3500’
2/03/1984	53672	4000’
20/09/1986	A6029, A6030	4000’
9/09/1987	A10358	4000’
27/09/1988	A14494, A14495, A14496	4000’
21/03/1990	A20823, A20824, A20825	4000’
4/10/1991	A28057, A28058	4000’
12/05/1992	A30964, A30965, A30966	4000’
5/12/1993	A36994, A36995	4000’
5/12/1993	A37020, A37021, A37022	4000’
5/05/1994	CN6892, CN6893	4000’
17/11/1994	CN8106, CN8107	4000’
7/12/1995	CN12760, CN12761, CN12762	3500’
7/12/1995	CN12702, CN12703	3500’
7/06/1996	CN14127, CN14128	4000’
23/10/1996	CN15560, CN15561, CN15562	4000’
23/07/1997	CN17655, CN17656	4000’
23/10/1998	CN21134, CN21135, CN21136	4000’
3/11/1999	CN24036	5000’
26/07/2000	CN27554, CN27555	4000’
31/05/2001	CN31234, CN31235	4000’
27/09/2001	CW34329, CW34330	4000’
3/01/2002	CW38349, CW38350, CW38351, CW38352	2500’
3/01/2002	CW38396, CW38397, CW38398	2500’
17/04/2002	CW39544, CW39545, CW39546	3500’
11/05/2003	CW47237, CW47239	4000’
26/11/2003	CW53610, CW53611, CW53612	4000’

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APPENDIX B

RESULTS OF TRIAXIAL TESTING

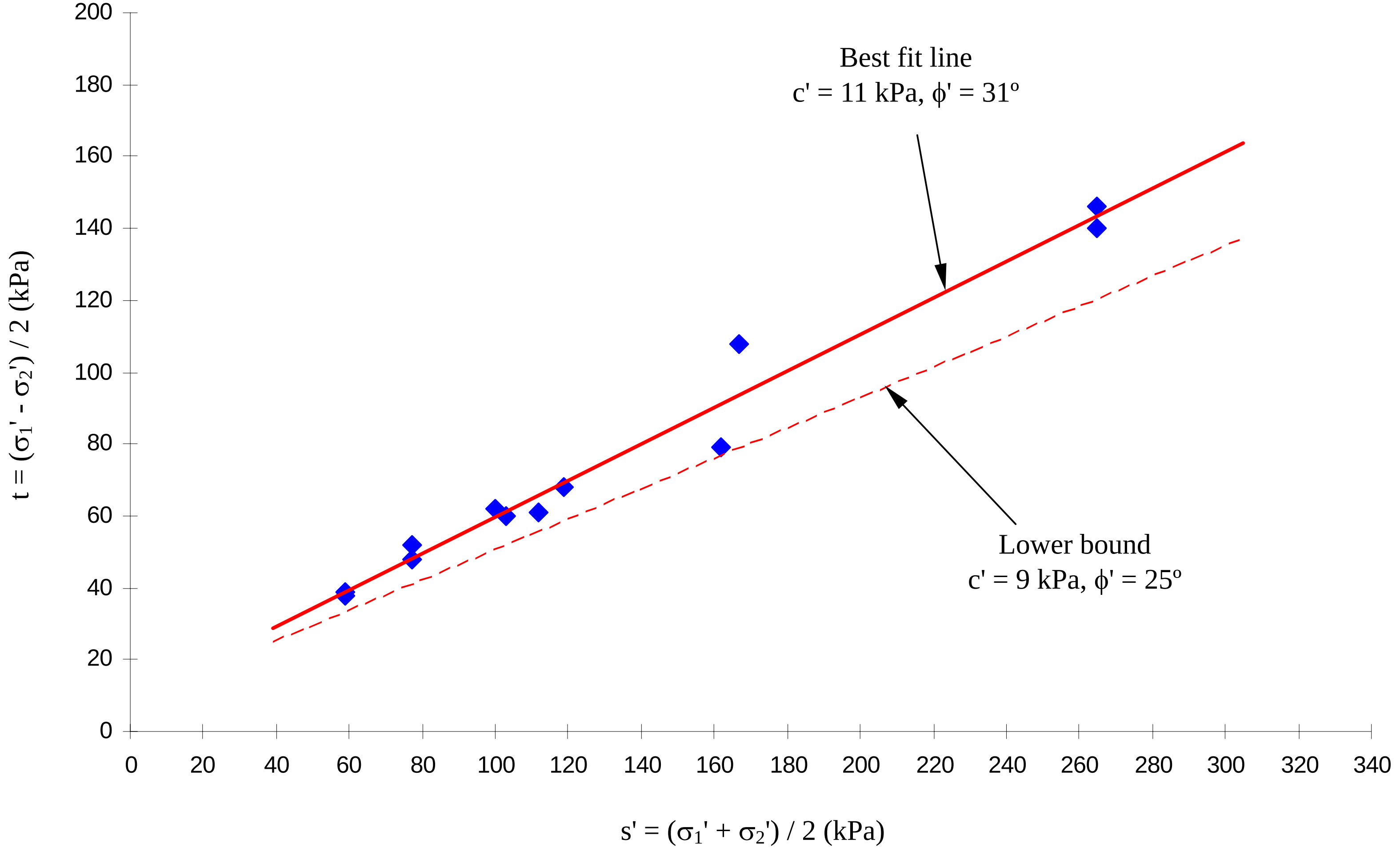

Figure B1 - s' - t Plot for Colluvium

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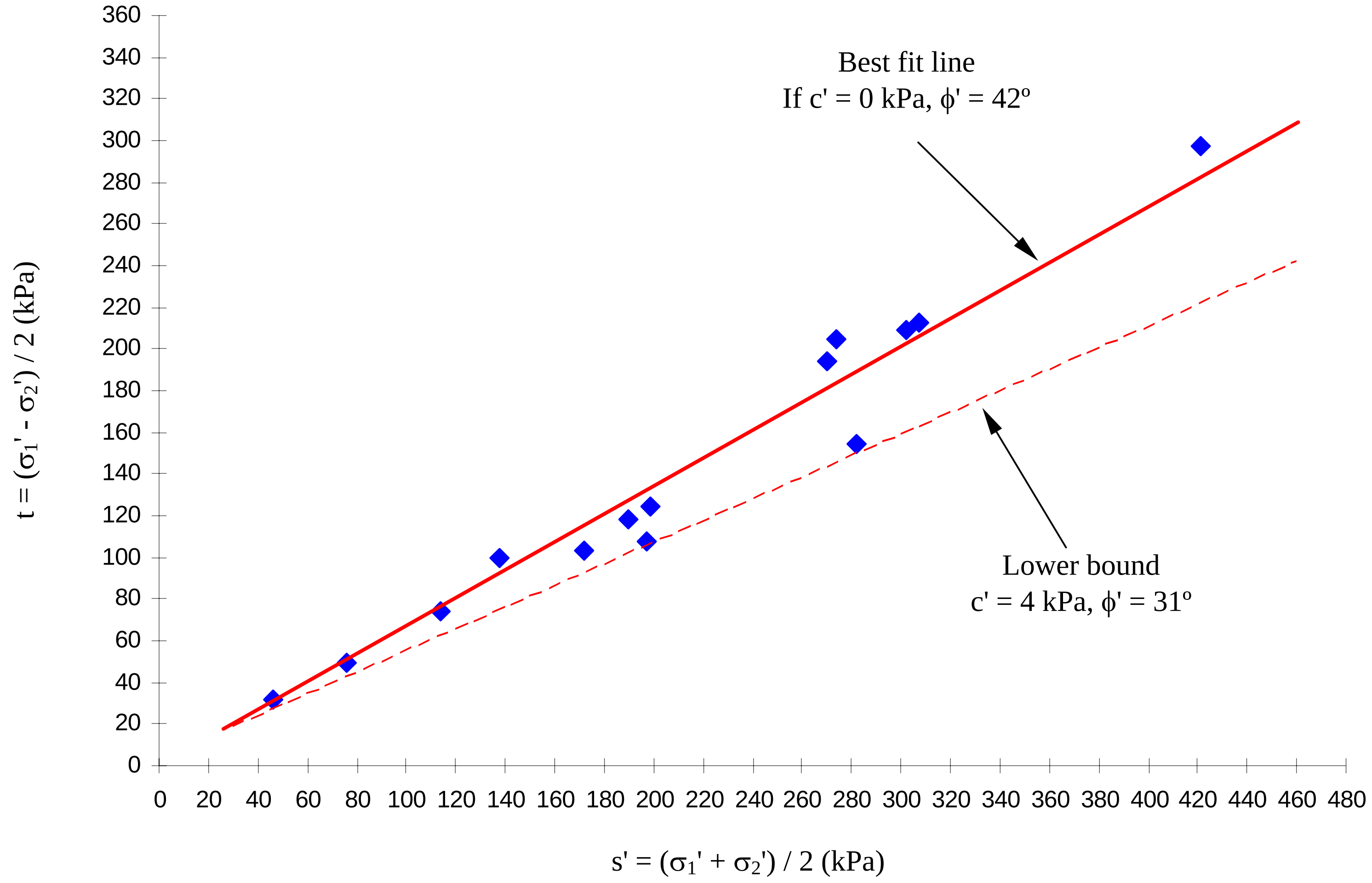

Figure B2 - s' - t Plot for Completely/Highly Decomposed Tuff

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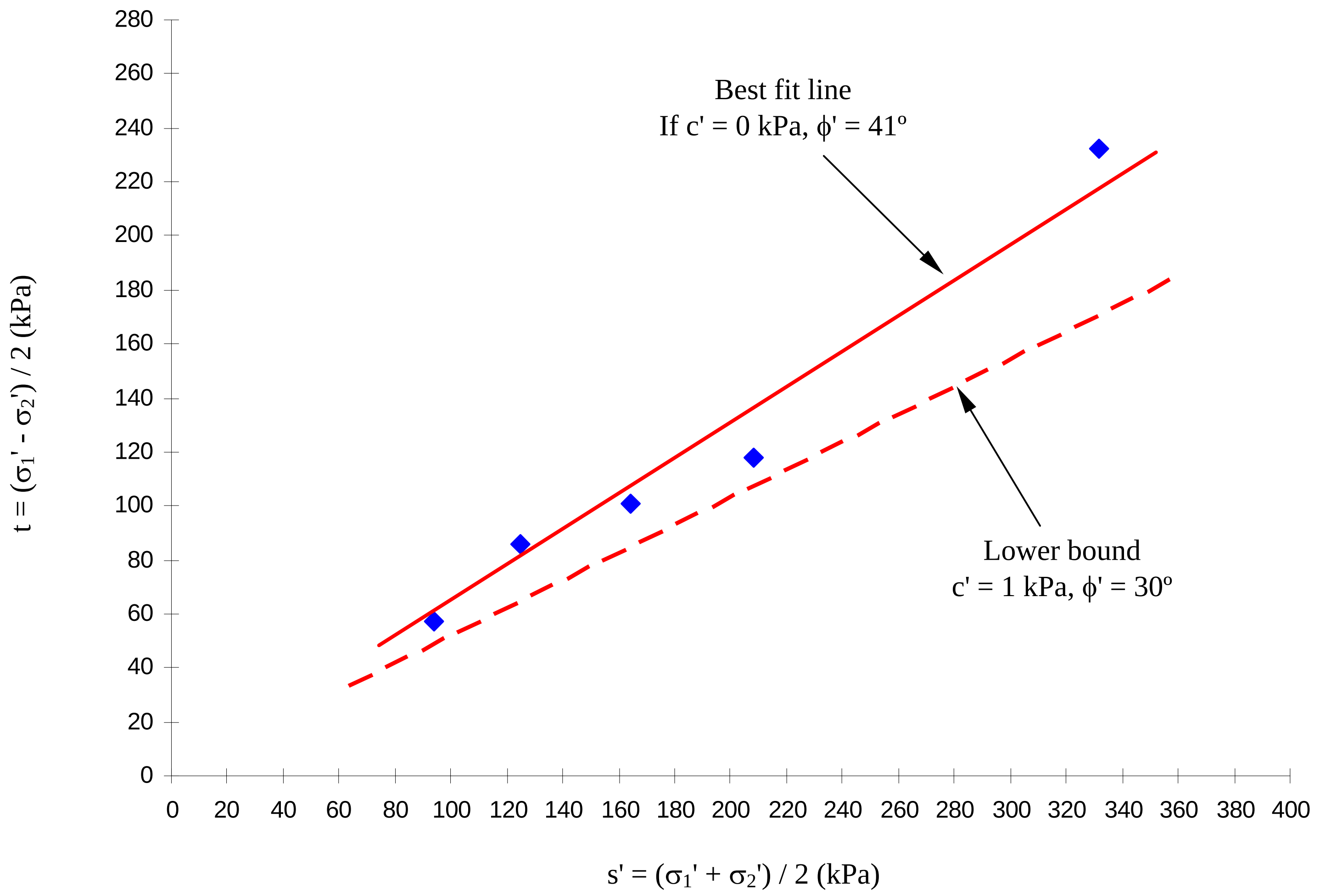

Figure B3 - s' - t Plot for Kaolinised Tuff

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APPENDIX C

GROUNDWATER MONITORING DATA

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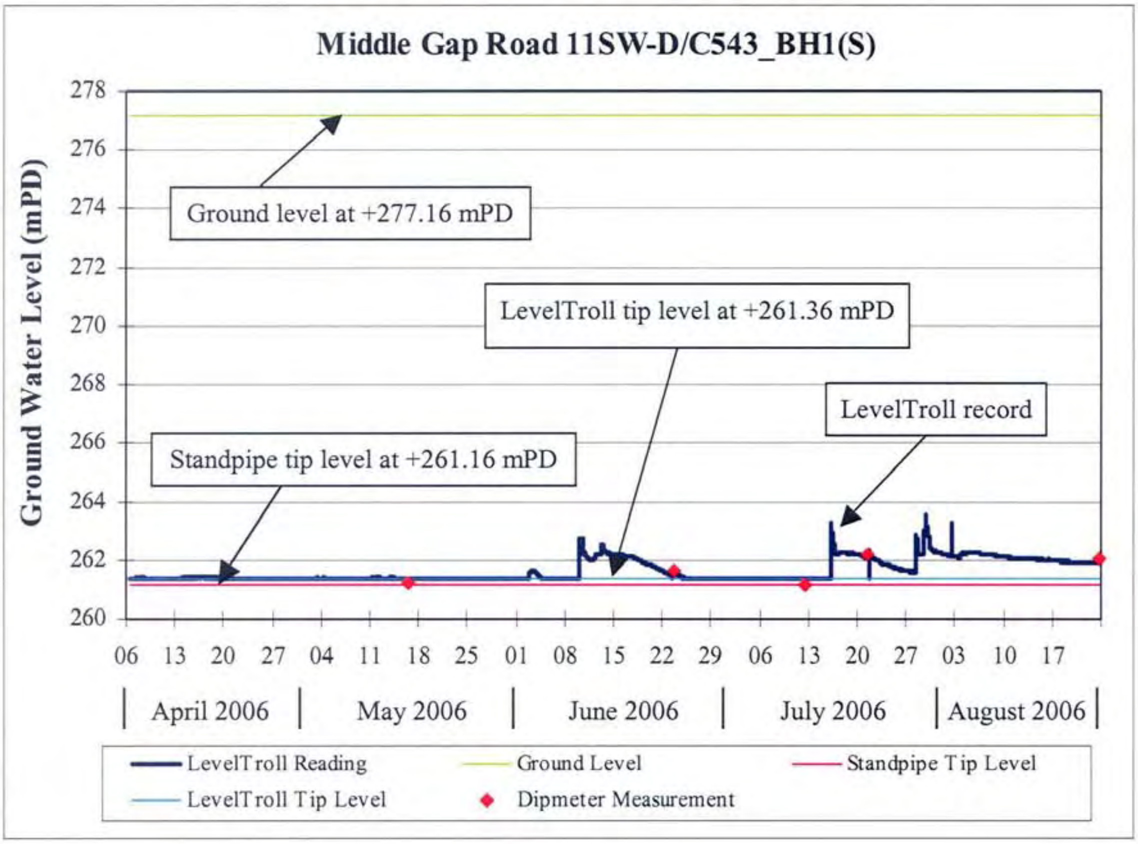

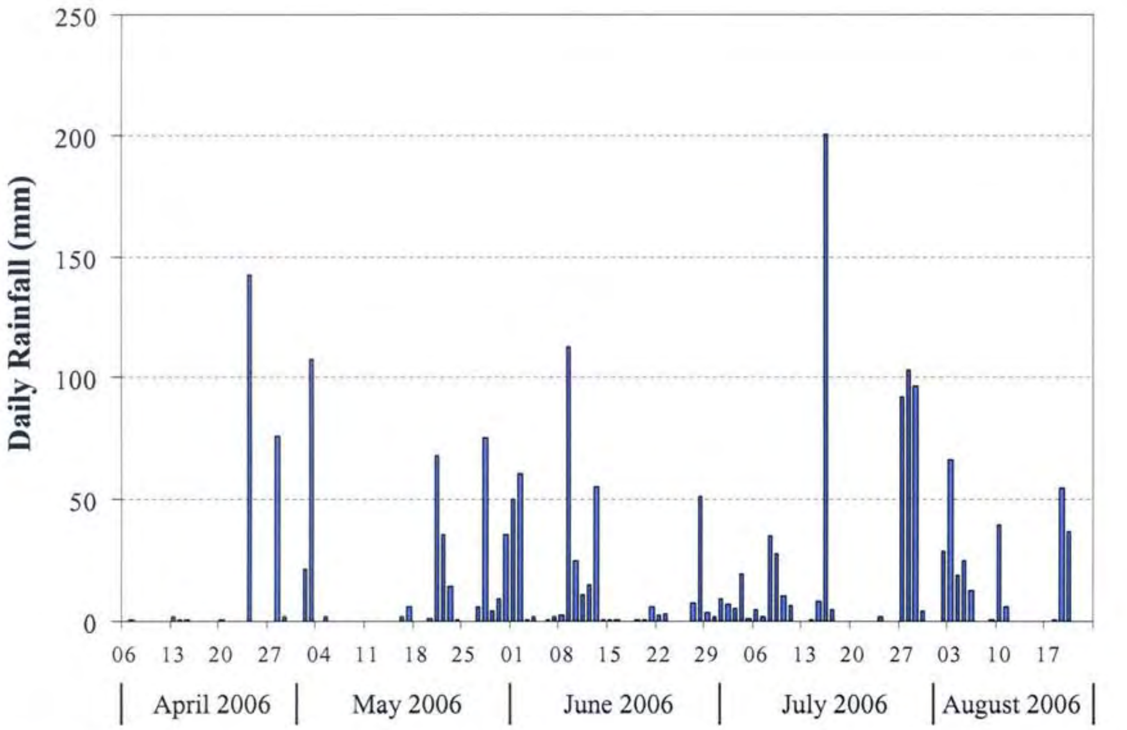

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C1 - Graphical Plot of Groundwater Data (Sheet 1 of 12)

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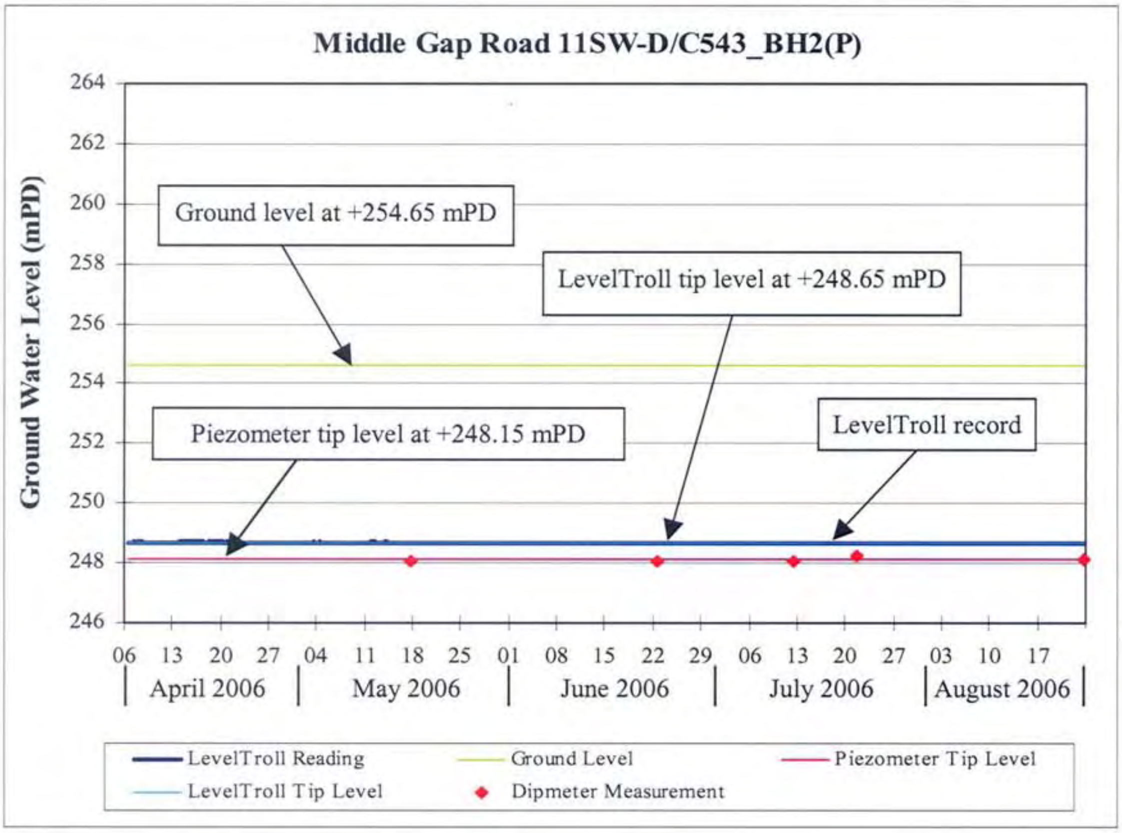

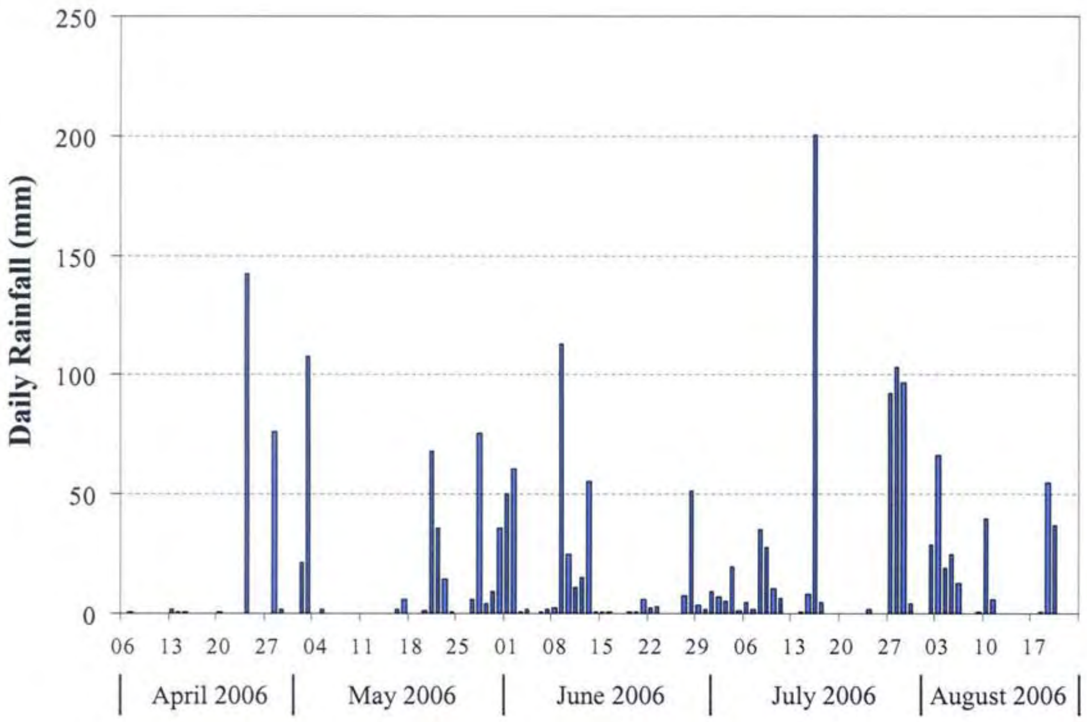

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C2 - Graphical Plot of Groundwater Data (Sheet 2 of 12)

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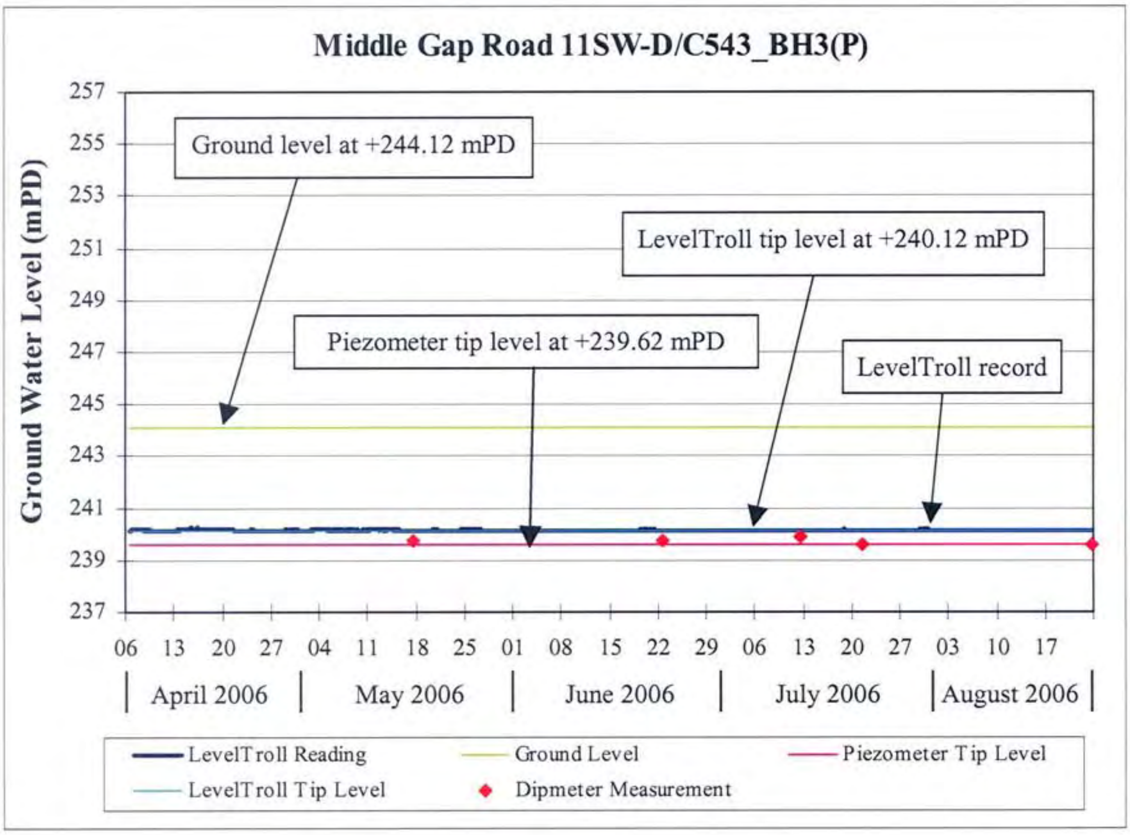

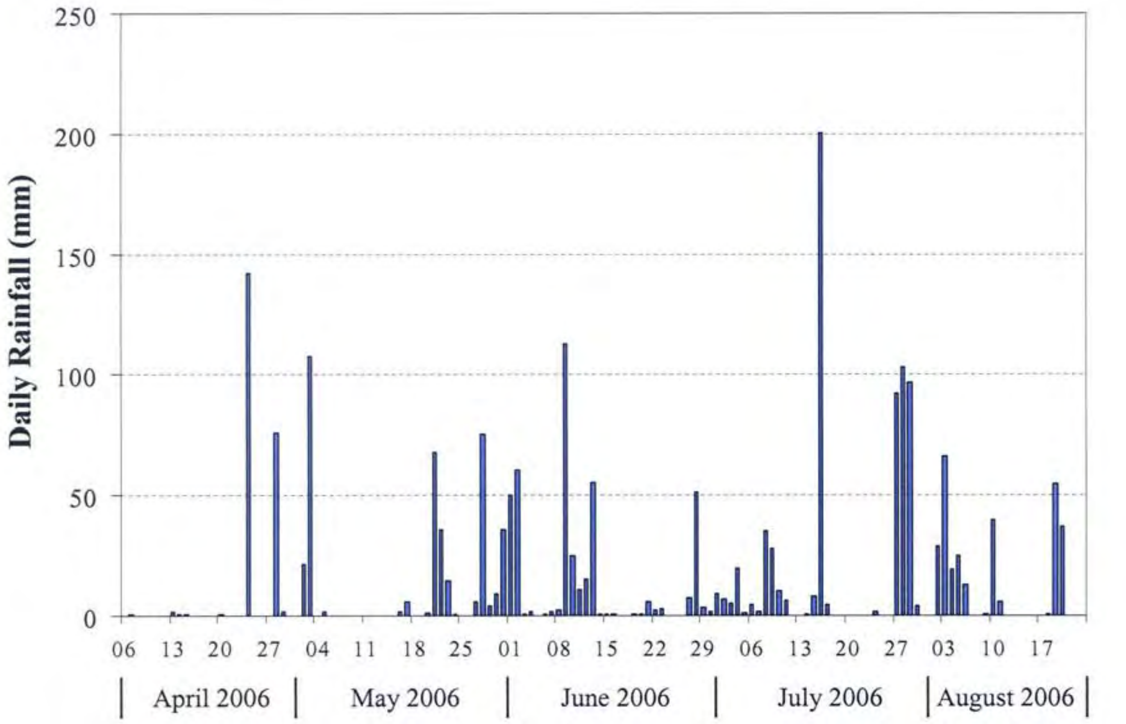

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C3 - Graphical Plot of Groundwater Data (Sheet 3 of 12)

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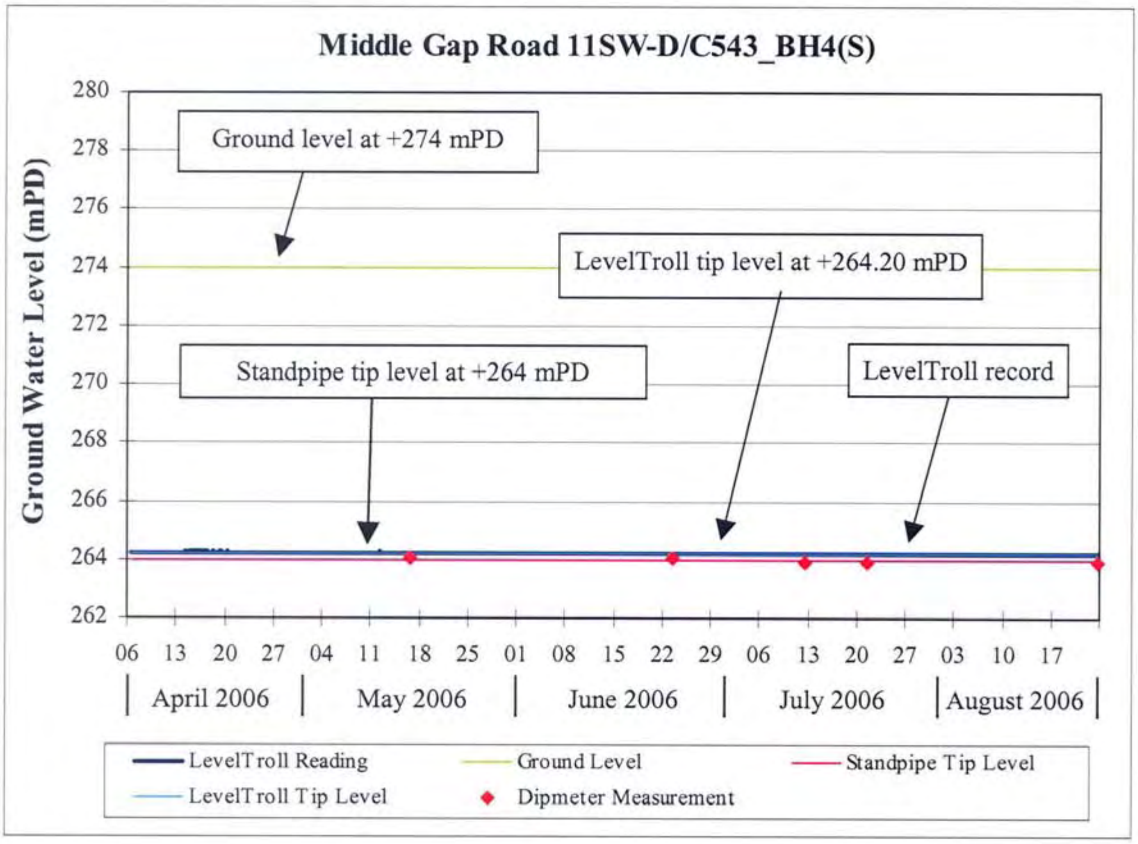
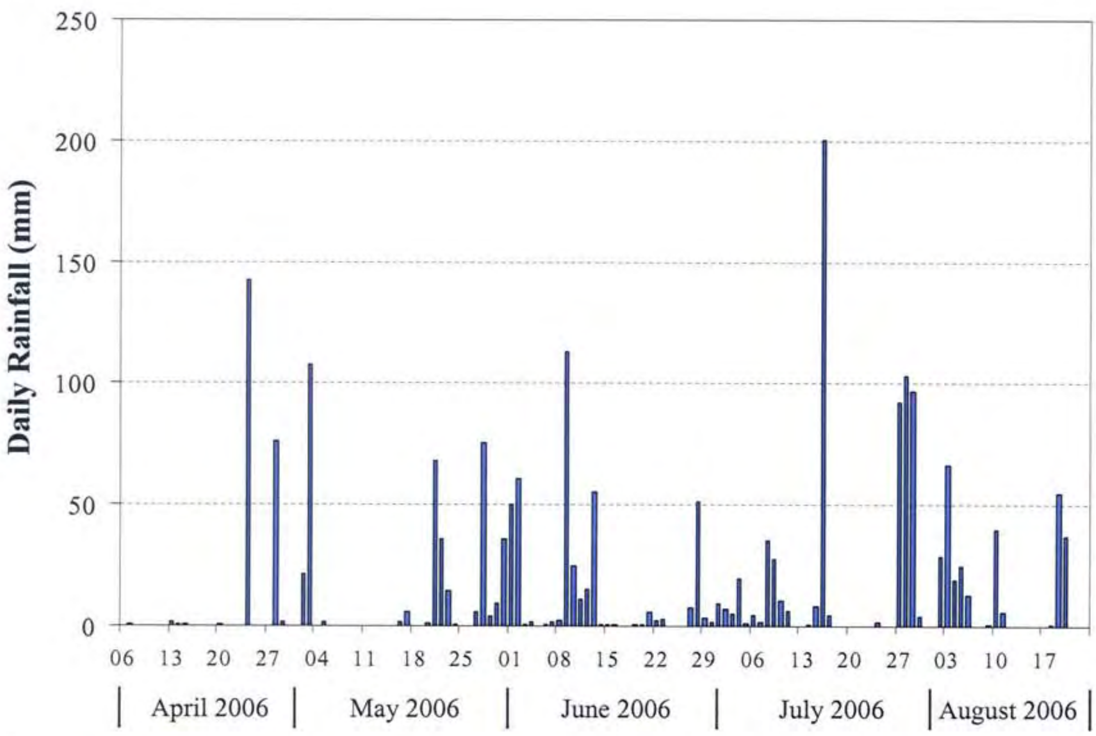
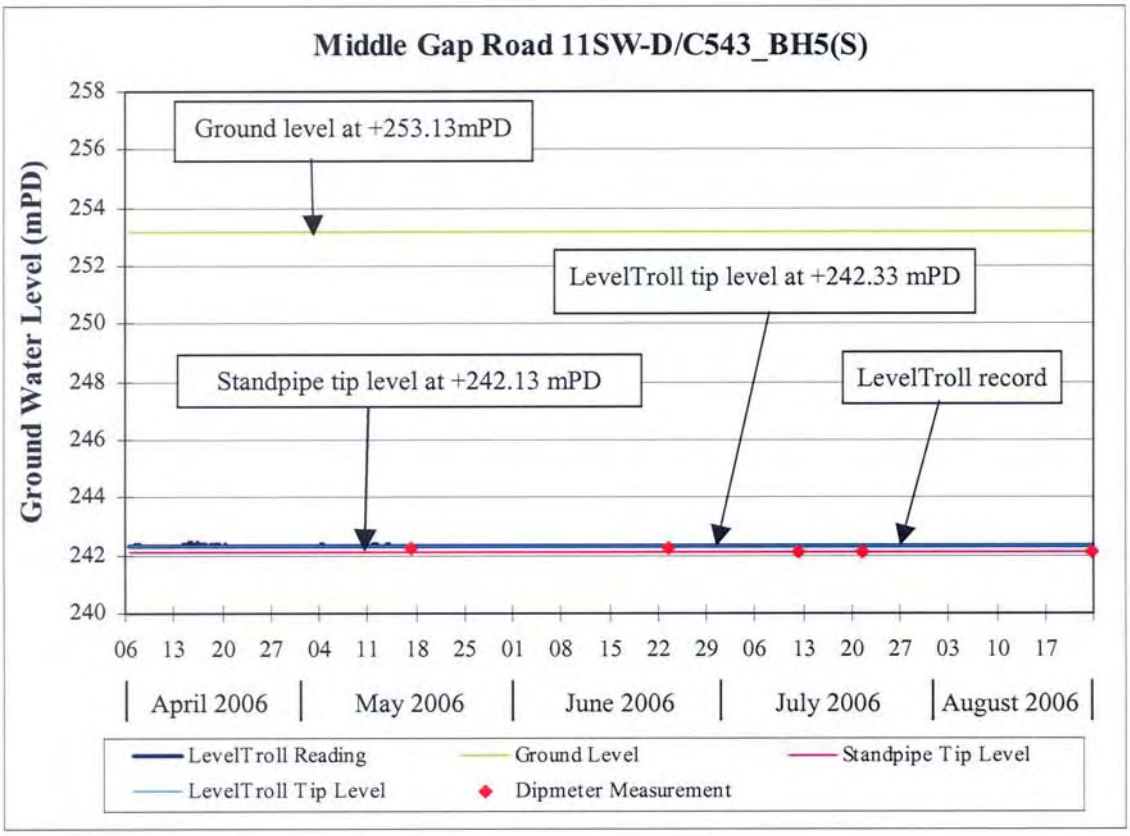
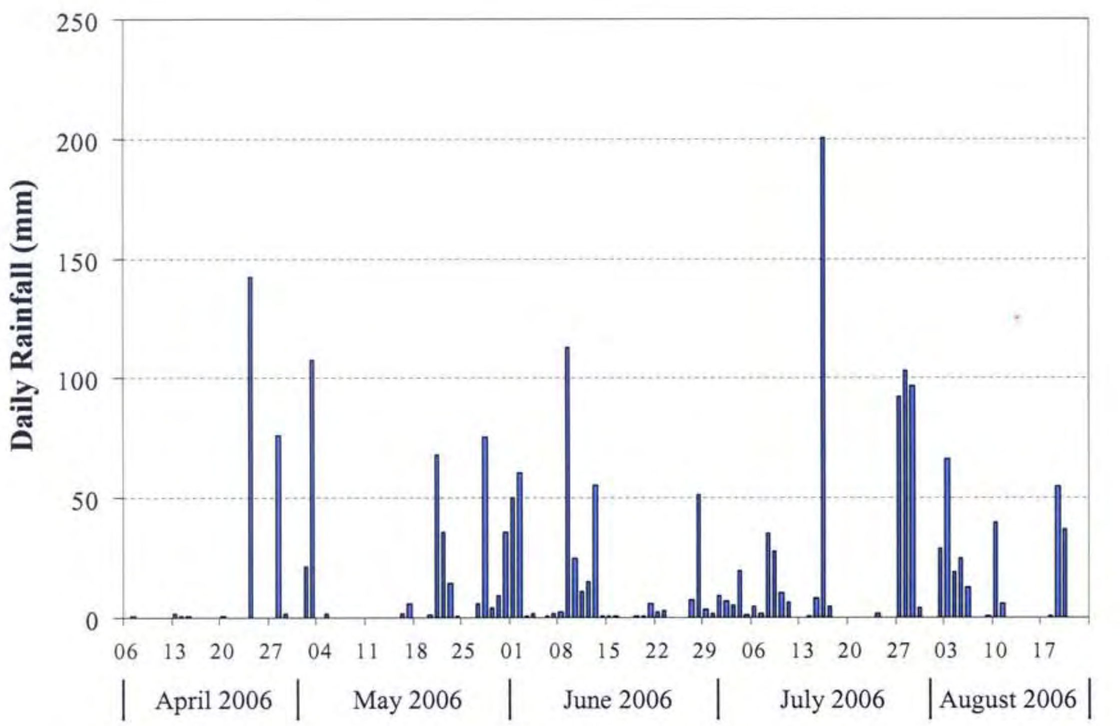




Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C4 - Graphical Plot of Groundwater Data (Sheet 4 of 12)





Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C5 - Graphical Plot of Groundwater Data (Sheet 5 of 12)

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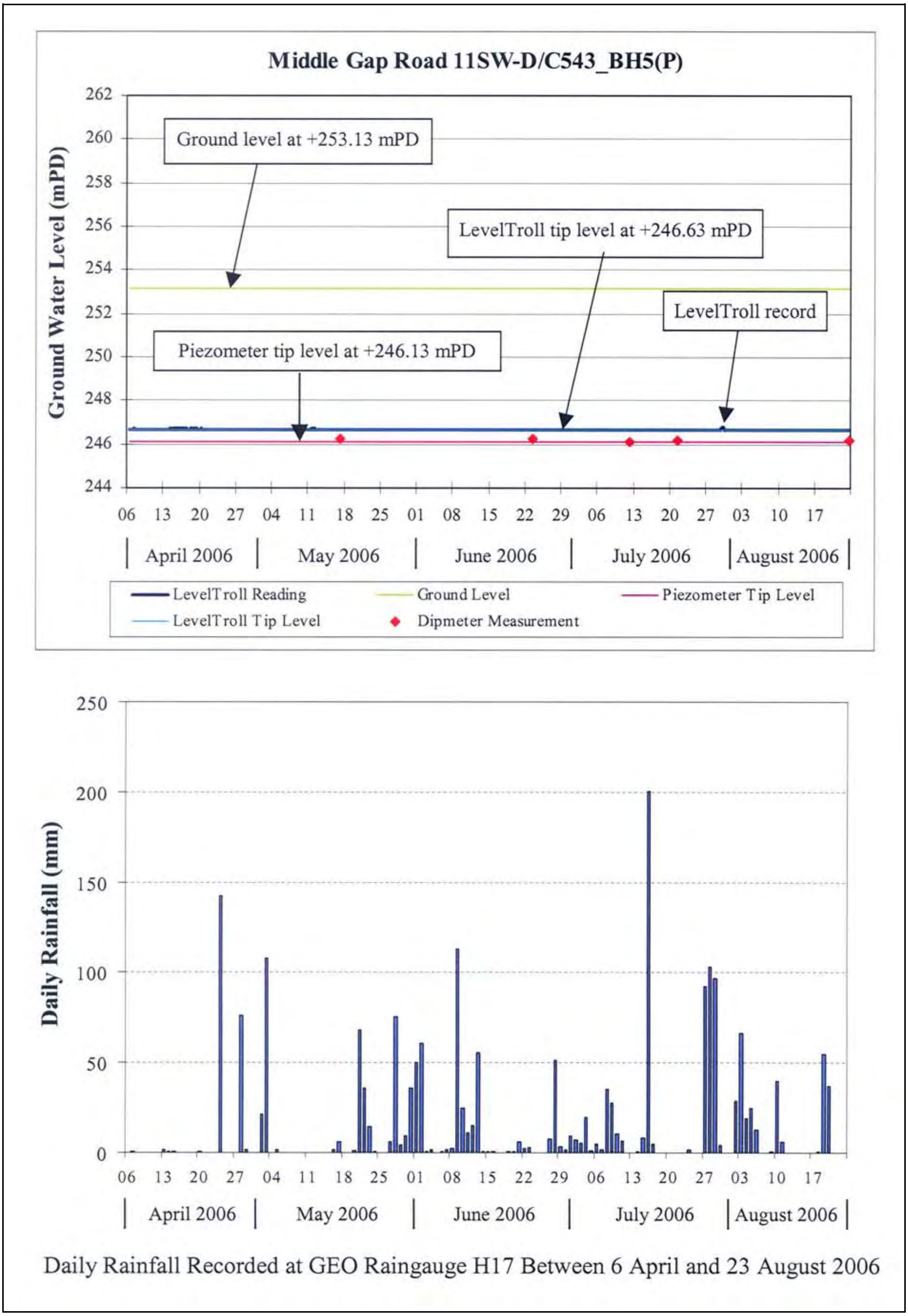

Figure C6 - Graphical Plot of Groundwater Data (Sheet 6 of 12)

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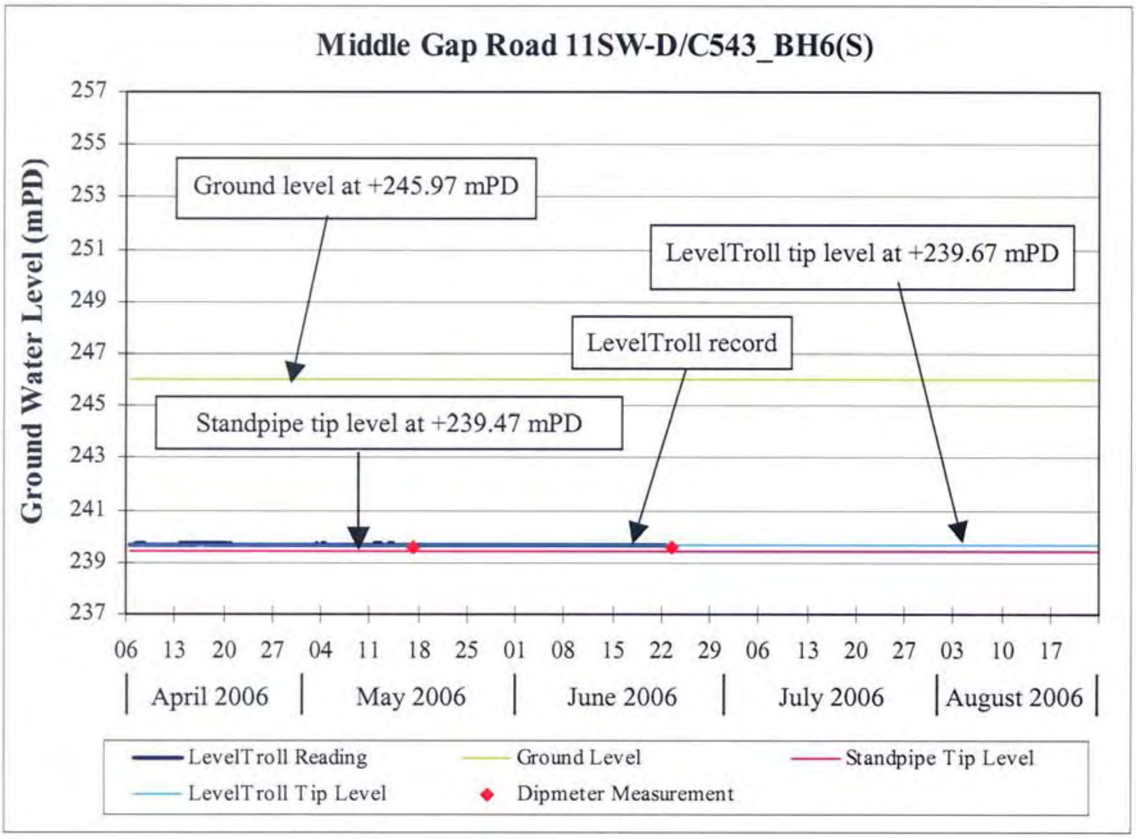

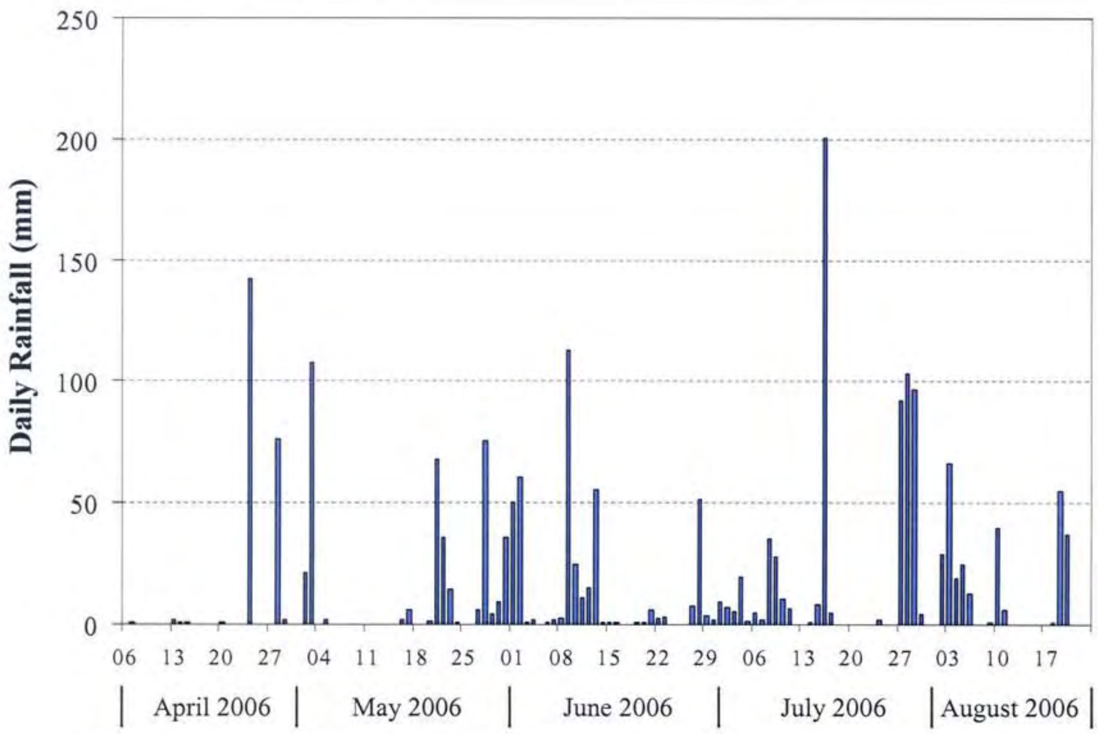

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C7 - Graphical Plot of Groundwater Data (Sheet 7 of 12)

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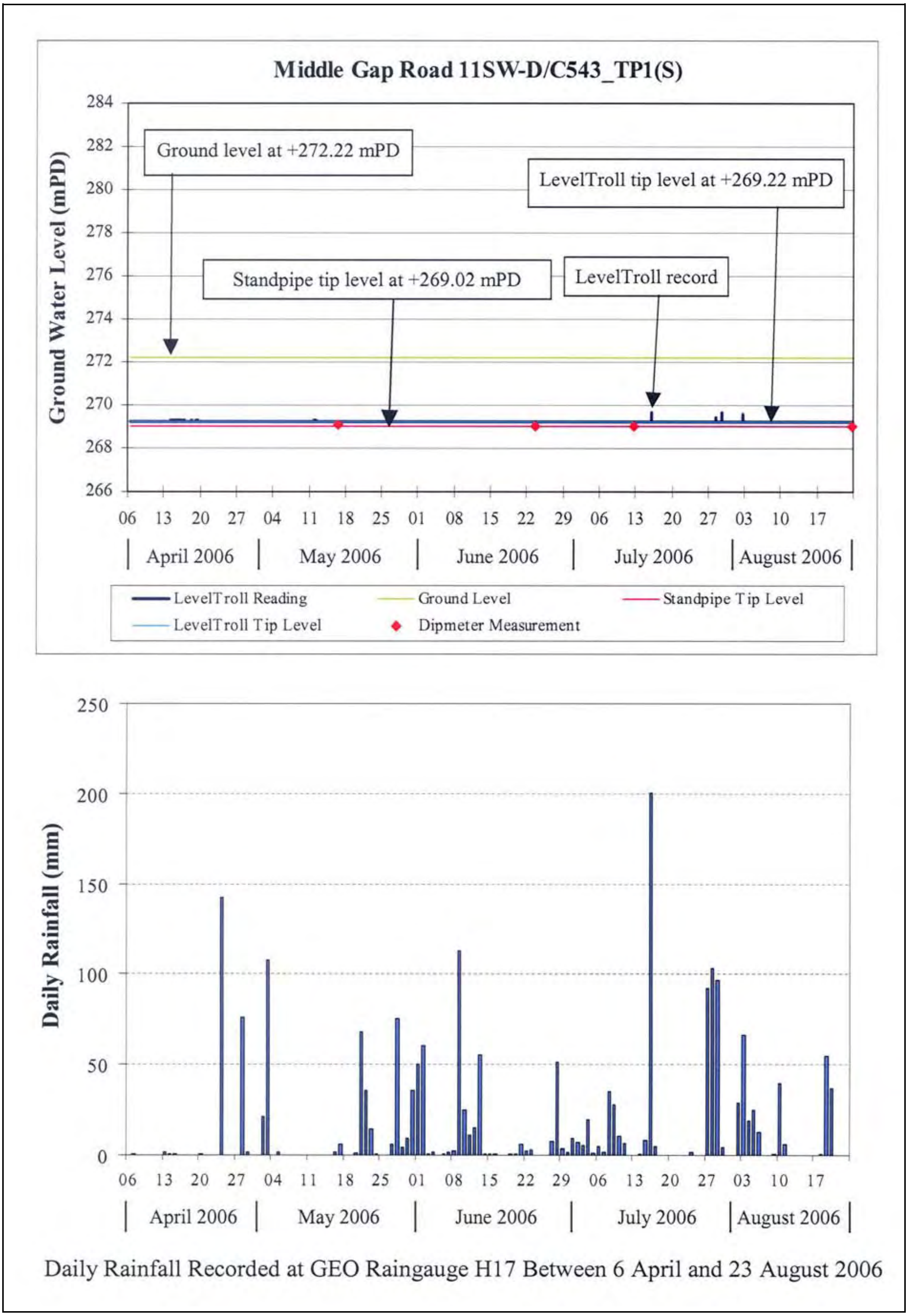

Figure C8 - Graphical Plot of Groundwater Data (Sheet 8 of 12)

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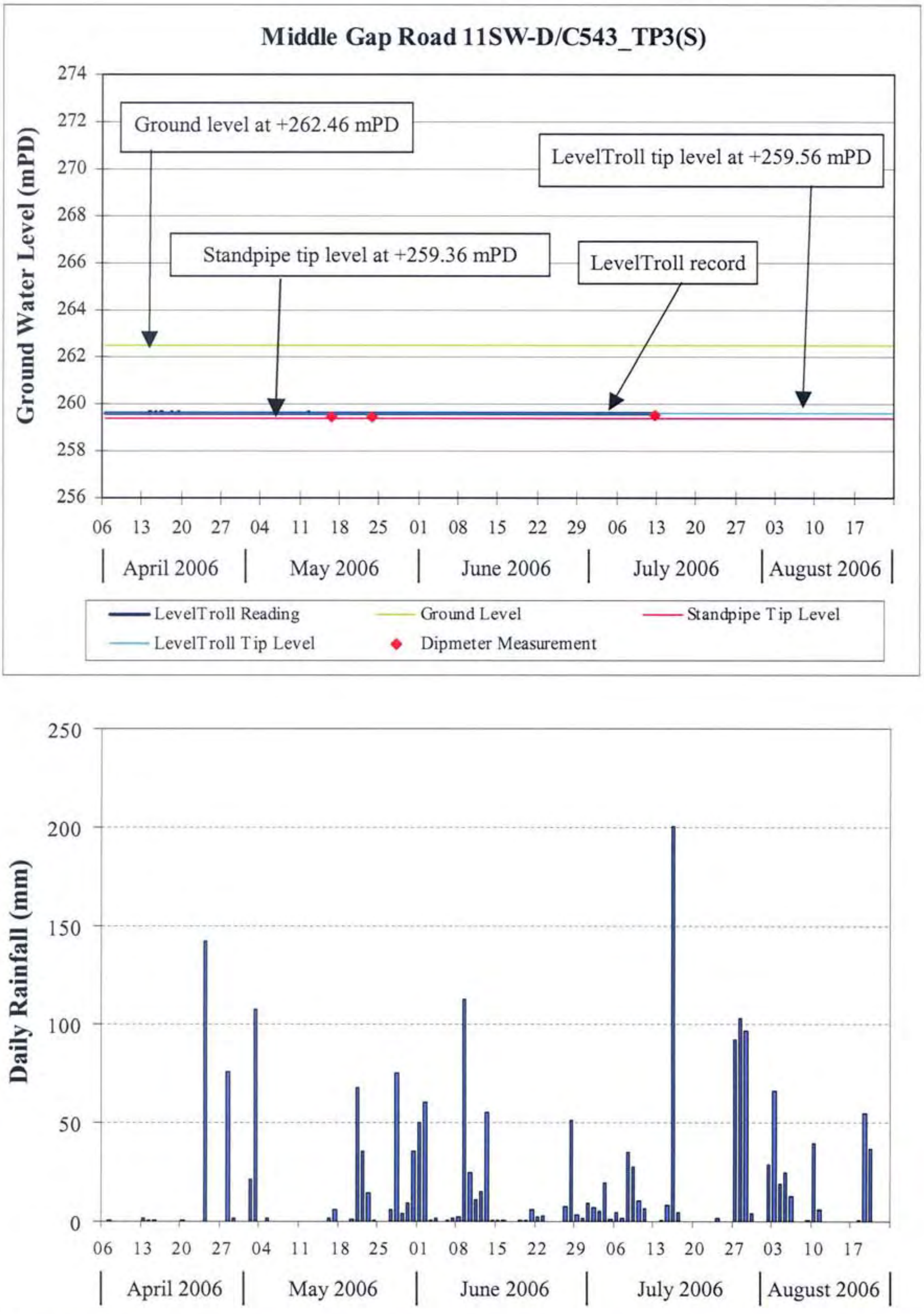

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C9 - Graphical Plot of Groundwater Data (Sheet 9 of 12)

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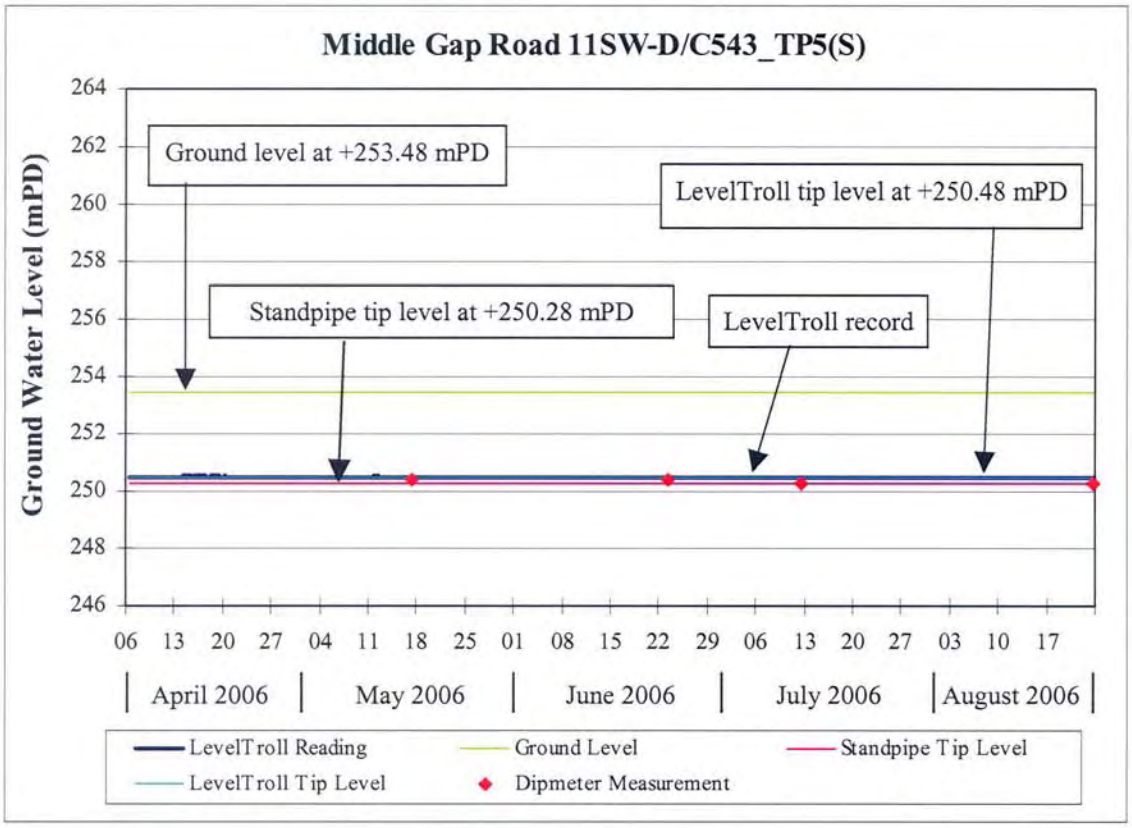

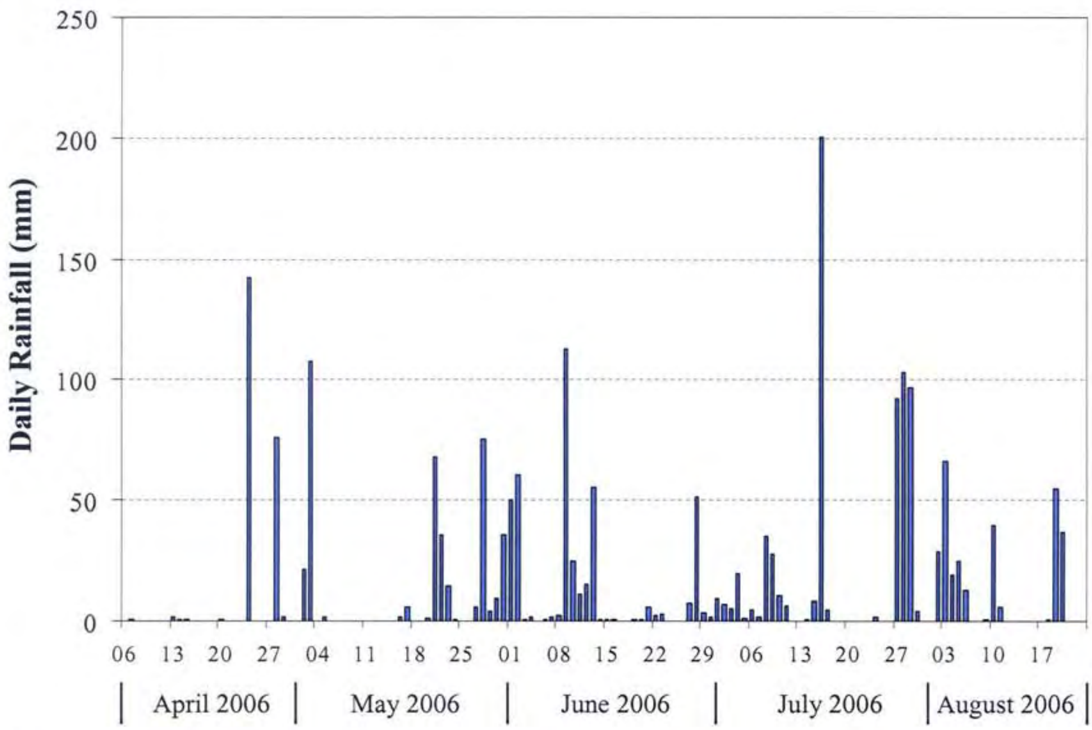

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C10 - Graphical Plot of Groundwater Data (Sheet 10 of 12)

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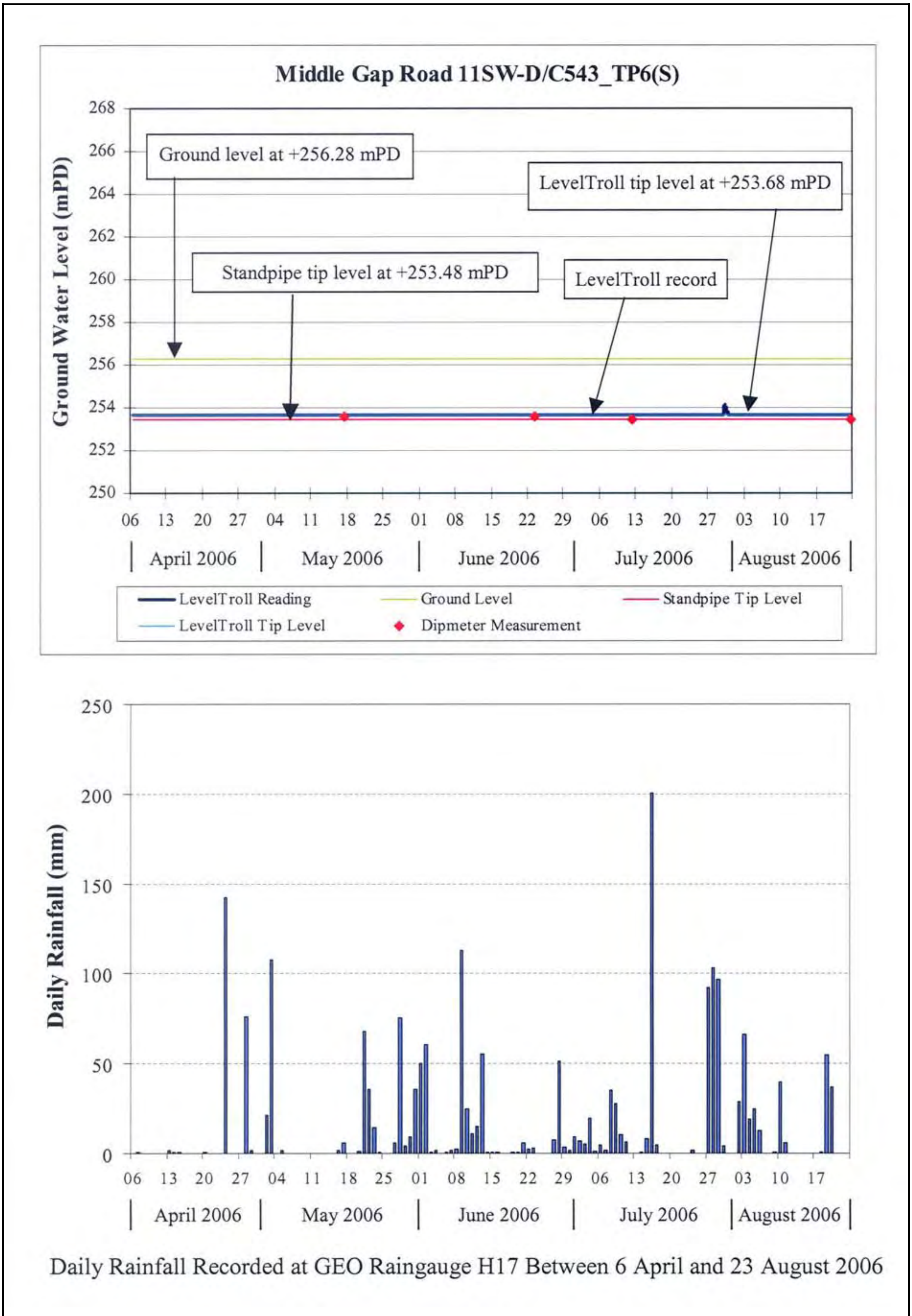

Figure C11 - Graphical Plot of Groundwater Data (Sheet 11 of 12)

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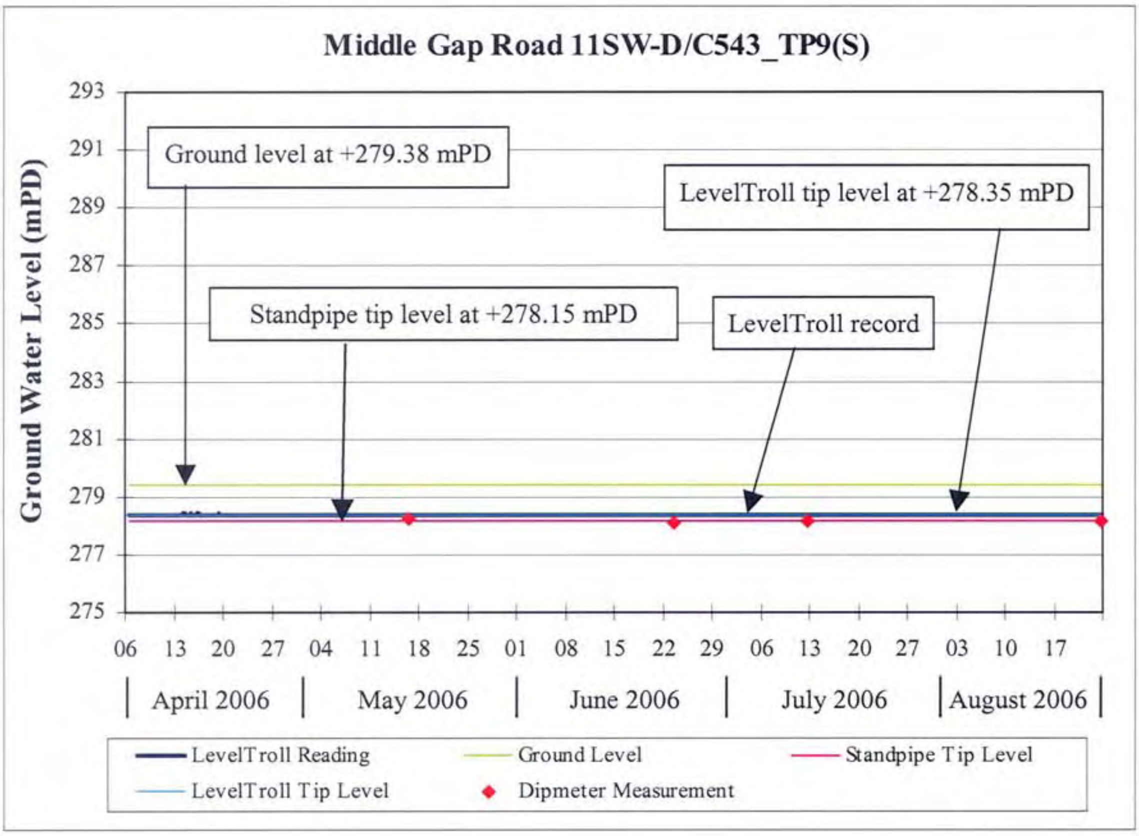

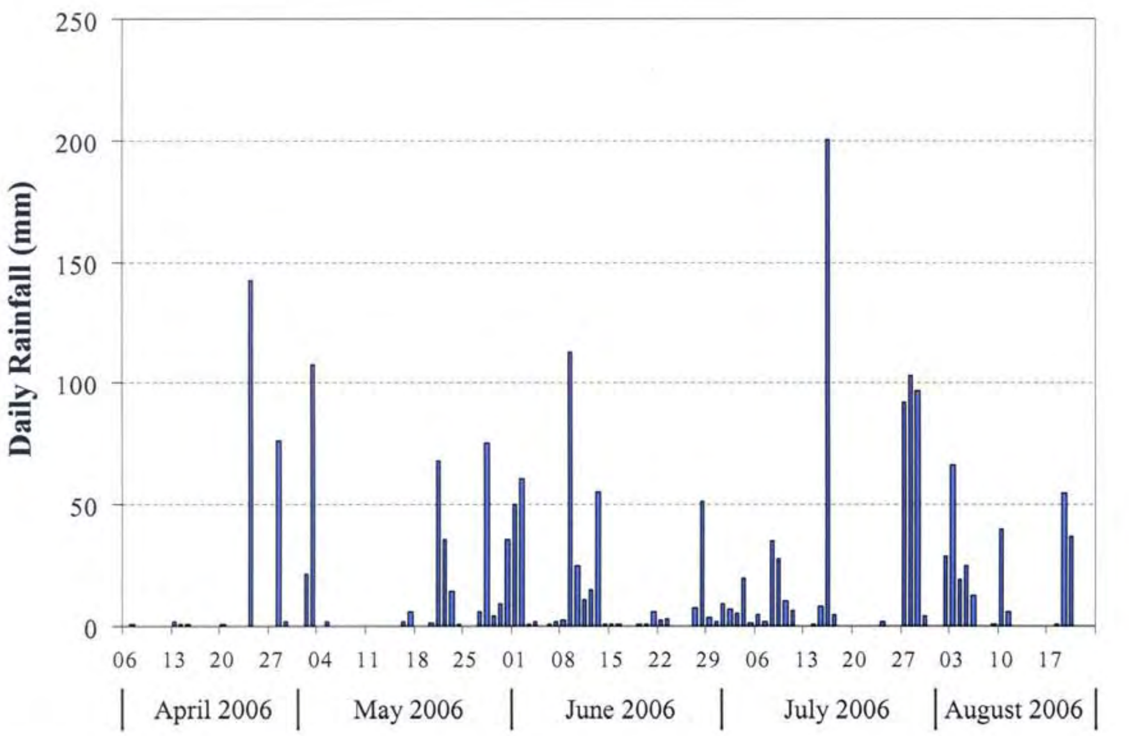

Daily Rainfall Recorded at GEO Raingauge H17 Between 6 April and 23 August 2006

Figure C12 - Graphical Plot of Groundwater Data (Sheet 12 of 12)

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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:

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

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

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

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TECHNICAL GUIDANCE NOTES

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