INVESTIGATION OF SOME SELECTED LANDSLIDES IN 1999

(VOLUME 1)

GEO REPORT No. 120

Fugro Maunsell Scott Wilson Joint Venture

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

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Prepared by:

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

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. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
December 2001

EXPLANATORY NOTE

This GEO Report consists of two Landslide Study Reports on the investigation of selected slope failures that occurred in 1999. The investigations were carried out by Fugro Maunsell Scott Wilson Joint Venture (FMSW) for the Geotechnical Engineering Office as part of the 1999 Landslide Investigation Consultancy.

The LI Consultancies aim to achieve the following objective through the review and study of landslides:

(a) establishment of an improved slope assessment methodology,

(b) identification of slopes requiring follow-up action, and

(c) recommendation of improvement to the Government's slope safety system and current geotechnical engineering practice in Hong Kong.

The Landslide Study Reports prepared by FMSW are presented in two sections in this Report. Their titles are as follows:

The Landslip Investigation Division of the Geotechnical Engineering Office worked closely with the LI Consultants and provided technical input and assistance to the landslide studies.

SECTION 1:
DETAILED STUDY OF THE LANDSLIDE ABOVE SOUTH LANTAU ROAD NEAR LAI CHI YUEN ON 24 AUGUST 1999

Fugro Maunsell Scott Wilson Joint Venture

This report was originally produced in June 2000
as GEO Landslide Study Report No. LSR 2/2000

FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. MW 1999/8/37) which occurred on 24 August 1999 in a cut slope above South Lantau Road, near Lai Chi Yuen on Lantau Island. Debris from the landslide, with an estimated volume of 1000 m^3 was deposited on South Lantau Road, blocking both lanes to traffic and causing damages to a parked vehicle and bus shelter. No fatalities or injuries were reported.

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, limited 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 1999 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), under Agreement No. CE 101/98. This is one of a series of reports produced during the consultancy by Fugro Maunsell Scott Wilson Joint Venture (FMSW).

Y.C. Koo
Project Director/Fugro Maunsell Scott Wilson
Joint Venture

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1. INTRODUCTION

On the morning of 24 August 1999, a landslide (GEO Incident No. MW 1999/8/37) occurred in slopes Nos. 10SW-C/C116 and 10SW-C/C117 located above South Lantau Road near Lai Chi Yuen, approximately 1 km south-west of Mui Wo, Lantau Island, during a rainstorm (Figure 1 and Plate 1). Debris from the landslide was deposited on South Lantau Road, completely blocking both lanes. A vehicle parked in a bus bay on the opposite side of South Lantau Road, together with the bus shelter, were damaged by the debris. No fatalities or injuries were reported as a result of the landslide.

Following the landslide, Fugro Maunsell Scott Wilson Joint Venture (FMSW, the 1999 Landslide Investigation Consultants) carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98.

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

(c) limited ground investigation and laboratory testing,

(d) analysis of rainfall records,

(e) engineering analysis of the slope, and

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

2. THE SITE

2.1 Site Description

Slopes Nos. 10SW-C/C116 and 10SW-C/C117 are located on the southern side of South Lantau Road (Figure 1 and Plate 1), near Lai Chi Yuen and approximately 1 km from Mui Wo Ferry Pier on Lantau Island.

The general landform in this area consists of a broad north-easterly trending spur associated with a minor peak (275 mPD) approximately 1.2 km to the south-west. The natural terrain falls away to the north and north-east to low-lying ground (2 mPD to 5 mPD) west of Mui Wo at angles of between 30° and 35°.

South Lantau Road broadly follows natural surface contours in the concerned area, traversing the site between approximately 65 mPD and 70 mPD, and rising at a grade of about 7.5% to the west. The carriageway is typically 7.5 m in width, widening to 10 m at a bus bay opposite the landslide location. The road formation in the locality is predominantly in cut, with the resultant slope formation incorporating the registered features as indicated on Figure 1.

The cut slopes extend continuously over a distance of about 650 m from Lai Chi Yuen Road, approximately 85 m east of the landslide. The cut slopes are relatively steep (slope angle 50° to 60°) and are up to 20 m in height. All have shotcrete surfacing and drainage channels at crest and toe.

The landslide occurred in slopes Nos. 10SW-C/C116 and 10SW-C/C117 where the slope height is between 12 m and 20 m. The natural hillside above the landslide site (Plate 2) is typically convex in form, with a small valley within the overall spur landform located approximately 60 m to the west. The hillside is heavily vegetated with dense undergrowth and small bushy trees providing a canopy about 3 m to 4 m above ground level in a strip approximately 30 m wide. Above this strip, the vegetation reverts to a low bushy scrub (about 1 m high), which is characteristic of the majority of the local hillside. Many boulders are exposed at the ground surface.

Below South Lantau Road, a number of valley features, which are not obvious in the landform above the road, become more pronounced downslope. Vegetation is similar to that immediately above the slope crest line

2.2 Water-carrying Services and Utilities

There are no water-carrying services in the vicinity of the landslide site.

A water tunnel supplying the Water Supplies Department (WSD) Silver Mine Bay Water Treatment Works from Pui O follows an approximate NE-SW axis approximately 250 m to the south-east of the landslide site. A review of WSD records indicates that the tunnel invert level at its closest proximity to the site is about 55.5 mPD (i.e. 8 m to 9 m below the toe of the slope).

2.3 Maintenance Responsibility

According to the "Systematic Identification of Maintenance Responsibility of Slopes in the Territory" (SIMAR) project undertaken by the Lands Department (LD), slopes Nos. 10SW-C/C116 and 10SW-C/C117 are under the maintenance responsibility of Highways Department (HyD).

3. SITE HISTORY AND PREVIOUS STUDIES

3.1 General

The development history of the landslide site, past landslides and details of previous studies carried out on slopes Nos. 10SW-C/C116 and 10SW-C/C117 have been compiled from a review of available aerial photographs and relevant documentation. Details of observations from aerial photographs are given in Appendix A and the salient points are given in the following sections.

3.2 Site History and Past Landslides

There are no significant changes observed in the natural landform above and below South Lantau Road during the period covered by the available aerial photographs from 1963 to 1998. The vegetation line defining the change from dense vegetation to the low, bushy scrub on the hillside above South Lantau Road (Section 2.1) advances and recedes with time and the dense vegetation above the cutting becomes progressively heavier. There are no records of past failures in the natural terrain in the vicinity of the landslide site in the GEO's Natural Terrain Landslide Inventory (NTLI). This is consistent with the detailed API carried out by FMSW.

The main observations in relation to the history of the landslide site are shown in Figure 2. The cutting now incorporating slopes Nos. 10SW-C/C20, 10SW-C/C116, 10SW-C/C117, 10SW-C/C118 and 10SW-C/C119 was formed during the construction of South Lantau Road, which is in its current form in the 1963 aerial photographs. This appears as a steep cut with a drainage channel located upslope of the crest (Figure 2). The hillside above the cutting was strewn with large boulders. A large, irregular depression was present in the cut face where the 1999 landslide scar subsequently developed, indicating possible past instability. A dark line, which is interpreted as seepage issuing from a point near the crown, roughly bisects the depression. The drainage channel in this area appears to have been constructed/re-constructed after the formation of the depression, following an irregular path further upslope than the adjacent sections of channel. A smaller, concave feature to the west of the larger depression also suggests possible previous instability.

There is relatively little change to the surface of the cutting between 1963 and 1992, except for possible localised application/re-application of hard surfacing over various portions of the face. The Lai Chi Yuen Road was constructed between 1974 and 1979, and defines the present eastern extent of the cutting. Consultants who inspected the slope for the Geotechnical Control Office (GCO, re-named GEO in 1991) in 1978 (Section 3.3) reported that the slope was surfaced with chunam, that seepage was issuing from high on the slope face and that landslide scars were present. Possible seepage lines are also visible within the large depression in the 1982 aerial photographs. The cutting was registered on the 1977/78 Catalogue of Slopes as slope No. 10SW-C/C20.

Three small landslides are visible in slope No. 10SW-C/C20 in the 1992 aerial photographs. The GEO landslide database identifies two of the incidents (Nos. MW92/5/10 and MW92/6/35), which occurred at the 1999 landslide site. Failure volumes were reported as 6 m^3 and 3 m^3 respectively. Both incidents are indicated as being caused by infiltration and as having blocked one lane of South Lantau Road. The failures were included in the GEO Report No. 35 (Chen, 1993) and were listed as "Minor" and as having occurred during rainstorm events on 8 May and 13-14 June 1992 respectively.

The third incident, for which no records could be found, was located approximately 40 m east of the 1999 landslide site. This failure appears to be very shallow and no debris is visible on South Lantau Road. The GEO landslide database shows Incident No. MW 92/6/37 in the vicinity of the third failure. However, desk study indicates that this incident actually relates to slope No. 13NE-B/C2 located in Pui O and is not relevant.

A larger volume failure (30 m^3) was recorded in the adjacent slope (No. 10SW-C/C21) during the same period (Incident No. MW92/6/34) and was located about 120 m south-west of the 1999 landslide site.

There are no available records relating to the repair works carried out on slopes Nos. 10SW-C/C20 and 10SW-C/C21. Aerial photographs indicate that these works probably comprised trimming of loose material from the slope face and application of shotcrete. The works appear to be mostly completed by November 1993. Other portions of the slopes were also re-surfaced at this time. Seepage lines are visible at the 1999 landslide site in the 1993 aerial photographs.

A landslide (Incident No. MW93/11/26) occurred in slope No. 10SW-C/C21 and affected the road embankment and hillside below South Lantau Road on 5 November 1993. The northern edge of the road was undermined by the landslide. Debris, with an estimated volume of around 250 m^3, travelled some 180 m downslope from the road, reaching flatter ground at the base of the hillside (Wong & Ho, 1995). The landslide was included as two incidents (Nos. MW SP/32 and MW SP/33) in GEO Report No. 43 (Chan, 1995). The incidents were listed as "Major" and occurred during a rainstorm event.

Further shotcreting works were carried out during 1996 to sections of slopes Nos. 10SW-C/C20 and 10SW-C/C21. In 1996 aerial photographs, recent shotcrete is visible on slope No. 10SW-C/C20 on the slope face excluding the 1992/93 repairs, and extends beyond the slope crest to the drainage channel above. The interfaces between the separate applications of hard surfacing appear to coincide approximately with present feature boundaries for slopes Nos. 10SW-C/C20, 10SW-C/C116, 10SW-C/C117, 10SW-C/C118 and 10SW-C/C119 (Figure 1) indicated in the New Catalogue of Slopes.

No significant changes are visible in the aerial photographs between October 1996 and August 1998.

On the basis of the available information, it would appear that the 1999 landslide occurred at a location with a history of instability (locally and in the general vicinity) and which had shown signs of groundwater seepage on a number of occasions.

3.3 Previous Studies

In March 1978, the road cutting was inspected by Binnie & Partners as part of the "Phase 1 Re-Appraisal of Cut and Natural Slopes and Retaining Walls" study

(Binnie & Partners, 1978) and was subsequently registered as slope No. 10SW-C/C20 in the 1977/78 Catalogue of Slopes. The field sheet for this feature records the presence of previous failure scars and the observation of seepage issuing from a point high on the slope face.

The Design Division of the GEO completed a Stage 1 Study Report for slope No. 10SW-C/C20 in March 1992 (GEO, 1992). The study included an inspection of the feature on 15 January 1992, which identified the previous failure scars at the smaller concave feature west of the 1999 landslide site (Section 3.2), the 1999 landslide site and the third failure scar observed in the 1992 aerial photographs (Section 3.2). The study report recommended that no further action was required at that time as the priority for consideration of inclusion into the LPM Programme was not high.

Slope No. 10SW-C/C20 was nominated for inclusion in the Landslip Preventive Measures (LPM) Programme between 1992 and 1995 based on the consideration of history of failure, indirect risk posed by debris blocking the sole access to Mui Wo and economic importance of South Lantau Road. The slope had not been included in the LPM Programme because of its low overall priority ranking.

In April 1995, slope No. 10SW-C/C20 was inspected by consultants appointed by HyD under the project "Roadside Slope Inventory and Inspections". The Engineer Inspection Records (FMR Consultants, 1995) indicate the overall state of maintenance as "Fair" and notes moderate seepage from the slope toe at the same location as the western flank of the 1999 landslide scar. Cracking of the hard surfacing was also recorded. Photographs attached to the records show vegetation growing through the hard surfacing at the location of the 1999 landslide scar (Plate 3).

The GEO initiated the consultancy agreement entitled “Systematic Inspection of Features in the Territory” (SIFT) in 1992 which, inter alia, aimed to identify features not registered in the 1977/78 Catalogue of Slopes and to update information on registered slopes based on studies of aerial photographs and limited site inspection. The Phase 2 SIFT Study for Map Sheet 10SW-17D was completed in November 1996 and divided slope No. 10SW-C/C20 from the 1977/78 Catalogue of Slopes into the current slopes Nos. 10SW-C/C20, 10SW-C/C116, 10SW-C/C117, 10SW-C/C118 and 10SW-C/C119. Slopes Nos. 10SW-C/C116 and 10SW-C/C117, affected by the 1999 landslide, were assigned Class "C2" (i.e. “Assumed formed post-1977”) and "C1" (i.e. “Assumed formed pre-1978 or illegally formed”) respectively. The SIFT report notes both features as comprising part of the original slope No. 10SW-C/C20. Slope No. 10SW-C/C116 was confirmed by API as being formed between 1991 and 1993 following a failure in an older cut. Slope No. 10SW-C/C117 was confirmed by API as being formed just before 1963.

The consultancy agreement entitled “Systematic Identification and Registration of Slopes in the Territory” (SIRST) was initiated by the GEO in 1994 to update the 1977/78 Catalogue of Slopes and to prepare a New Catalogue of Slopes. SIRST inspections carried out on 28 June 1998 (slope No. 10SW-C/C117) and 26 August 1998 (slope No. 10SW-C/C116), by Maunsell Geotechnical Services Ltd, indicated that no signs of seepage, distress or past instability were observed and that crest drainage channels were clear.

4. THE LANDSLIDE

4.1 Description of the Landslide

The landslide affected the full height of cut slopes Nos. 10SW-C/C116 and 10SW-C/C117. The landslide scar measured approximately 30 m to 35 m in width and the main scarp was located approximately 3 m to 4 m behind the crest drainage channel. Landslide debris comprising soil, cobbles, boulders and broken shotcrete with a volume estimated at about 1000 m^3 was deposited on South Lantau Road, completely blocking both lanes and extending across the footpath and adjacent verge. The debris impacted on a vehicle parked in the bus bay opposite the cut slopes, moving it northwards over a distance of about 1.5 m, and damaged the bus shelter.

Based on an eye-witness account of the landslide (i.e. the driver of the vehicle), the failure occurred suddenly and rapidly and involved an initial detachment of debris that blocked about 20% of the road width. This was followed shortly after by a larger detachment, which completely blocked the road and impacted on the vehicle and bus shelter. The driver left the scene for approximately 30 minutes. Upon returning, he observed that the scar had extended further to the east and that the volume of debris had increased substantially to the east of the vehicle.

The maximum depth of the landslide scar, measured normal to the surface of rupture, occurred at the original crest line and was of the order of 2 m to 3 m. The scar was bowl-shaped, with a steep main scarp dipping at about 70° to the horizontal. The flanks of the scar were relatively gentle and poorly defined, the western flank being somewhat better defined than the eastern flank and coinciding with an existing concave feature on the slope face.

The surface of rupture was at an angle of about 35° to 45° and daylighted in the slope face approximately 4 m to 5 m above the slope toe at the eastern flank. From this location, the daylight of the surface of rupture described an arc intersecting with the slope toe about mid-way across the scar and followed the slope toe over the western side of the scar. The surface of rupture was generally lower in the western side than in the eastern side of the scar. A general view of the landslide is presented in Plate 4. Material exposed in the scar comprised completely decomposed fine-grained quartz syenite with exposures of corestones and jointed, less weathered (Grades II and III) material. The failure partially exploited adversely orientated relic joint surfaces.

The travel distance of the landslide debris was about 12 m to 13 m (on plan) beyond the original toe of the cut slopes (Plates 5 and 6). The debris was deposited in a 3 m to 4 m high mass, reposed at an angle of between 20° and 25°. The debris predominantly comprised a reddish-brown sand and silt, but with a significant content of cobbles and boulders up to about 2 m in diameter. The debris was largely saturated, without much excess water. The travel angle of the landslide debris (Wong & Ho, 1996) is estimated to be about 35°.

Based on the results of the post-failure topographic survey of the landslide site, the general topography and profile of the landslide are presented in Figures 3, 4 and 5.

4.2 Observations Made Prior to the Landslide

The eye-witness reported that he regularly travels along South Lantau Road several times a day and did not observe anything unusual in the vicinity of the slopes Nos. 10SW-C/C116 and 10SW-C/C117 in the days preceding the landslide.

Immediately prior to the time of the landslide on 24 August 1999, the eye-witness had been attempting to re-start his vehicle after experiencing engine troubles. He noted that the rainfall, which had been heavier in the preceding hours, reduced in intensity at this time. The eye-witness observed a number of boulders (300 mm to 600 mm diameter) detach from the slope crest and deposit on South Lantau Road. Randomly orientated cracks appeared in the shotcrete surfacing within the subsequent location of the scar, rapidly opening to around 75 mm in width. Boulders continued to detach from the slope crest, prompting the eye-witness to retire to a safe vantage 20 m to 30 m east of his vehicle from which location he observed the landslide occur at about 9:30 a.m. The eye-witness estimated that the elapsed time between the initial observation of boulders depositing on South Lantau Road and the occurrence of the landslide was of the order of a few minutes.

4.3 Observations Made Following the Landslide

The eye-witness continued to observe the landslide scar following the major detachment of debris and noted that water was flowing from two locations adjacent to the scar, high up on the slope face (Figure 3). On the eastern side of the scar, water was flowing under some pressure from a weephole in the shotcrete surfacing, while to the west, water was entering the scar from beneath the cracked shotcrete.

Based on the eye-witness account, an estimate has been made of the extent of the landslide scar and the sources of water flow, which are indicated on Figure 3. According to the eye-witness, about 50% of the debris detached from the slope during the initial failure, involving the two separate phases of movement (Section 4.1), with the remaining detachment occurring subsequently within the following half hour at most.

The landslide site was inspected by representatives of the GEO and HyD at about 3:00 p.m. on 24 August 1999. The GEO Incident Report noted blocked/broken drains at the slope crest and groundwater seepage at the failure location. The FMSW inspection team visited the site at about 11:00 a.m. on 25 August 1999. At this time, a temporary track had been cleared through the debris along the toe of the mound to permit the passage of vehicles, initial trimming works were being carried out at the main scarp and excavation plant had been assembled for further clearance works (Plate 7). The damaged vehicle is shown in Plate 8. The damage caused by the landslide to the bus shelter is less certain, as the observed condition (Plate 8) may have been caused by excavation plant.

The pertinent observations from the FMSW inspection are presented below.

(a) The landslide debris was arranged in a number of semi-discrete mounds (Figure 3 and Plates 7 & 9), suggesting detachment in a number of stages.

(b) A light brown, plastic silty clay deposit was observed as a coating on several of the boulders present in the debris. This material differed from the predominantly reddish-brown saprolite in the debris mass (Plate 9).

(c) Muddy water was observed flowing from a weephole in the shotcrete surfacing adjacent to the eastern flank of the scar (Plate 10).

(d) Adverse joint orientations were present in exposures of moderately decomposed bedrock within the scar (Plate 11).

(e) Water was flowing into the scar at the base of the main scarp (Figure 3 and Plates 7 & 11).

Mapping of the landslide scar and debris was carried out on 29 August 1999. The results of this work are presented in Section 5.4.

It is noteworthy that the seepage from the scar continued following the failure (Plate 12) and was still present at the completion of the post-landslide ground investigation in mid-November 1999.

4.4 Urgent Repair Works

Urgent repair works carried out by HyD at the recommendation of the GEO included trimming of the main scarp, which extended the scar a further 10 m upslope, removal of debris and application of a shotcrete surfacing with weepholes. A surface drainage channel was constructed along the slope crest and a rockfill toe berm was provided to a height of about 7 m along the slope toe over a distance of 110 m. Following completion of these works, the east-bound lane of South Lantau Road was opened to traffic on 4 September 1999.

Further remedial works, which were carried out by HyD at the recommendation of the GEO, comprised soil nails and 5 rows of horizontal drains installed down to the slope toe, with staged removal of the rockfill toe berm. The west-bound lane of South Lantau Road was re-opened to traffic on 8 January 2000.

5. SUBSURFACE CONDITIONS

5.1 General

The subsurface conditions within the landslide site have been assessed on the basis of information obtained from the desk study, field mapping and limited post-failure ground investigation. No previous ground investigation has been carried out in the vicinity of the failed slope.

5.2 Current Investigation

Geological mapping of the exposed landslide scar was carried out by FMSW in the week following the failure and was completed on 29 August 1999. The major observations made during this exercise are presented on Figure 6.

The post-landslide ground investigation comprised five vegetation strips, seven trial pits to depths of 2 m and 3 m and the retrieval of disturbed and undisturbed samples. The locations of ground investigation stations are also indicated on Figure 6. GCO probing was carried out at each trial pit location and insitu density tests were carried out within the pits. The results of this work are reported in Soils & Material Engineering Co. Ltd (1999a & b). Insitu density test results are summarised in Table 1. Trial pit logs prepared by FMSW are presented in Appendix B. Photographs detailing the various observations made during the investigation are presented in Plates 13 to 33.

Laboratory testing on samples included classification, moisture content determination and compaction tests, as well as triaxial and direct shear box testing. A summary of the laboratory test results is presented in Tables 1, 2 and 3. Samples of groundwater were collected from the landslide scar and analysed (Table 4).

5.3 Deduced Conditions

5.3.1 Geology and Geomorphology

Sheet 10 of the Hong Kong Geological Survey 1:20000 scale map series HGM20 (GEO 1991) indicates that the solid geology of the landslide site and its surroundings is fine-grained quartz syenite (Figure 7). Debris flow deposits are indicated at the eastern margin of the landslide site. Details relating to the local quartz syenite bedrock formation are presented in Hong Kong Geological Survey Memoir No. 6 (Langford, et al, 1995). An abundance of corestones in a reddish-brown saprolitic soil is typical of the syenite regolith.

The quartz syenite in the area of the concerned slopes is located along the NE-SW trending Pui O – Sha Tau Kok Fault zone and most syenite contacts are reported to be steep-sided and dyke-like. A trace of the fault zone is mapped on the hillside above slope No. 10SW-C/C21 (Figure 7) and projects across South Lantau Road near the western end of slope No. 10SW-C/C209 (Figure 1). This trace juxtaposes the quartz syenite against fine-grained granite to the north-west and may correspond to the linear break in slope south-west of slope No. 10SW-C/C209, visible in the 1963 aerial photographs.

The 1963 aerial photographs also show a narrowly-spaced NW-SE trending linear pattern in the hillside above South Lantau Road, which appears to be the strike of a steeply dipping structural element in the quartz syenite. The orientation is consistent with a number of joint sets logged in trial pits. However, the interpretation of this feature as a discontinuity related to jointing or other elements (e.g. flow banding) remains conjectural in the absence of detailed mapping of the broader hillside. The feature appears to control the natural drainage line at the south-western end of slope No. 10SW-C/C21, and may represent a potential path for groundwater to be channelised towards the slope.

5.3.2 Ground Profile

The landslide scar exposes predominantly Grades IV and V quartz syenite containing corestones of Grades II and III material. The Grade IV and V material is typically brown and reddish-brown, clayey, sandy silt. Corestones are generally up to about 1 m in diameter and range from isolated sub-rounded cobbles and boulders to exposures of blocky, jointed material.

Landslide debris deposited on the landslide scar and South Lantau Road comprised reddish-brown soil with a significant content of sub-angular to sub-rounded cobbles and boulders, as well as fragments of slope surfacing and drainage channel (Plate 13). Vegetation was present in the debris that remained within the scar. The debris was highly to completely disturbed saprolite, with no indication of rafting of material.

The main scarp (Plate 14) exposed up to 1 m thickness of colluvium/residual soil overlying the Grade V material, with sub-angular to sub-rounded cobbles and boulders. The colluvial soil matrix comprises a grey-brown, clayey silt with sand and organics.

Typical joint orientations in blocky exposures located in the upper central western portion of the scar (Plates 15 and 16) are presented on Figure 6 and include three sets dipping out of the slope (020° – 050°/60° – 65°, 330°/35° and 335°/60°), and two sets dipping into the slope (174°/70° and 209°/35°). The sets dipping out of the slope are marginally adverse, as they are orientated obliquely to the slope face by about 25° to 35°. The intersection of these sets would produce a sliding wedge.

Light brown silty clay infill was observed on a number of relic joint surfaces exposed in the scar (Plates 14, 15 and 17), as well as on boulders contained in the landslide debris (Section 4.3). This material had a soft to firm consistency at the time of inspection.

Trial pits were excavated below the surface of rupture to a depth of 2 m within the landslide scar and exposed further Grade IV and V material before terminating in Grade IV or Grade III/IV material, indicating that the surface of rupture was not controlled by an abrupt change in material type. Trial pits were excavated to depths of 2 m to 3 m in the hillside above the landslide scar and confirmed the typical ground profile described above. However, the thickness of the colluvium/residual layer varied from 0.1 m to 1 m thickness and less-weathered material, as well as an increased prevalence of corestones, were observed towards the base of the pits.

The orientations of relic joints exposed in all trial pits show considerable scatter, although there appears to be a general grouping around the typical sets logged in the scar. Joint aperture varied from tight to moderately wide and joints were generally infilled. A number of open and infilled joints (Plates 18 and 19) up to 50 mm wide, and orientated parallel to the slope face, were observed in trial pits located above the scar. These may be tension features resulting from downslope ground movement. Infill material at these locations was compact and no obvious surface expression of the tension features was observed on the hillside above the scar.

The results of triaxial testing on samples of Grades IV and V quartz syenite (Table 2 and Figure 8) indicate 'best-fit' shear strength parameters of $c' = 7$ kPa and $\phi' = 40°$, and a lower bound shear strength of c' = 4 kPa and ϕ' = 36°. Direct shear box tests on similar material (Table 3 and Figure 9) indicate a 'best-fit' ϕ' = 41°, with c' set to zero. Direct shear box testing was also carried out on samples of Grades IV and V quartz syenite containing relic discontinuities. These tests were carried out using modified shear box apparatus in which gypsum was used to mount the specimen and shear was applied along the discontinuity surfaces. Test results (Table 3 and Figure 9) indicate ϕ' in the range of 30° to 38° with c' set to zero.

Small quantities of kaolin and manganiferous deposits were observed on some of the joint surfaces. However, the overall occurrence of these materials was relatively minor. A noteworthy observation made through comparison of the nature of joint infill within (Plates 20 and 21) and outside (Plates 18 and 19) the landslide scar was the general absence of the light brown silty clay infill from the trial pits located above the scar. In these pits, the infill typically comprised the reddish-brown clayey, sandy silt from the surrounding soil matrix.

The joint infill material generally contained a noticeably higher clay content than the Grades IV and V quartz syenite (Table 1) and was determined by Atterberg Limits testing to be of very high to extremely high plasticity (GCO, 1988). The fines content of the Grades IV and V quartz syenite was similarly determined to be of high to very high plasticity.

5.3.3 Other Observations

No obvious signs of further instability were observed in the hillside above the landslide scar. The crest drainage channel was totally blocked by dead vegetation a few metres to the west of the landslide scar (Plate 22). Instances of previous instability (see Section 3.2) were observed in the adjacent slope face (Plates 23 and 24).

There are many quartz syenite boulders/exhumed corestones up to about 2 m in diameter partially and fully exposed on the hillside (Plates 25 and 26), as noted in earlier sections. Any downslope movement of the boulders has not been significant, as evidenced by matching joint surfaces between adjacent blocks in a number of instances. A number of shallow erosion channels were noted around the boulders (Plate 27) and voiding was observed beneath the downslope side of boulders at a number of locations (Plate 28). In one location, the arrangement of boulders appeared to form an irregular shallow channel with the potential to concentrate surface flow and direct it towards the slope crest (Figure 6 and Plate 29). Other signs of concentrated surface flow were observed immediately following the failure in the form of locally flattened vegetation.

The hillside behind the scar was observed to be heavily infested with termites, whose presence was visible at ground level through the processing of topsoil into amorphous pellets around 3 mm to 5 mm in diameter. Numerous voids were exposed in the landslide scarp (Plate 30) and trial pits, ranging up to about 60 mm in diameter (Plate 31). Voids were observed to penetrate the insitu ground profile along the clayey silt material (Plate 32). It is not known whether the voids are termite galleries or erosion pipes, or a combination of the two. Termites were observed in the majority of voids. Tree roots were also observed to have penetrated to depths in excess of 2 m and were exposed in trial pits as well as the main scarp.

There did not appear to be any obvious cause for the change in vegetation to a low scrubby brush on the hillside above the concerned slopes (Section 2.1). No changes in ground surface conditions or topography were noted and termite infestation appeared equally prevalent above and below the vegetation transition.

5.3.4 Groundwater

Information on the groundwater regime at the landslide site is limited. Trimming works at the main scarp revealed two sources of flow into the scar, both from joint apertures in blocky exposures. Seepage was also encountered in trial pit TP4 (Figure 4 and Plate 33). However, this was considered likely to have derived from the source described above, the trial pit being located a short distance downslope of the seepage.

API has indicated that the site has exhibited periodic seepage flows at this location from at least 1963 onwards (Appendix A). No source for the present flow of water could be positively identified during the course of the study. Laboratory testing (Table 4) indicates that the water samples recovered from the scar were slightly acidic and contained few impurities.

The relatively localised occurrence of the seepage suggests the presence of preferential drainage paths within the ground profile, rather than a general rise in the base groundwater table. The persistence of the flow for more than 3 months after the landslide suggests that the seepage is fed by an extensive catchment. This may be explained by the structural element in the local geology interpreted from aerial photographs (Section 5.4.1), which could be influencing the regional hydrogeological setting.

Infiltration rates for the hillside above the landslide site may be influenced (increased) by the presence of voids observed in the landslide scar and in trial pits (i.e. increased porosity of the near-surface ground profile). The presence of significant numbers of boulders may also act to concentrate surface flow. However, the relative contribution of these influences to water ingress cannot be quantified based on the available information.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge (No. N18) to the landslide is located at the Mui Wo Police Station, about 900 m to the north-east of the site.

For the purposes of rainfall analysis, it is assumed that the landslide occurred at 9:30 a.m. on 24 August 1999 (Section 4.2), which is well defined by the eye-witness account.

Daily rainfall for one month preceding and seven days following the landslide, together with hourly rainfall for 48 hours before and 10 hours following the landslide, are given in Figure 10. The daily rainfall records show that the storm was concentrated around 22 to 24 August 1999, with the hourly data indicating intense peaks from 6:00 a.m. to 7:00 a.m. and 7:00 a.m. to 8:00 a.m. on 23 August 1999, generally in the range of 60 mm/hr to 80 mm/hr. Rainfall in the hours prior to the landslide were of the order of 10 mm/hr to 40 mm/hr.

Isohyets of rainfall for the 24-hour period preceding the landslide are given in Figure 11.

Table 5 presents the estimated return periods for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The 48-hour maximum rolling rainfall (692 mm) was the most severe, with a return period of about 150 years. A comparison of the severity of the August 1999 rainstorm and other historical major rainstorms is presented in Figure 12. This shows that the August 1999 rainstorm was the most severe for durations greater than 4 hours, since installation of the raingauge in the early 1990's.

7. 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 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 4. The pre-failure slope profile was based on topographic survey plans, photographic records and engineering judgement. The geometry of the surface of rupture and ground profile is based on site measurements by FMSW, post-failure topographic survey and ground investigation. The idealised section used in the analyses is presented in Figure 13.

In the absence of characteristic shear strength parameters for quartz syenite in the published literature, the stability analyses were carried out using a range of shear strengths which covers the generalised range of parameters given for decomposed granite and volcanics in Table 8 of Geoguide 1 (GEO, 1993), as well as the parameters determined from laboratory testing on samples of syenite as part of this study (Section 5.4.2). 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 13. These indicate that the development of an elevated groundwater pressure of about 0.5 m above the surface of rupture would be required to initiate failure in the slope.

8. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

8.1 Mode and Sequence of Failure

The eye-witness account, together with 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.

According to the eye-witness account, the landslide occurred in three stages over a period of approximately 30 minutes. The first and second stages occurred within a few minutes in the western portion of the landslide scar at the locations of seepage issuing on the slope face. These involved the successive detachment of about 50% of the total debris volume from the slope. The evidence from the eye-witness account also suggests that significant deformation of the slope took place prior to the main failure to cause the dislodgement of boulders from the slope crest and cracking in the slope surfacing.

The final detachment took place at the eastern portion of the landslide scar. There was no indication of significant seepage over this portion of the scar as for the western portion. It is possible that this area was de-stabilised by the previous stages of failure, which had the effect of removing support. This is consistent with the NNW trend of the surface of rupture in the eastern portion of the landslide scar.

The eye-witness account is consistent with the observed landslide debris, comprising a number of semi-discrete mounds of highly to completely disturbed saprolite.

8.2 Probable Causes of Failure

The landslide occurred in a steep soil cut slope standing at an angle of between 50° and 60°. The close correlation between the severe rainstorm of 24 August 1999 and the timing of the landslide suggests that the failure was probably triggered by the severe rainfall.

The landslide was probably caused by transient elevated groundwater pressures within the soil mass due to direct infiltration and subsurface seepage via preferential flow paths. In the months following the failure, the seepage has continued to discharge from the scar. The historic record also indicates that the present landslide site has been prone to periodic seepage flows and minor slope failures in the past.

Theoretical stability analyses indicate that relatively small increases in groundwater pressures above the surface of rupture are required to initiate the significant failure using reasonable estimates of soil shear strength.

The relative influence of the seepage flow in causing the landslide may be evidenced by the scarp forming at a point just above the locations of seepage flow and a critical rainfall duration of 48 hours.

Other factors that probably contributed to the landslide are as presented below:

(a) Adverse relic jointing in the insitu weathering profile of quartz syenite.

(b) By-products of the more advanced weathering along the preferential flow paths in the form of a plastic silty clay infill on relic joint surfaces being present at part of the surface of rupture.

(c) The presence of voids in the near-surface soil profile, which may be erosion pipes or termite galleries, or both, leading to increased infiltration rates.

(d) The presence of numerous boulders on the hillside above the landslide site to concentrate surface runoff, resulting in increased water ingress.

(e) Blockage of crest surface drainage provisions due to inadequate maintenance, resulting in increased infiltration.

(f) A history of slope instability, which may have contributed to local opening of the relic joints as observed in trial pits, and progressive slope deterioration.

8.3 Discussion

The landslide site and the adjacent slopes have a history of instability, indicating that the concerned slopes are substandard. The landslide site also exhibited signs of distress in the form of cracking of the hard surfacing as well as seepage high on the slope face. Observations from aerial photographs suggest that seepages, indicative of transient water flows, may be linked to the local structural geology. This could support the movement of groundwater over considerable distances to produce the sustained flow of seepage as observed following the rainstorm of 24 August 1999. Given the site history and the geological and hydrogeological setting of the cut slopes, the occurrence of further instability at the site was no surprise.

There are no records of historic landsliding in the natural landform at the present landslide site. This suggests that instability at the site was primarily promoted by the cut slope formation.

The main uncertainty in relation to the present failure is the particular timing of the failure (i.e. "why this year?"). This is probably related to the severity of the rainstorm preceding the failure (return period of 150 years) in comparison to previous rainstorm events experienced. However, general slope deterioration, locally promoted by groundwater seepage flows and local slope movement, and blocked surface drainage provisions are also likely to have contributed to the present failure.

9. CONCLUSIONS

It is concluded that the landslide, which occurred on 24 August 1999 and affected cut slopes Nos. 10SW-C/C116 and 10SW-C/C117, was triggered by severe rainfall. The failure affected an old, cut slope with a history of instability, which had not been designed and checked to current geotechnical standards.

The failure was probably caused by the build-up of transient elevated groundwater pressure in the soil mass, following the severe rainfall that immediately preceded the failure. Preferential flow paths within the soil mass, as indicated by sustained seepage in the months following the failure, were probably an important source of water resulting in the elevated groundwater pressures.

Other factors contributing to the failure probably include adverse relic jointing in the insitu soil profile, by-products of the more advanced weathering in the vicinity of the flow paths, the concentration of surface flow by numerous boulders and increased infiltration through erosion pipes/termite galleries at the slope crest. Additionally, blockage of crest surface drainage provisions probably resulted in increased infiltration into the slope.

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LIST OF TABLES

Table 1 - Summary of Classification, Index and Compaction Test Results for Soil Samples (Sheet 1 of 3)

Material Type	Sample Location	Depth (m)	Sample Type	Particle Size Distribution				LL (%)	PL (%)	PI (%)	Moisture Content (%)	Maximum Dry Density (t/m^3)	Insitu Dry Density (t/m^3)	Remarks
				Gravel (%)	Sand (%)	Silt (%)	Clay (%)							
CDS	TP1	0.5-0.6	SDS	-	-	-	-	-	-	-	24	-	1.47	*
CDS		0.5-1.0	LDS	22	43	13	22	70	35	35	26	1.47	-	
C/HDS		1.10-1.25	U76	11	51	17	21	58	31	27	28	-	-	
C/HDS		1.0-1.5	HCB	27	53	10	10	NP	NP	-	21	1.52	-	
C/HDS		1.5-1.6	SDS	-	-	-	-	-	-	-	26	-	1.45	*
C/HDS		1.5-2.0	LDS	23	55	11	11	55	34	21	23	1.52	-	
C/HDS		2.0-2.5	U76	7	65	14	14	56	37	19	26	-	-	
C/HDS		2.0-2.5	HCB	11	63	14	12	NP	NP	-	23	1.52	-	
Joint Infill		0.0-3.0	SDS	7	26	19	48	-	-	-	26	-	-	
CDS	TP2	0.5-0.6	SDS	-	-	-	-	-	-	-	20	-	1.42	*
CDS		0.5-1.0	LDS	30	35	14	21	69	33	36	25	1.49	-	
C/HDS		1.03-1.47	U76	40	48	8	4	NP	NP	-	16	-	-	
C/HDS		1.5-1.6	SDS	-	-	-	-	-	-	-	22	-	1.39	*
C/HDS		1.5-2.0	LDS	27	54	10	19	50	32	18	20	1.63	-	
HDS		2.05-2.42	U76	8	64	14	14	NP	NP	-	23	-	-	
Joint Infill		0.0-3.0	SDS	2	28	18	52	-	-	-	34	-	-	
FILL	TP3	0.5-0.6	SDS	-	-	-	-	-	-	-	21	-	1.45	*
FILL		0.5-1.0	LDS	20	44	16	20	57	28	29	27	1.61	-	
HDS		1.03-1.47	U76	33	54	8	5	48	28	20	19	-	-	
HDS		1.0-1.5	HCB	15	59	14	12	47	28	19	25	1.62	-	
HDS		1.5-2.0	LDS	22	58	11	9	46	27	19	23	1.63	-	
Joint Infill		0.0-2.0	SDS	2	15	15	68	-	-	-	53	-	-	

Table 1 - Summary of Classification, Index and Compaction Test Results for Soil Samples (Sheet 2 of 3)

Material Type	Sample Location	Depth (m)	Sample Type	Particle Size Distribution				LL (%)	PL (%)	PI (%)	Moisture Content (%)	Maximum Dry Density (t/m^3)	Insitu Dry Density (t/m^3)	Remarks
				Gravel (%)	Sand (%)	Silt (%)	Clay (%)							
CDS	TP4	0.5-0.6	SDS	-	-	-	-	-	-	-	26	-	1.43	*
CDS		0.5-1.0	LDS	28	48	11	13	59	30	29	30	1.60	-	
CDS		1.05-1.45	U76	16	55	14	15	58	33	25	32	-	-	
Joint Infill		1.05-1.45	U76	4	39	16	41	-	-	-	-	-	-	
C/HDS		1.5-2.0	LDS	18	50	13	19	68	35	33	42	1.56	-	
Joint Infill		0.0-2.0	SDS	4	27	15	54	95	41	54	50	-	-	
C/HDS	TP5	0.5-0.6	SDS	-	-	-	-	-	-	-	23	-	1.42	*
C/HDS		0.5-1.0	LDS	19	54	15	12	57	32	25	29	1.52	-	
C/HDS		1.03-1.27	U76	17	64	10	9	54	30	24	25	-	-	
C/HDS		1.0-1.5	HCB	11	66	12	11	NP	NP	-	27	1.52	-	
C/HDS		1.5-2.0	LDS	16	59	14	11	54	31	23	29	1.57	-	
Joint Infill		0.0-2.0	SDS	5	43	19	33	-	-	-	40	-	-	
CDS	TP6	0.5-0.6	SDS	-	-	-	-	-	-	-	26	-	1.47	*
CDS		0.5-1.0	LDS	19	40	14	27	76	36	40	28	1.44	-	
C/HDS		1.03-1.47	U76	23	60	10	7	59	32	27	20	-	-	
C/HDS		1.0-1.5	HCB	12	64	11	13	58	35	23	29	1.43	-	
Joint Infill		1.0-1.5	HCB	4	28	19	49	82	39	43	37	-	-	
C/HDS		1.5-1.6	SDS	-	-	-	-	-	-	-	26	-	1.45	*
C/HDS		1.5-2.0	LDS	17	50	12	21	70	36	34	30	1.45	-	
C/HDS		2.33-2.67	U76	4	34	18	44	89	36	53	37	-	-	
Joint Infill		0.0-3.0	SDS	3	21	18	58	88	41	47	36	-	-	

Table 1 - Summary of Classification, Index and Compaction Test Results for Soil Samples (Sheet 3 of 3)

Material Type	Sample Location	Depth (m)	Sample Type	Particle Size Distribution				LL (%)	PL (%)	PI (%)	Moisture Content (%)	Maximum Dry Density (t/m^3)	Insitu Dry Density (t/m^3)	Remarks
				Gravel (%)	Sand (%)	Silt (%)	Clay (%)							
C/HDS	TP7	0.5-0.6	SDS	-	-	-	-	-	-	-	24	-	1.47	*
C/HDS		0.5-1.0	LDS	32	39	12	17	67	34	33	27	1.49	-	
C/HDS		1.0-1.5	U76	20	80	0	0	82	41	41	32	-	-	
C/HDS		1.5-1.6	SDS	-	-	-	-	-	-	-	23	-	1.42	*
C/HDS		1.5-2.0	LDS	18	58	12	12	52	32	20	27	1.50	-	
C/HDS		2.0-2.5	U76	3	46	21	30	73	31	42	33	-	-	
C/HDS		2.0-2.5	HCB	10	57	16	17	88	41	47	27	1.43	-	
Joint Infill	Face A	0.0-3.0	SDS	5	20	15	60	-	-	-	28	-	-	
Joint Infill	Face C	0.0-3.0	SDS	4	30	16	50	86	38	48	34	-	-	

Legend:

LL	Liquid Limit	U76	76mm Dia. Undisturbed Sample	C/HDS	Completely/Highly Decomposed Syenite
PL	Plastic Limit	S/LDS	Small/Large Disturbed Samples	NP	Not Plastic
PI	Plasticity Index	HCB	Hand-Cut Block Sample	TP2	Trial Pit 2

* Tests carried out by Soil and Materials Engineering Co. Ltd

Note: (1) See Figure 6 for locations of trial pits.

Table 2 - Summary of Triaxial Compression Test Results for Soil Samples

Sample Location	Depth (m)	Material Type	Sample Type	Moisture Content before Testing (%)	Dry Density before Testing (Mg/m^3)	Particle Density (Mg/m^3)	Type of Test	p' (kPa)	q (kPa)
TP1	1.25 to 1.45	C/HDS	U76	29.7	1.36	2.63	CUM	52.9 105 278.4	41.2 74 165.3
TP1	1.0 to 1.5	C/HDS	Block	26.6	1.31	2.65	CUM	90.1 139.3 206.7	74 105.4 144.1
TP1	2.0 to 2.5	C/HDS	Block	28.5	1.26	2.63	CUM	59.8 93 136.7	46 64.7 87.3
TP5	1.27 to 1.47	C/HDS	U76	25	1.36	2.61	CUM	68.8 121.5 319.3	51.4 82.7 203.3
TP5	1.0 to 1.5	C/HDS	Block	29.9	1.28	2.65	CUM	61.8 93.1 142.6	43.6 59.7 90.2
TP7	2.27 to 2.47	C/HDS	U76	35.7	1.21	2.66	CUM	35.1 61.8 106.9	25 40.5 63.4
TP7	2.0 to 2.5	C/HDS	Block	32.8	1.23	-	CUM	63.3 96.5 168	48.8 67.7 103.6

Legend:		
	TP1	Tril Pit No. TP1
	C/HDS	Completely/Highly decomposed syenite
	CUM	Consolidated undrained multi-stage

$p' = ½(\sigma_1'+\sigma_3')$

$q = ½(\sigma_1'-\sigma_3')$, where σ_1' and σ_3' are the major and minor principal effective stresses respectively

Notes:
(1) See Figure 6 for the locations of samples.
(2) All samples of CDG extracted for the triaxial compression tests were outside the distressed zone of the slope.

Table 3 - Summary of Direct Shear Box Test Results for Soil Samples

Sample Location	Depth (m)	Material Type along Shearing Plane	Sample Type	Direction of Shearing	Vertical Stress at the Beginning of Test (kPa)	Maximum Shear Stress (kPa)	Horizontal Displacement at Maximum Shear Stress (mm)	Vertical Displacement at Maximum Shear Stress (mm)	Vertical Stress at Maximum Shear Stress (kPa)
TP1	2.0-2.5	Relict Discontinuity in Grade IV/V Quartz Syenite	Block	Along Discontinuity	50.24	47.12	11.98	-2.02	59.09
TP3	1.0-1.5	Relict Discontinuity in Grade IV/V Quartz Syenite	Block	Along Discontinuity	49.93	30.22	4.67	-0.67	53.02
TP5	1.0-1.5	Grade IV/V Quartz Syenite	Block	Horizontal	25	19.82	4.23	+0.16	25
TP5	1.0-1.5	Grade IV/V Quartz Syenite	Block	Horizontal	50	41.99	11.62	-1.04	50
TP5	1.0-1.5	Grade IV/V Quartz Syenite	Block	Horizontal	100	88.46	9.11	-0.39	100
TP7	2.0-2.5	Relict Discontinuity in Grade IV/V Quarts Syenite	Block	Along Discontinuity	50.17	36.52	5.76	-0.73	54.34

Legend: TP3 Trial Pit No. TP3

Notes:
(1) See Figure 6 for the locations of samples.
(2) The rate of shearing was 0.08 mm/min.
(3) The positive vertical displacement denotes dilation and a negative vertical displacement denotes compression.

Table 4 - Summary of Test Results for Water Samples

Sample I.D.	Source	pH	Chloride Ion Concentration (mg/l)	Calcium Ion Concentration (mg/l)	Fluoride Ion Concentration (mg/l)	Sulphate Ion Concentration (mg/l)
LS01	Landslide Scar	5.7	< 10	< 1	< 0.2	2.2
LS02		5.7	< 10	< 1	0.7	2.7

Notes: (1) See Figure 6 for source locations.
(2) Laboratory Testing completed by the Hong Kong Government Laboratory.

Table 5 - Maximum Rolling Rainfall at GEO Raingauge No. N18 for Selected Durations Preceding the 24 August 1999 Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	11.0	06:05 on 23 August 1999	2
15 Minutes	28.0	06:10 on 23 August 1999	2
1 Hour	96.0	06:15 on 23 August 1999	20
2 Hours	144.5	06:55 on 23 August 1999	16
4 Hours	207.0	08:50 on 23 August 1999	15
12 Hours	345.0	08:40 on 23 August 1999	25
24 Hours	470.0	15:20 on 23 August 1999	35
2 Days	692.0	09:30 on 24 August 1999	150
4 Days	700.5	09:30 on 24 August 1999	47
7 Days	700.5	09:30 on 24 August 1999	30
15 Days	869.0	09:30 on 24 August 1999	28
31 Days	931.0	09:30 on 24 August 1999	9

Notes:
(1) Return periods were derived from Table 3, of Lam and Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for duration up to 48-hours, and from hourly data for longer rainfall durations.
(3) The use of 5-minute data for durations between 4 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam and Leung (1994)'s data, which are based on hourly rainfall for these durations.

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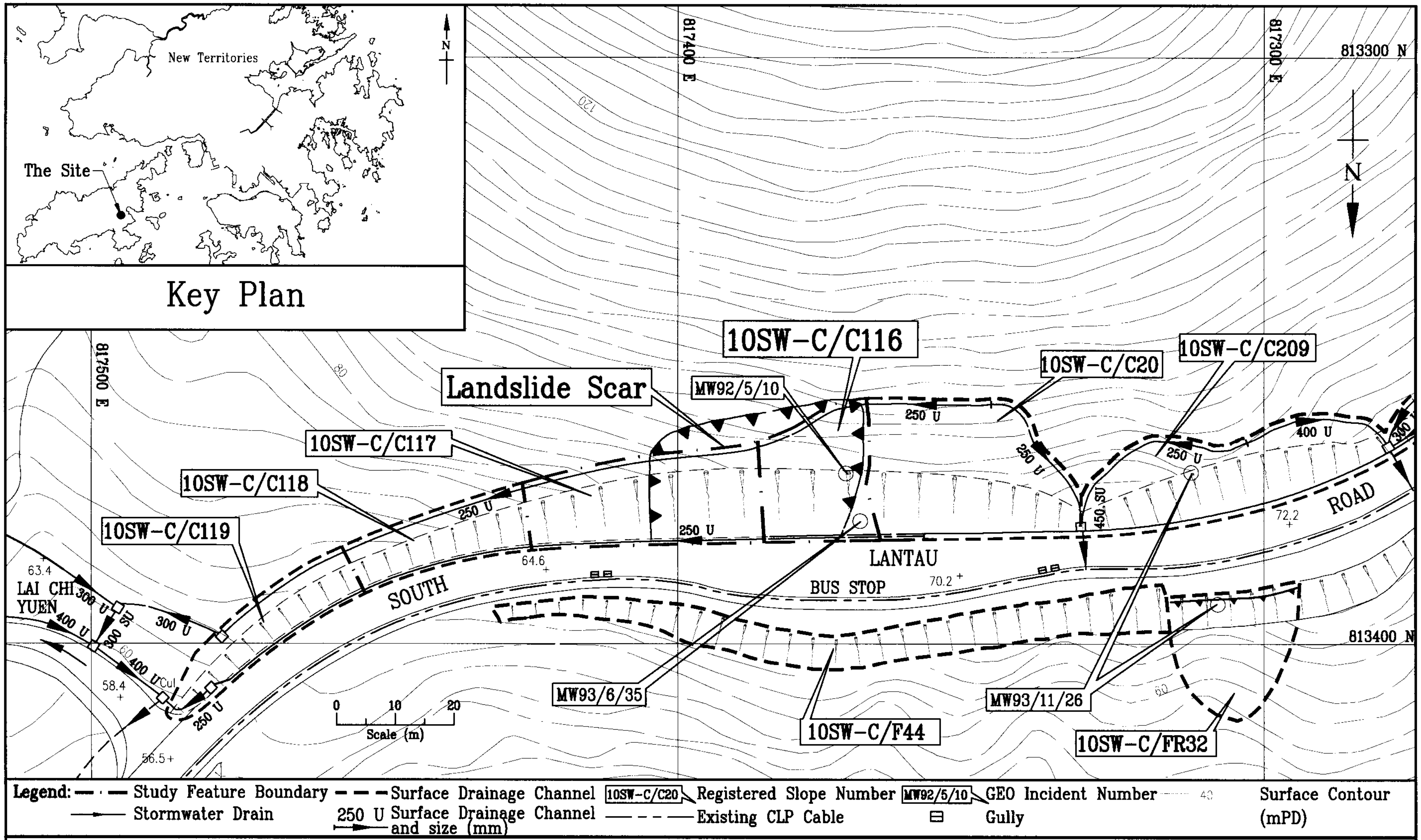
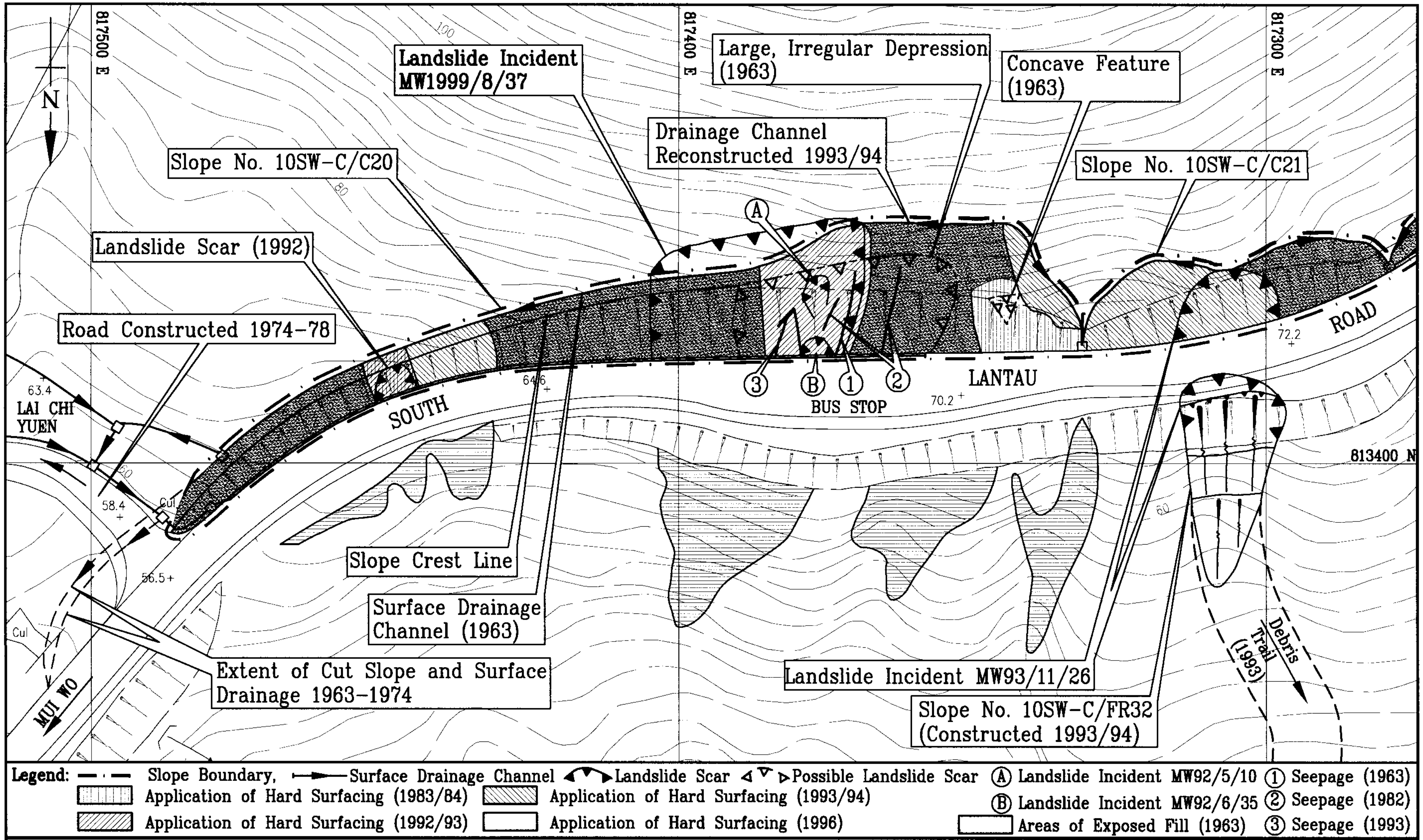


Notes: (1) Base Map is extracted from Survey Sheet No. 10SW-17D, scale 1 : 1000

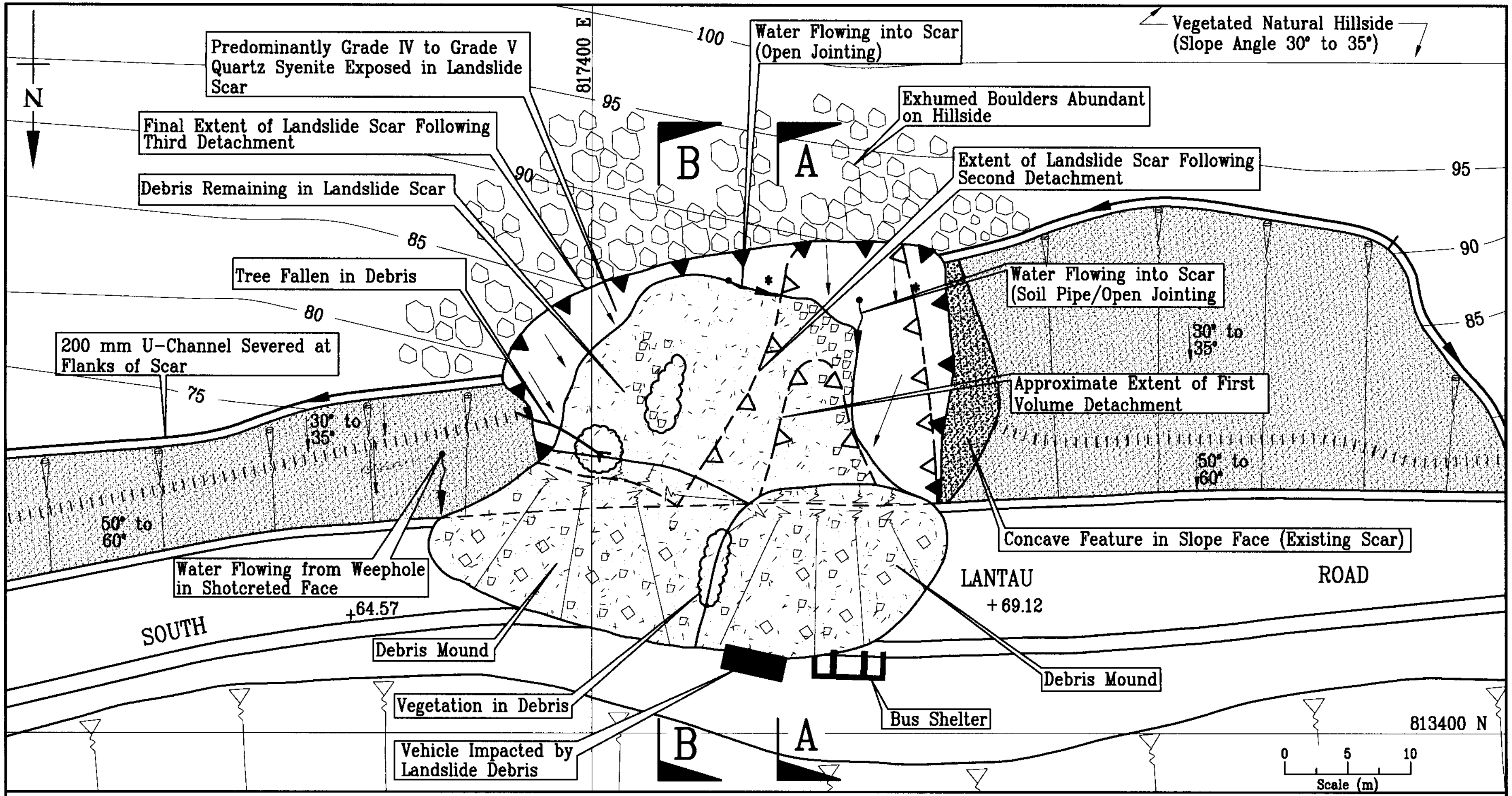
(2) Feature boundaries and registration numbers are based on form the GEO Slope information System, Aerial Photograph interpretation and site observation.

Figure 1 - Site Location Plan



Notes: (1) Base Map is extracted from Survey Sheet No. 10SW-17D, scale 1 : 1000
(2) Slope Registration Number and Boundaries are Pre-SIFT/SIRST.

Figure 2 - Site History

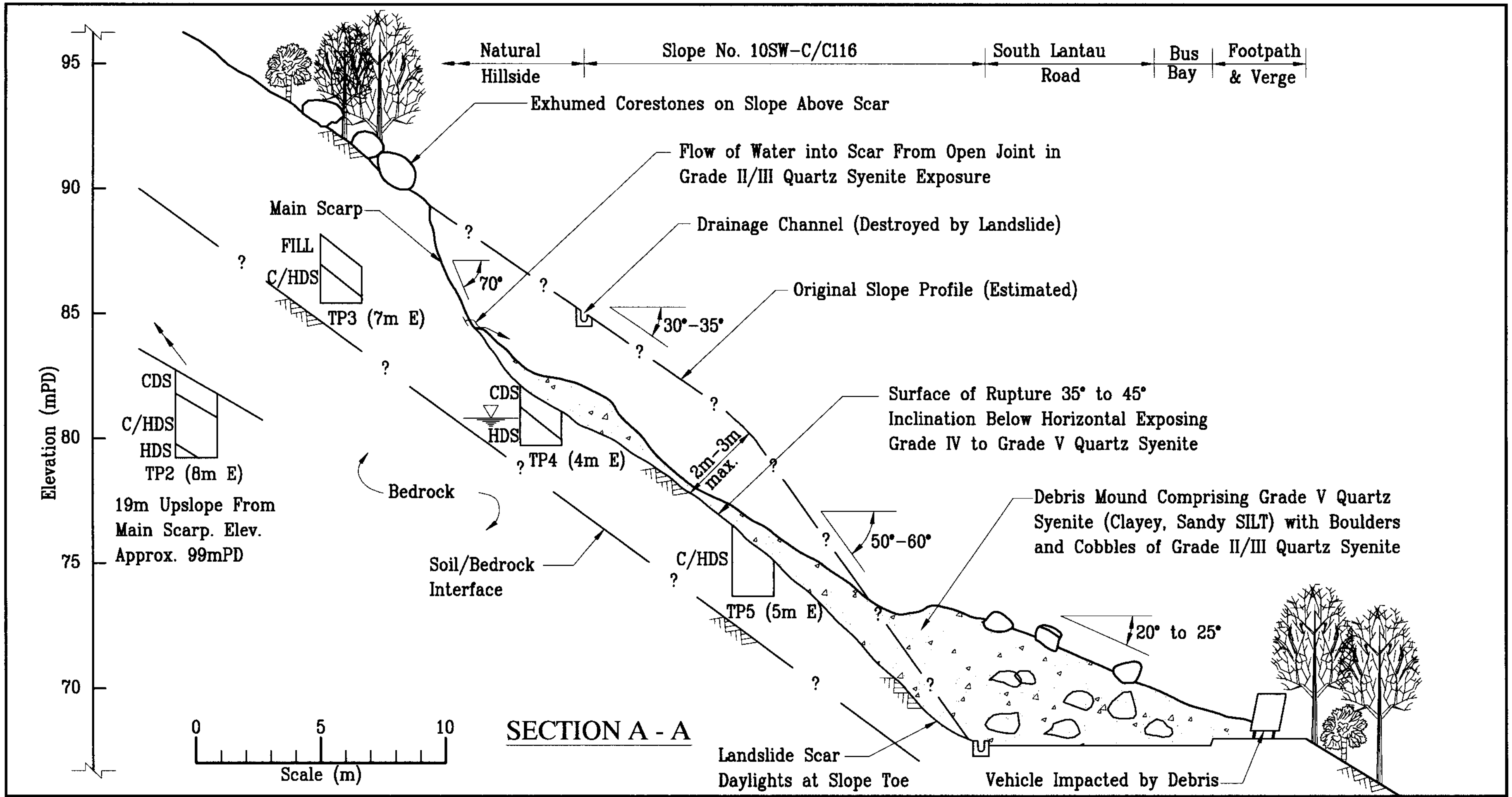


Legend: Local Direction of Fall; ı ı ı ı ı ı Change in slope angle; —90— Surface Elevation Contour (mPD); +69.12 Surface Spot Level (mPD)

▨ Shotcrete with Weepholes; ▨ Landslide debris

Notes:
(1) Local topography and landslide geometry are based on Topographic Survey Drg. No. 1201/2MW/01 (Tang Surveys Ltd., 1999).
(2) Section A-A and Section B-B are presented on Figures 4 and 5 respectively.
(3) Mapping of the landslide scar is presented on Figure 6.
(4) Locations of seepage observed following initial large volume detachment indicated by ' * '.

Figure 3 - Plan View of the Landslide

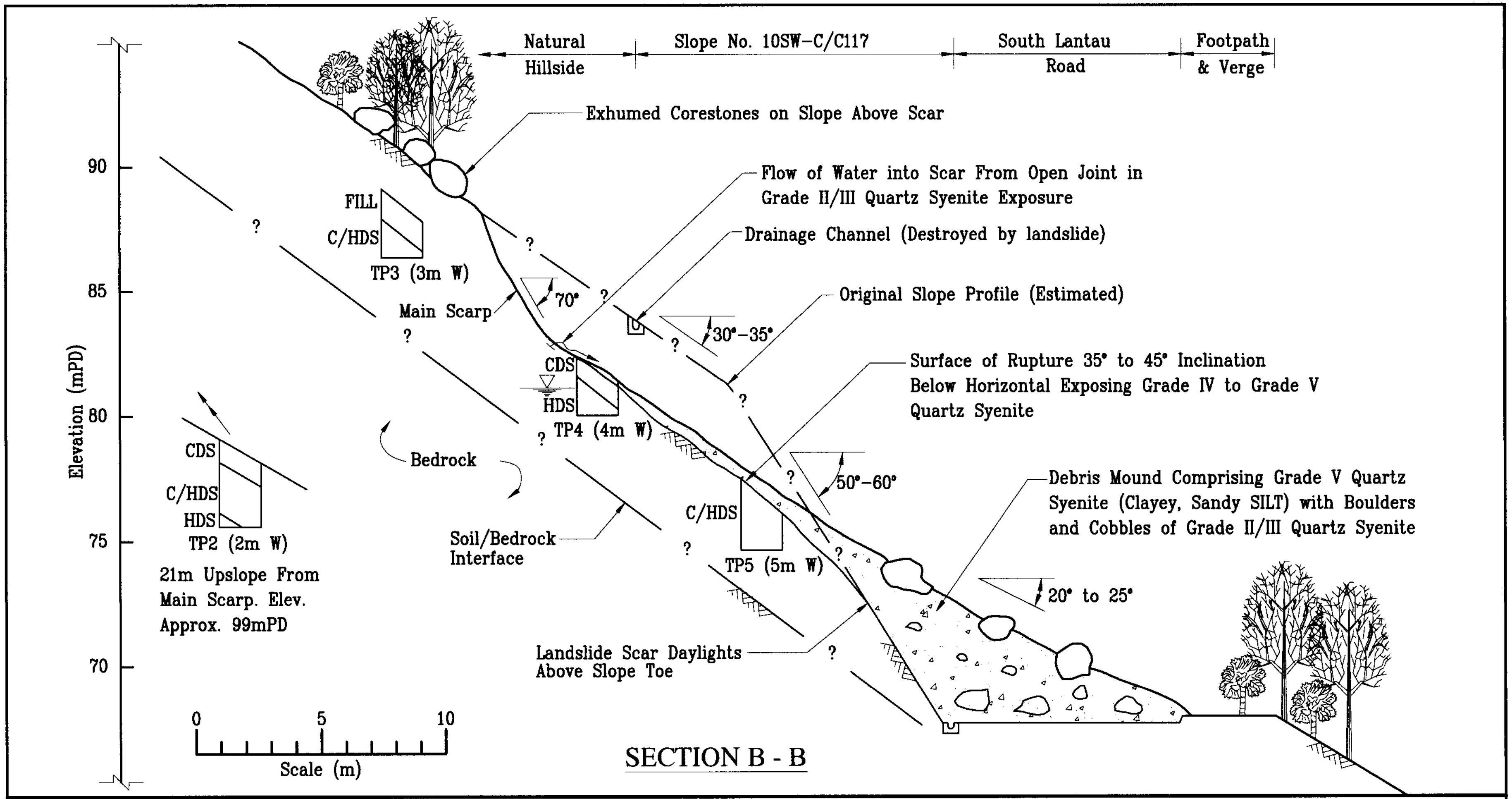


Legend: FILL Loose material/debris remaining in scar following trimming works CDS Completely Decomposed Syenite HDS Highly Decomposed Syenite

TP3 (7m E) Trial pit reference No., offset and direction ▽ Observed water level during the GI works

Notes:
(1) Section geometry is based on Topographic Survey Drg. No. 1201/2MW/01 (Tang Surveys Ltd, 1999).
(2) Section is taken along Hong Kong Metric Gridline 817385E.
(3) The location of Section A-A is indicated on Figure 3.
(4) Trial pit information indicated on section is based on the ground investigation carried out in 1999. Refer to Figure 6 for trial pit locations.

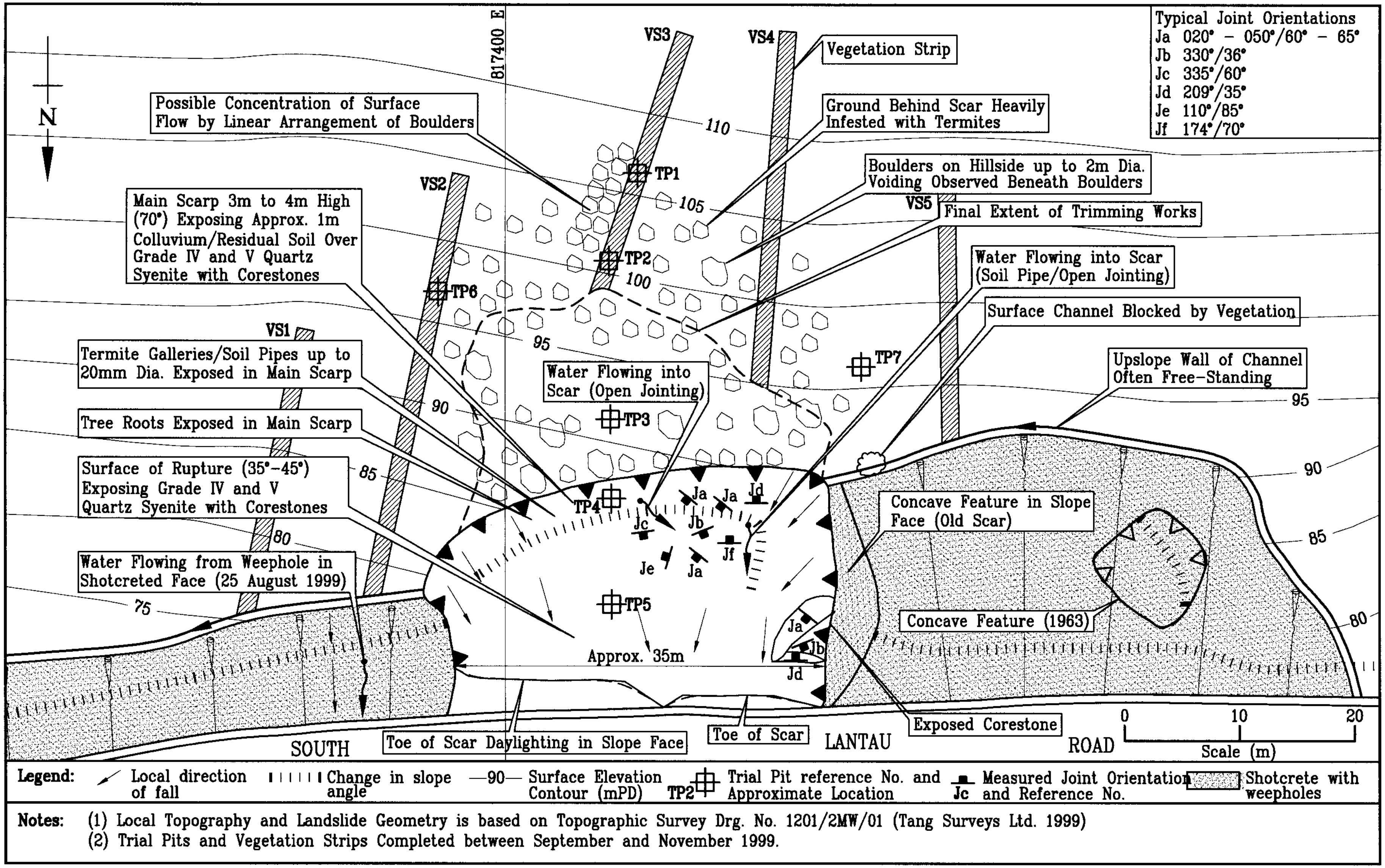
Figure 4 - Section A - A through the Landslide



Legend: FILL Loose material/debris remaining in scar following trimming works CDS Completely Decomposed Syenite HDS Highly Decomposed Syenite
TP3 (7m E) Trial pit reference No., offset and direction ▽ Observed water level during the GI works

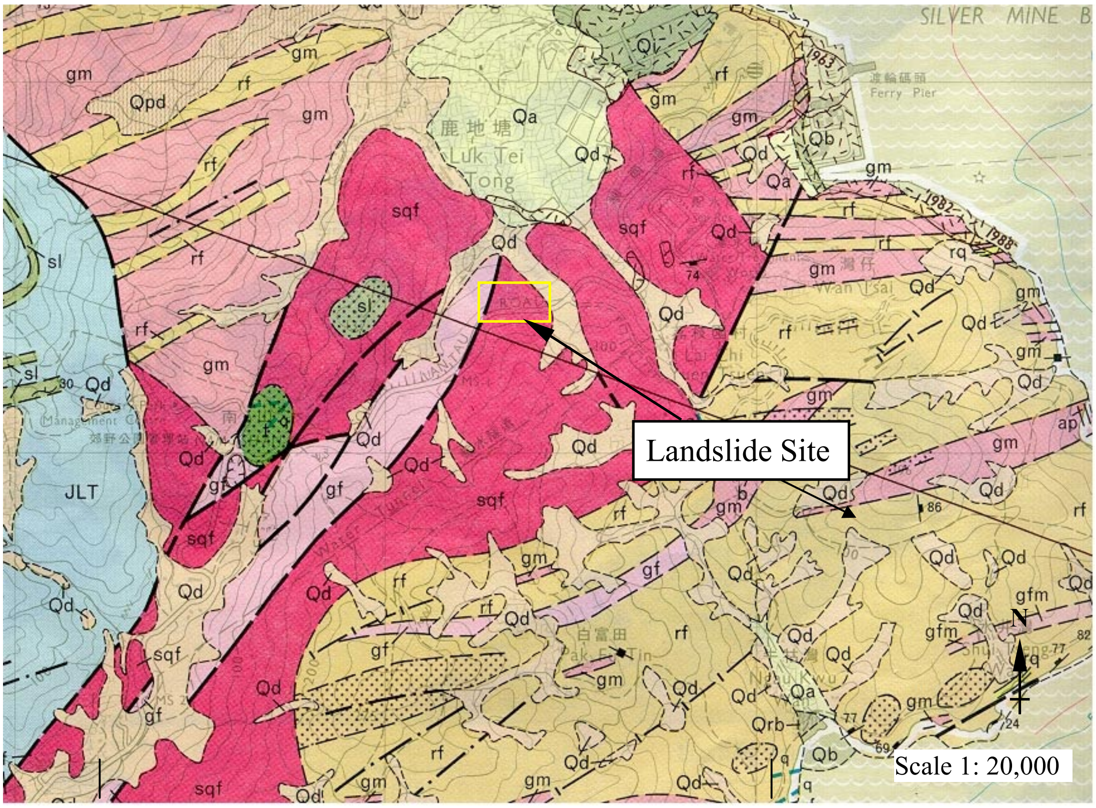
Notes:
(1) Section geometry is based on Topographic Survey Drg. No. 1201/2MW/01 (Tang Surveys Ltd, 1999).
(2) Section is taken along Hong Kong Metric Gridline 817395E.
(3) The location of Section B-B is indicated on Figure 3.
(4) Trial pit information indicated on section is based on the ground investigation carried out in 1999. Refer to Figure 6 for trial pit locations.

Figure 5 - Section B - B through the Landslide



Notes: (1) Local Topography and Landslide Geometry is based on Topographic Survey Drg. No. 1201/2MW/01 (Tang Surveys Ltd. 1999)
(2) Trial Pits and Vegetation Strips Completed between September and November 1999.

Figure 6 - Mapping of the Landslide Scar



LEGEND:

SUPERFICIAL GEOLOGY

▨	Fill, sanitary fill (Qfs)
Qa	Alluvium
Qi	Estuarine deposits
Qd	Debris flow deposits (Pleistocene and Holocene)
Qpd	Debris flow deposits (Pleistocene)

SOLID GEOLOGY

sl	Siltstone
t	Undifferentiated tuff and tuffite
gf	Fine-grained granite; < 2 mm
gm	Medium-grained granite; 2-6 mm
sqf	**Fine-grained quartz syenite, < 2 mm**
rf	Feldsparphyric rhyolite
▨	Metamorphosed

GEOLOGICAL LINES

- - - - - - - -	Geological boundary, superficial deposit
———— — —*	Geological boundary, solid rock
——┴—— —*	Fault (crossmark indicates downthrow side)
—·—·—	Photogeological lineament

(* Broken lines on map face denote uncertainty)

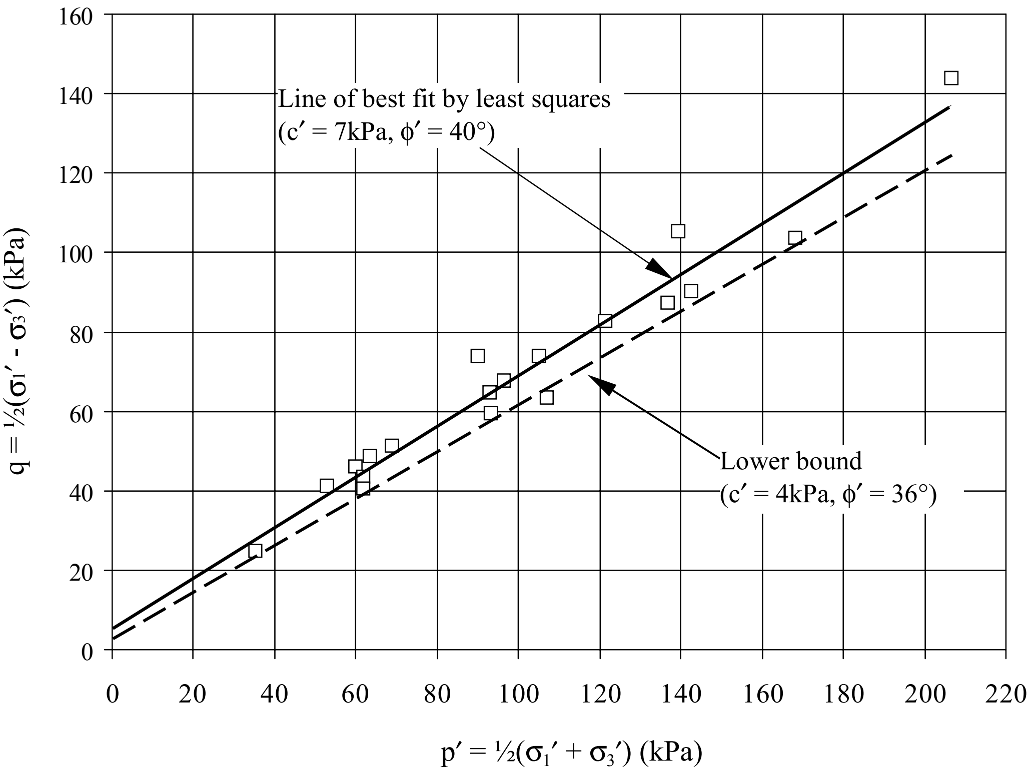
STRUCTURAL SYMBOLS

┴ 20	Inclined bedding
▬ 20	Inclined jointing
▲ 20	Inclined metamorphic foliation
—■—	Vertical jointing

Notes: (1) Geology relevant to study area shown bold.

(2) Extract from Sheet 10 of the Hong Kong Geological Survey 1 : 20,000 Scale Map Series HGM20 (GEO, 1991).

Figure 7 – Solid and Superficial Geology of the Landslide Site



Legend:

c′ Effective cohesion

σ_1' Major principal effective stress

σ_3' Minor principal effective stress

ϕ′ Effective angle of shearing resistance

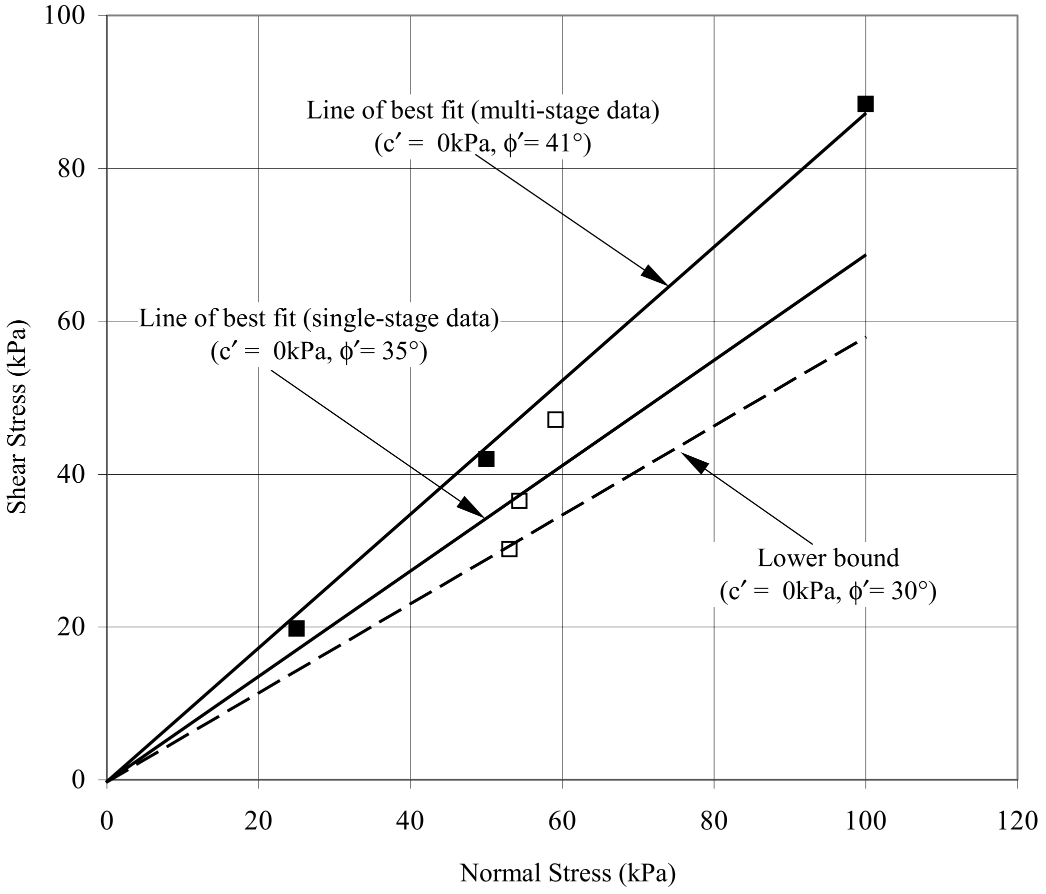
☐ Multi-stage triaxial test results

Notes:

(1) Triaxial compression test results correspond to those at the point of maximum deviator stress, i.e. maximum value of $\sigma_1' - \sigma_3'$.

(2) Only test results corresponding to p′ up to 200 kPa have been included.

Figure 8 – Results of Triaxial Compression Testing



Legend :	c′	Effective cohesion	ϕ′	Effective angle of shearing resistance
	■	Multi-stage direct shear test results	□	Single-stage direct shear test results along relic joint surfaces

Notes :

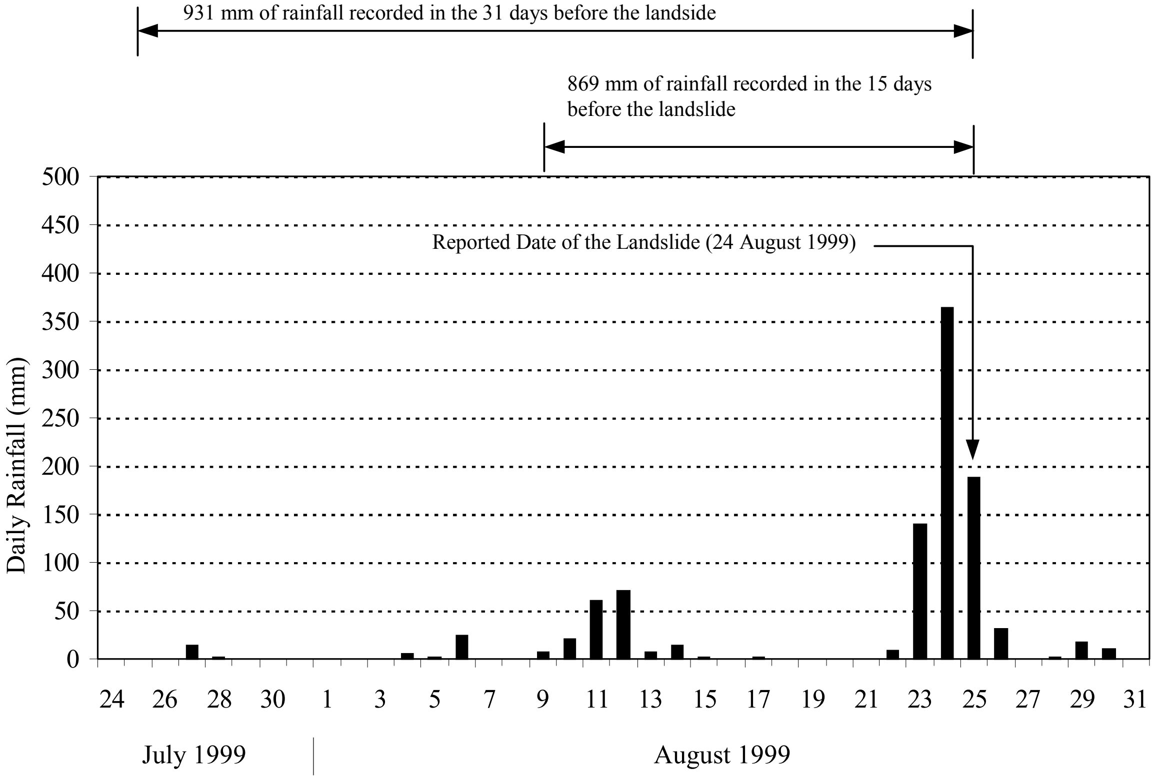
(1) Direct shear box test results shown in this figure correspond to those at the point of peak shear stress.

(2) Multi-stage test specimen horizontally sheared using conventional shear box apparatus.

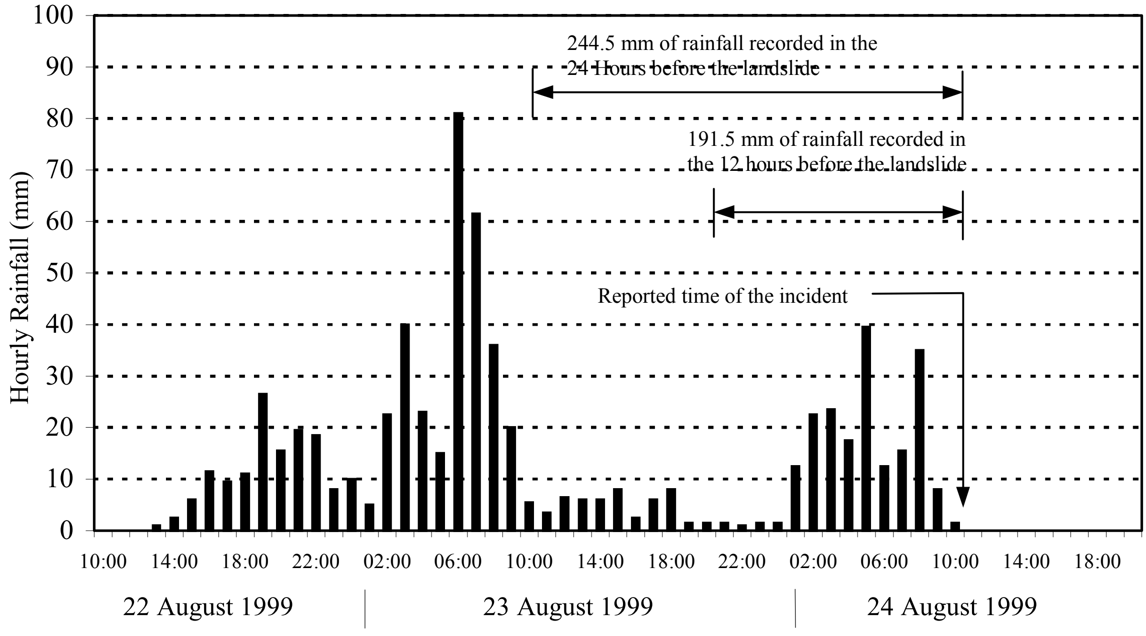
(3) Single-stage test specimen horizontally sheared along relic joint surface using modified shear box apparatus (specimen mounted in gypsum).

(4) Lines of best fit and lower bound line determined with horizontal and vertical intercept set to zero.

Figure 9 - Results of Direct Shear Box Testing

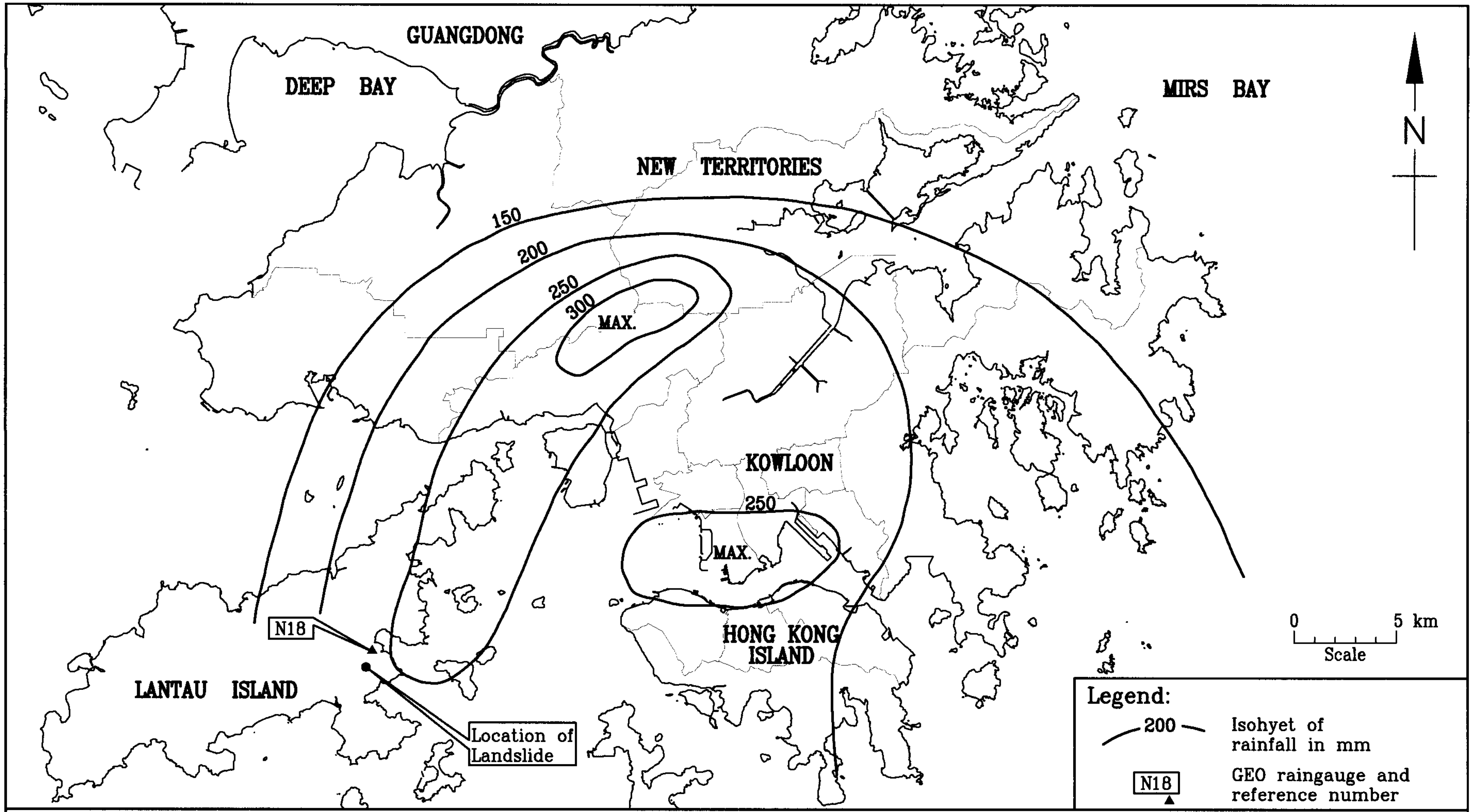


(a) Daily Rainfall Recorded between 24 July and 31 August 1999



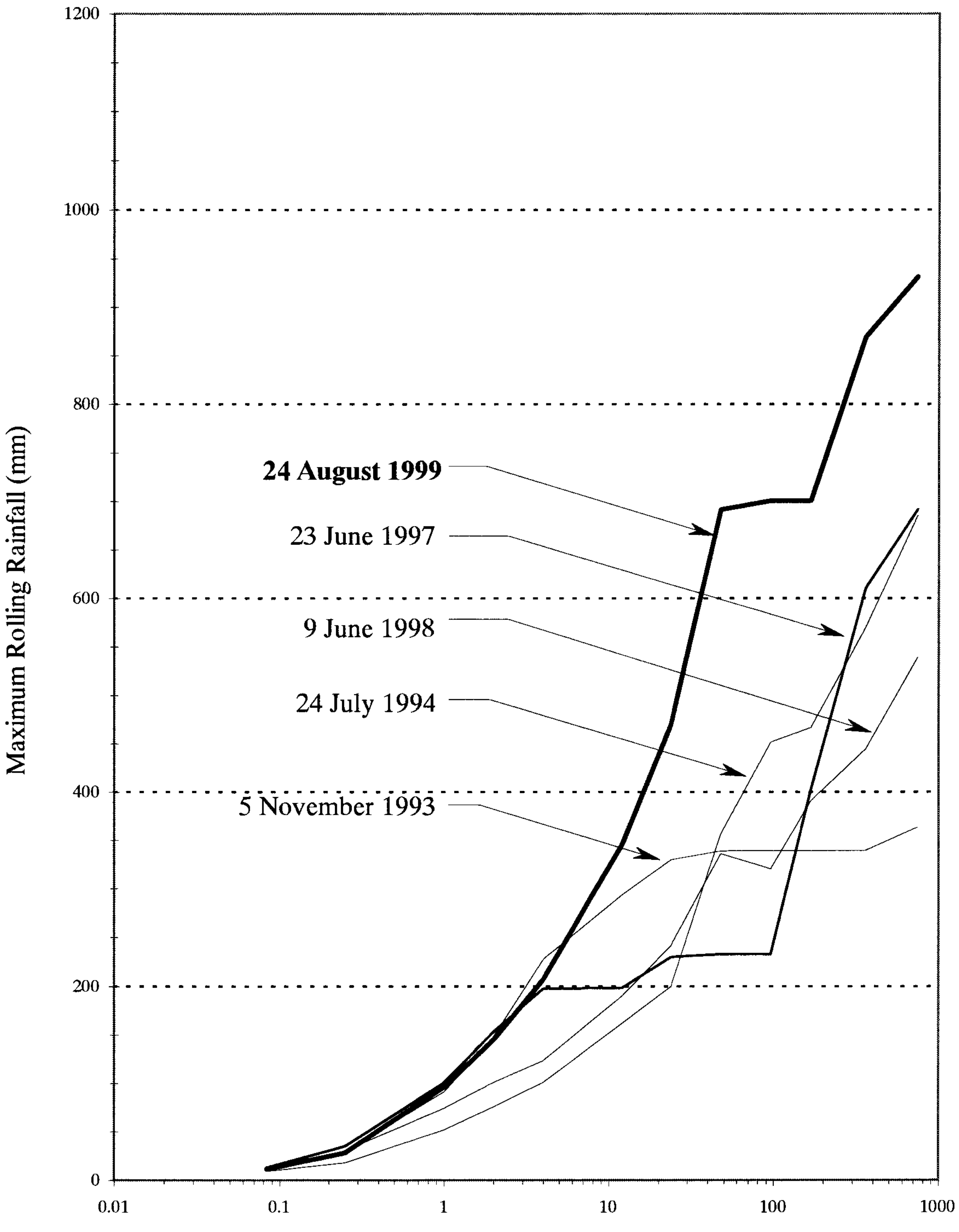
(b) Hourly Rainfall Recorded between 10:00 hours on 22 August and 20:00 hours on 24 August 1999

Figure 10 - Rainfall Recorded at GEO Raingauge No. N18



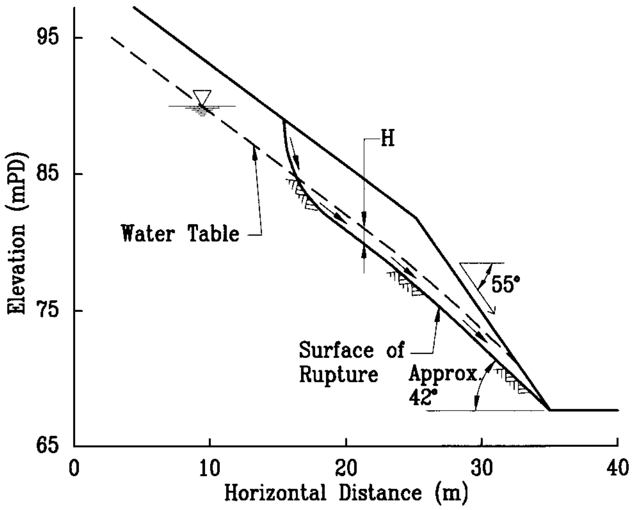
Note: (1) Isohyets of rainfall for the period from 09:30 on 23 August 1999 until 09:30 on 24 August 1999.

Figure 11 - Rainfall Distribution for the 24-Hour Period Preceding the Landslide of 24 August 1999

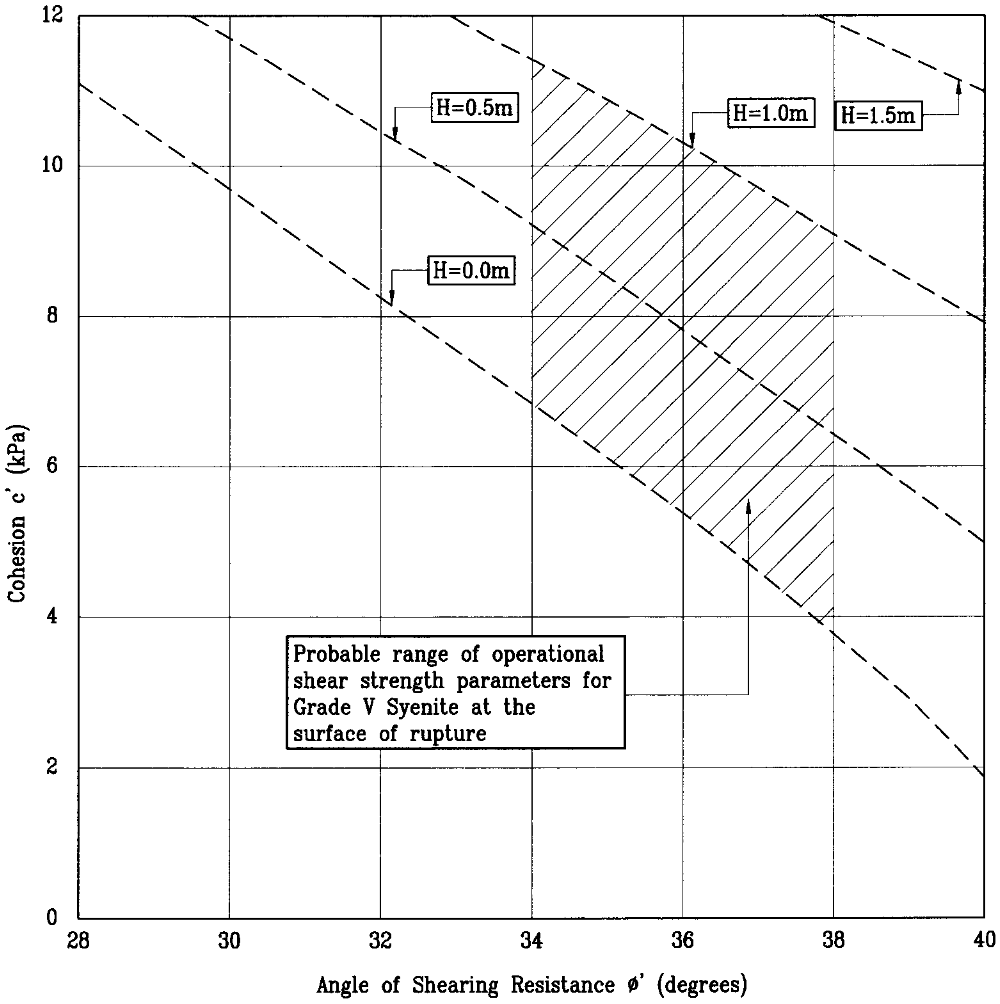


Note : Rainfall data are 5-minute statistics from GEO raingauge No. N18

Figure 12 - Maximum Rolling Rainfall Preceding the Landslide of 24 August 1999 and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. N18



Idealised Section A – A



Notes: (1) — — — — Factor of Safety Equal to Unity (i.e. Limiting Equilibrium)
(2) Refer to Figure 4 for details of Section A–A.

Figure 13 - Summary of Sensitivity Analyses

LIST OF PLATES

LIST OF PLATES

LIST OF PLATES

Plate 1 – Oblique View of the Landslide Site (Photograph Taken on 25 August 1999)

Plate 2 - Oblique View of the Landslide Site and Natural Hillside above.
Note Change in Vegetation Approximately 30 m above Scar and
Many Exposed Boulders (Photograph Taken on 25 August 1999)

Plate 3 - View South-East across Western Portion of Slope No. 10SW-C/C20 on 26 April 1995. 1999 Landslide Site Indicated. Note Vegetation Growing through Hard Surfacing (Photograph Taken by FMR Consultant)

Plate 4 - General View of the Landslide Scar (Photograph Taken on 25 August 1999)

Plate 5 - View East along South Lantau Road towards Debris Mound. Note Boulder and Cobble Content of Debris and Angle of Repose (20° to 25°) (Photograph Taken on 25 August 1999)

Plate 6 - View West along South Lantau Road. Debris Reposed at Approximately 20° to 25° (Photograph Taken on 25 August 1999)

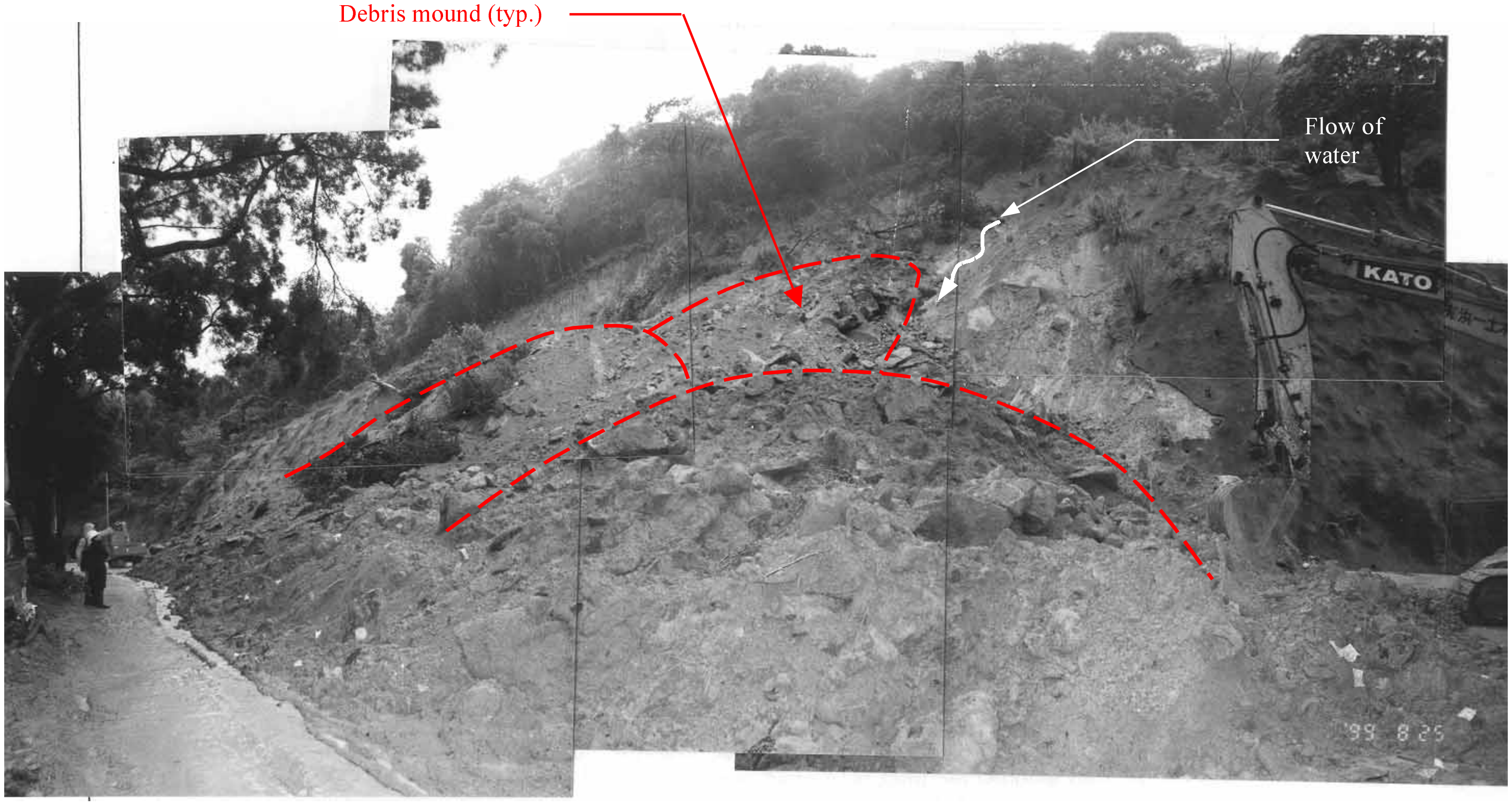


Plate 7 – General View South-East towards Landslide Scar. Note Form of Debris as a Number of Semi-Discrete Mounds (Indicated). Flow of Water Into Scar at Location Indicated. South Lantau Road Footpath Has Been Cleared of Debris (Photograph Taken on 25 August 1999)

Plate 8 - Vehicle Impacted by Landslide Debris. Bus-Stop Shelter Damaged by Landslide Visible in Foreground (Photograph Taken on 25 August 1999)

Plate 9 – View South towards Landslide Scar. Note Semi-Discrete Debris Mounds Comprising Predominantly Reddish-Brown Saprolite (Photograph Taken on 25 August 1999)

Water flowing from weephole

Plate 10 - Intact Portion of Shotcreted Slope beyond Eastern Flank of Scar.
Note Muddy Water Flowing from Weephole (Indicated)
(Photograph Taken on 25 August 1999)

Plate 11 – View South-East towards Upper Portion of Landslide Scar and Main Scarp. Note Adverse Joint Surfaces on Corestone Exposed beneath Shotcrete on Right of Frame. Note also Joint Set Dipping into Slope Face Providing Release Plane. Flow of Water into Scar at Location Indicated (Photograph Taken on 25 August 1999)

Plate 12 – View South towards Shotcreted Landslide Scar. Note Continued Seepage of Water from Weepholes and Horizontal Drains (Photograph Taken on 20 September 1999)

Plate 13 - Close-up of Debris at Eastern End of Mound Showing Broken Sections of U-Channel and Hard Surfacing (Photograph Taken on 25 August 1999)

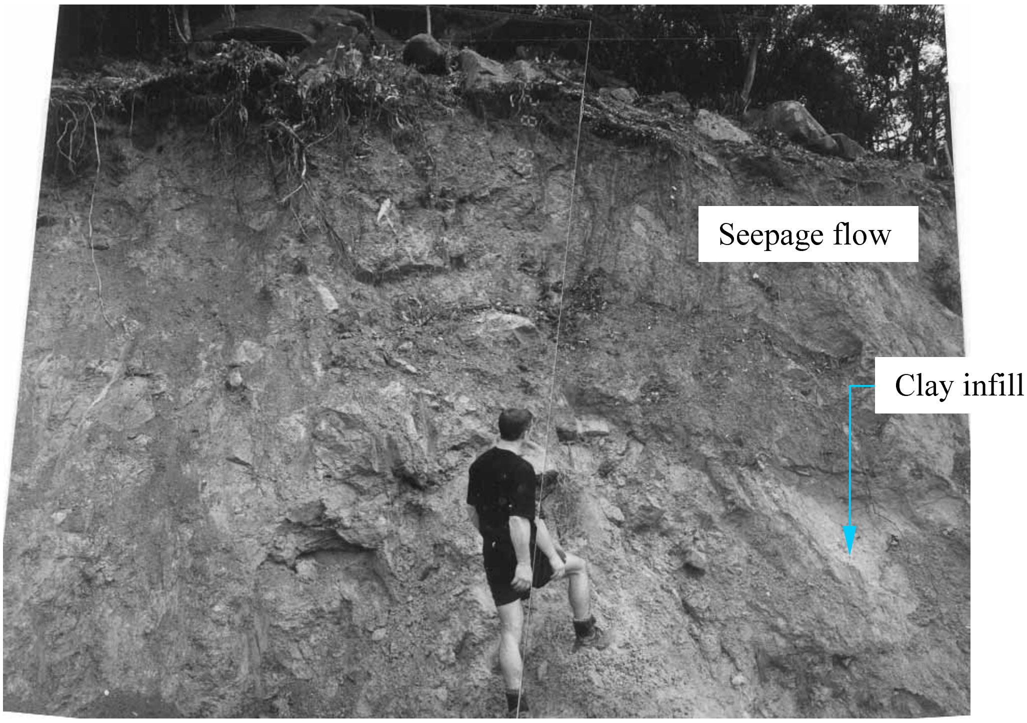


Plate 14 - View of Central Portion of Main Scarp. Seepage at Location Indicated. Clay Infilled Joint Visible on Right of Frame (Photograph Taken on 29 August 1999)

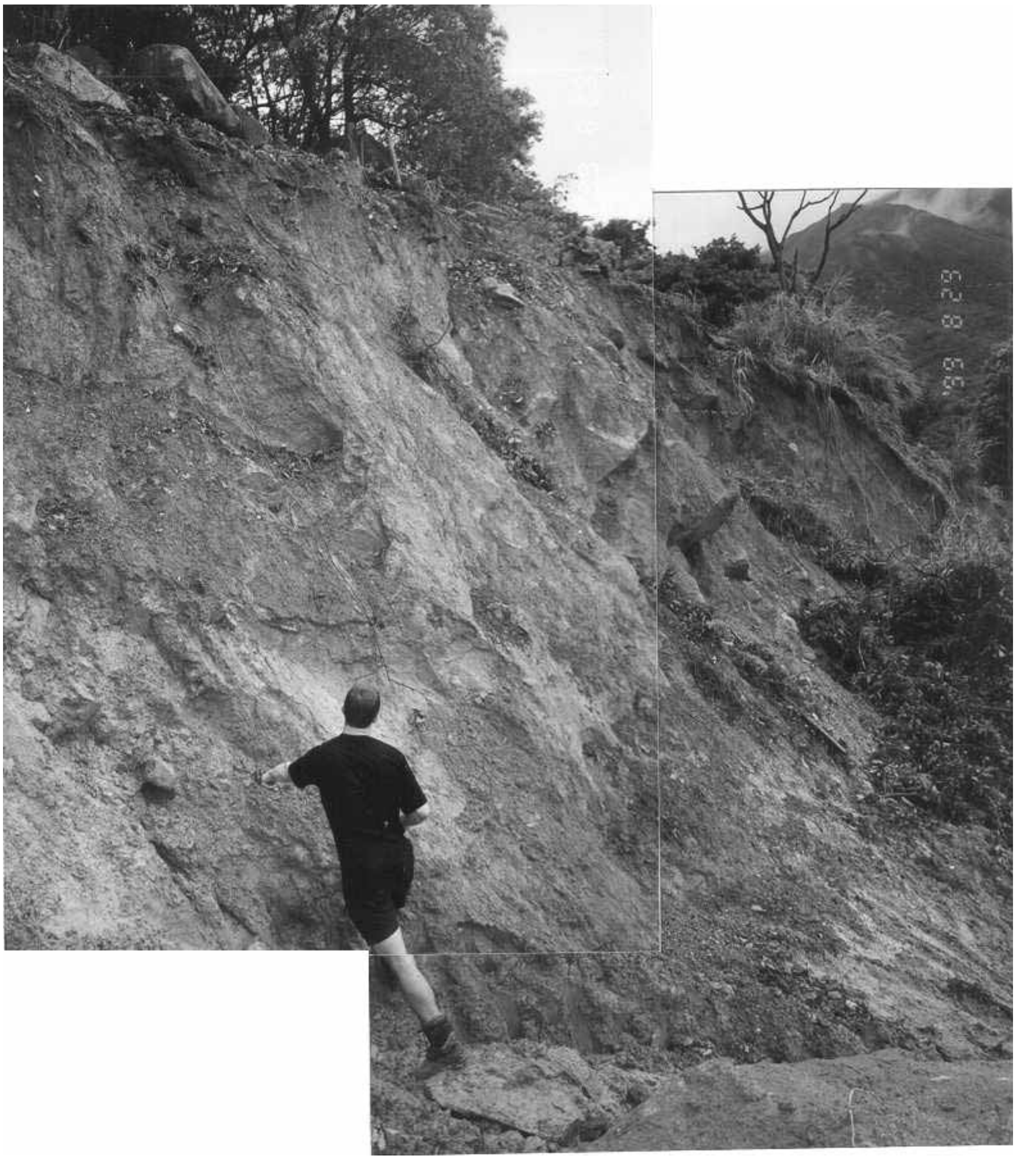


Plate 15 - View of Western Portion of Main Scarp. Adverse Relic Jointing and Light-Brown Clay Infill on Exposed Joints Visible (Photograph Taken on 29 August 1999)

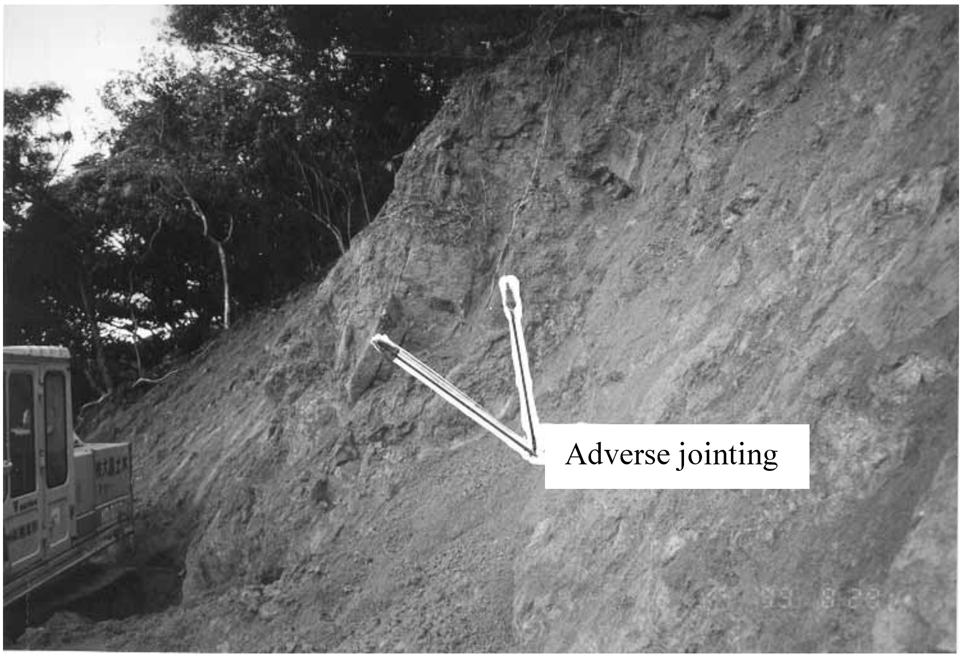


Plate 16 – View of Eastern Portion of Trimmed Main Scarp. Steep Adverse Joint Surfaces Indicated (Photograph Taken on 29 August 1999)

Plate 17 - Close-up of Clay Infilled Joint Exposed in Main Scarp (Photograph Taken on 29 August 1999)

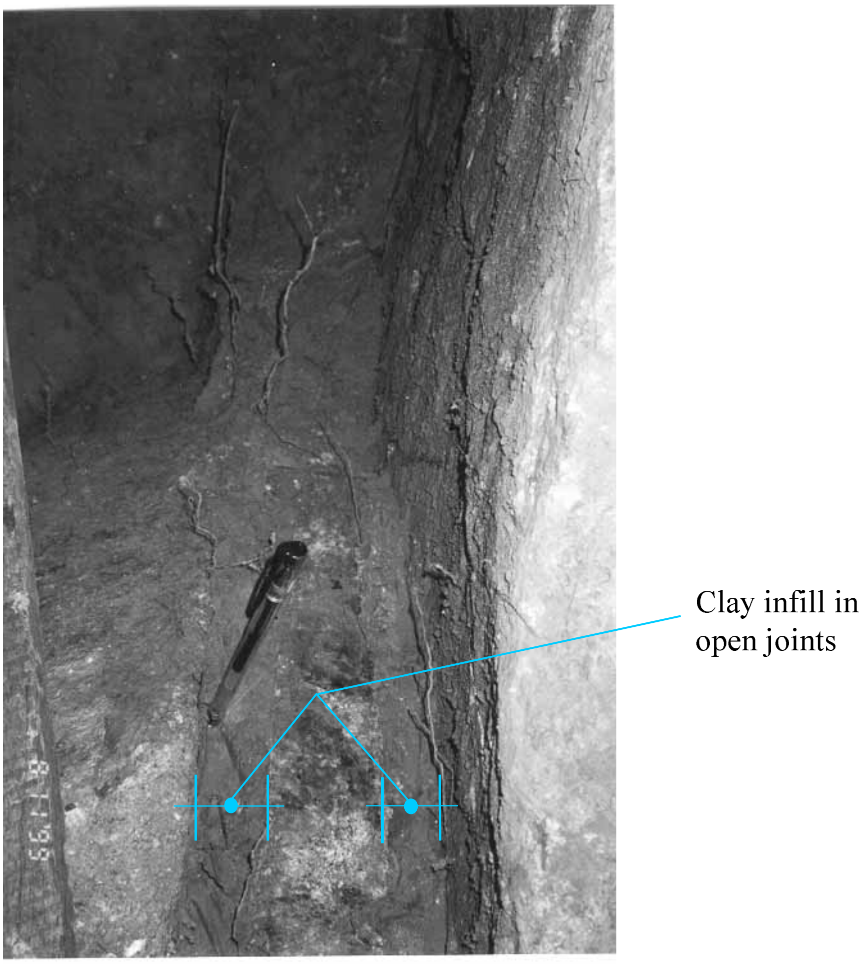


Plate 18 - Trial Pit TP2: Example of Clay Infill in Open Relic Joints (Possible Tension Features), Grade IV Quartz Syenite (Photograph Taken on 8 November 1999)

Plate 19 - Grade III/IV Quartz Syenite Exposed in Trial Pit TP2 with Closely to Very Closely Spaced, Saprolite Infilled Joints (Possible Tension Features) (Photograph Taken on 29 October 1999)

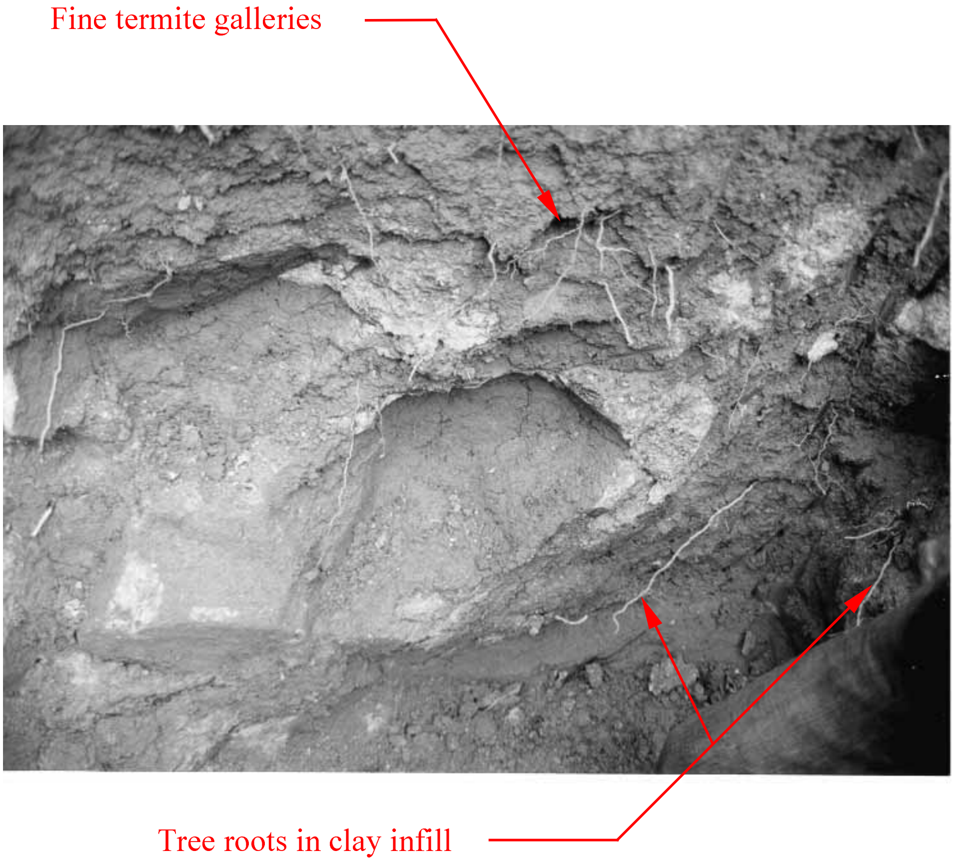


Plate 20 - Trial Pit TP5: Example of Clay Infill Surrounding Corestones in Weathered Rock Mass. Note also Fine Termite Galleries and Penetration of Tree Roots (Indicated) (Photograph Taken on 29 October 1999)

Plate 21 - Trial Pit TP4: Example of Light Brown Clay Infill Surrounding Corestones in Weathered Rock Mass (Indicated) (Photograph Taken on 29 October 1999)

Plate 22 - Vegetation Blocking Crest U-Channel beyond Western Flank of Scar. Fall of Channel is away from Camera (Photograph Taken on 29 August 1999)

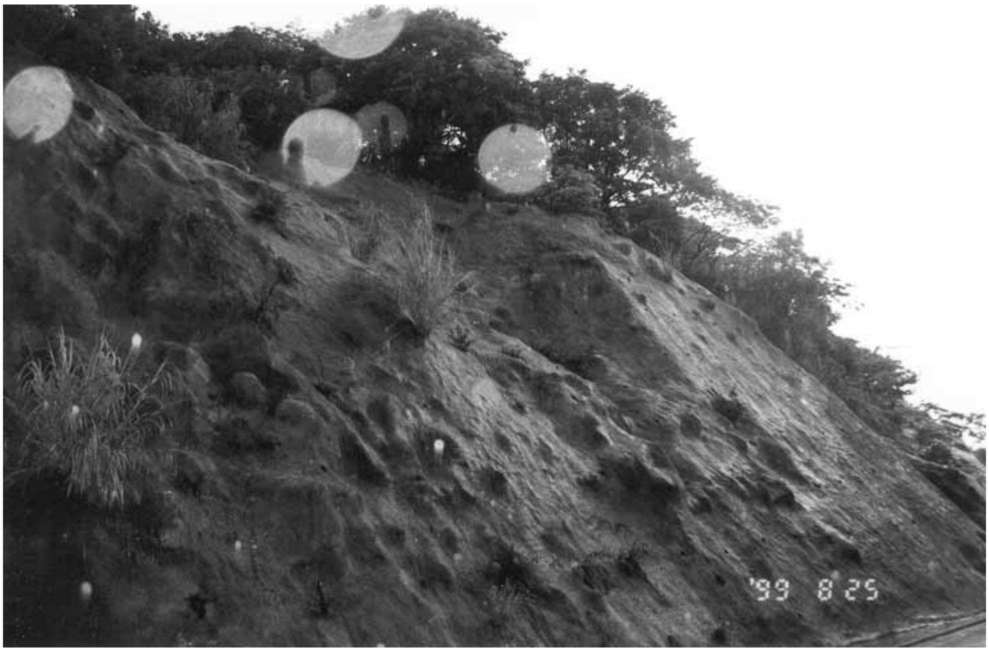


Plate 23 - View South-West towards Pre-Existing Wedge-Shaped Landslide Scar in Slope West of Present Failure. Note also Boulders and Cobbles Visible in Shotcreted Slope Face (Photograph Taken on 25 August 1999)

Plate 24 - View South-East along Western Flank of Scar. Adverse Joint Orientations Coincident with Previous Scar Visible in Centre-Right of Frame (Photograph Taken on 29 August 1999)

Plate 25 - View of Trimming Works in Eastern Portion of Scar. Note Large Number of Boulders Exposed on Hillside above (Photograph Taken on 29 August 1999)

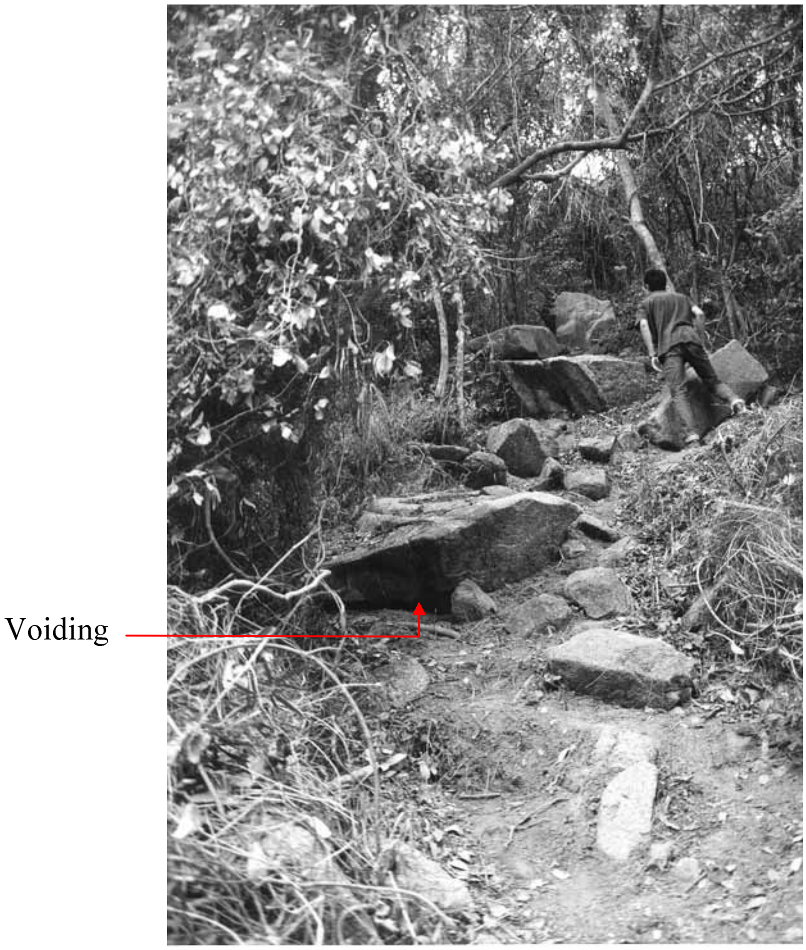


Plate 26 - Surface Strip SS2: Arrangement of Boulders and Cobbles on Natural Hillside above Landslide Scar. Note Void beneath Boulder in Foreground (Indicated) (Photograph Taken on 29 October 1999)

Plate 27 - Example of Erosion Channel around Boulders on Hillside above Scar (Photograph Taken on 20 November 1999)

Plate 28 - Voiding beneath Exposed Boulder/Corestone on Hillside behind Scar (Photograph Taken on 1 November 1999)

Plate 29 - Exposed Boulders on Natural Hillside above Landslide Scar. Possible Channel Indicated (Photograph Taken on 29 October 1999)

Plate 30 - Concentration of Termite Galleries/Erosion Pipes along Interface of Grade V Material with Underlying Corestone (Bedrock?) in Central Portion of Main Scarp (Photograph Taken on 29 August 1999)

Plate 31 - Example of Termite Gallery/Erosion Pipe Exposed in Grade V Quartz Syenite (Photograph Taken on 29 October 1999)

Plate 32 - Trial Pit TP1: Example of Clay Infill in Open Relic Joints with Large Termite Gallery/Erosion Pipe Exposed (Photograph Taken on 9 November 1999)

Plate 33 - Trial Pit TP4: Seepage Ponding in Base of Pit (Photograph Taken on 29 October 1999)

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The followings comprise the detailed observations made from the aerial photographs studied. A list of aerial photographs used in this study is given in Section A.2.

YEAR **OBSERVATIONS**

1963 South Lantau Road is constructed mostly in cut across the nose of a broad north-trending spur ridge. The bus bay is present in the road geometry. Fresh, apparently loose-tipped fill is present along the northern edge of the road, suggesting recent earthworks. However, the cut slopes along the southern edge of the road appear darker in colour (i.e. weathered). This may indicate recent road works (e.g. road widening/upgrading). The natural hillside above and below the road is vegetated with brush, grass and small trees, and is strewn with large boulders. A vegetation line is present on the spur 30 m to 70 m above the road, with darker, higher brush downslope of the line and lighter, lower brush and grass above.

Old landslide deposits may be present below South Lantau Road to the southwest and also to the east of the concerned area. The sources for these deposits are located on the flanks of the spur ridge above South Lantau Road. NTLI 10SWC L01D is mapped on the flank of the spur ridge to the south-east and debris flow deposits have been mapped in this area by the Hong Kong Geological Survey (GEO, 1991). Colluvial deposits are interpreted locally on slopes and in swales above and below the South Lantau Road. A strong NNW topographic lineament traverses the eastern part of the concerned area and is likely associated with a fault shown on the geological map.

The cut slope which now incorporates slope Nos. 10SW-C/C20, -/C116, -/C117, -/C118 and -/C119 is clearly visible and comprises a single cut face (approx. 160 m long), separated from adjacent slopes by natural drainage lines. The typical slope formation in this location, as with adjacent slopes, comprises a steep cutting with a surface drainage channel located a short distance upslope of the crest. The slope faces may have a chunam surfacing. Over the western 50 m of the slope, the crest channel follows an irregular path and is set back markedly, relative to the crest line of the cutting, when compared to the eastern portion. The ground between the crest channel and the slope crest is vegetated and boulders are visible.

A large irregular bowl-shaped depression (possible landslide scar) is present in the slope face between 20 m and 60 m from the western end (present landslide location) and extends further up the hillside than the adjacent cut slope crest. A thin black line extends from a point downslope of the surface channel to the slope toe, roughly bisecting the depression. The line is possibly seepage because it does not appear to have relief and is probably not a surface drain. A second (wedge-shaped) concave feature is present between about 10 m and 15 m from the western end of the slope. Both features appear lighter than the surrounding slope face and hillside. It is not obvious whether these areas expose the ground surface or have recently had a hard surfacing applied.

1968 Slope No. 10SW-C/C21 west of the concerned slope and the western 10 m of the concerned slope are visible and are at least partially covered by a hard surfacing. Vegetation covers most of the fill slopes below South Lantau Road. Trees along outside edge of road are well established. The vegetation line on the hillside above South Lantau Road is less distinct.

The majority of the concerned slope is in partial shadow, which provides emphasis in relief to the large depression (1963). The extent or presence of hard surfacing is unclear, except at the western end. The black line present on the slope face in 1963 is not visually distinct, although darker features are present on the slope face in the relevant area. The line of the crest channel is visible, but is more overgrown with vegetation.

1973 No significant changes from 1968. Two zones of exposed fill remain below South Lantau Road opposite the concerned slope. The fill slopes below the road to the west remain only partially vegetated, suggesting continuing erosion in these areas.

The large depression and the adjacent concave, wedge-shaped area on the concerned slope appear not to be covered in these photographs. The western half of the large depression appears to be slightly more concave, possibly resulting from erosion.

1974 No significant changes from 1973. Vegetation in the vicinity of the concerned slope appears to be well established. No exposed fill slopes are visible below South Lantau Road except to the west. The concerned slope is in shadow.

1979 No significant changes from 1974. The Lai Chi Yuen road joining South Lantau Road and defining the eastern extent of the concerned slope has been recently constructed. The vegetation line in the hillside above South Lantau Road is distinct. There are possible erosion features in the large depression in the concerned slope.

1982 No significant changes from 1979. The vegetation line in the hillside above South Lantau Road is lower on the slope to the southeast. South Lantau Road has been patched in many areas since 1979. The concerned slope is clearly visible. The slope is possibly shotcreted. However, many boulders remain on the slope face. There are darker streaks on the slope face in the large depression suggesting seepage. Vegetation appears to be present on the slope face to the east.

October 1984 No significant changes since 1982. The western 20 m of the concerned slope (wedge area) and the adjacent drainage channel are lighter than adjacent slopes, and appear to have been recently re-surfaced with chunam or shotcrete. The eastern portion of the concerned slope is in partial shadow. Lighter zones on the slope face located 40 m to 50 m from the eastern end can also be seen, suggesting additional slope works in this area.

November 1984 Similar to October 1984 photographs. The concerned slope is in shadow.

1991 No significant changes visible since 1984. The cut slope is in shadow. The trees along the road edge obscure much of the road.

1992 First colour photographs. Three obvious and very recent scars are visible in the cut slopes above South Lantau Road, two located in the concerned slope, the third located in slope No. 10SW-C/C21 to the west. The larger of the two scars in the concerned slope is located at the large depression (1963) and is estimated to be approximately 15 m wide and extends to the crest drain. Shotcrete is visible through the soil on the slope face and it is difficult to define accurately the failed areas. There appears to be a spoon-shaped feature (source area?) in the upper central portion of the scar, with a shallow channel extending to the slope toe, and possibly a second scar at the slope toe. Debris blocks the west-bound lane of South Lantau Road.

The smaller scar is located approximately 45 m from the eastern end of the concerned slope (the area re-surfaced in 1984) and is partially obscured by trees. It appears to be very shallow. There does not appear to be any debris from this failure on South Lantau Road.

The scar in slope No. 10SW-C/C21 is located about 80 m from the eastern extent of the feature and measures about 20 m in width at the toe, becoming narrower towards the slope crest. Debris completely blocks the west-bound lane of South Lantau Road. Clearance works appear to be under way.

November 1993 The scar present on slope No. 10SW-C/C21 southwest of the cut slope in 1992 appears to have been repaired, and the slope face appears to have been re-surfaced over a distance of about 40 m to the southwest. A recent landslide scar about 15 m wide is present approximately 20 m from the eastern end of the feature. Below South Lantau Road at this location, a recent landslide scar is present which undermines the outside edge (shoulder) of the road. Debris from this failure extends down the colluvium-filled swale to the valley below.

The two scars present on the cut slope in 1992 have been repaired. The western side of the larger scar is concave in relief. The eastern side is slightly convex and three lines of seepage radiate from a point high on the slope face at this location. A thin strip lighter than the surrounding area is visible to the east of this scar (surface strip?).

December 1993 The recent landslide scar present on slope No. 10SW-C/C21 in the November 1993 photographs is in partial shadow and not clearly visible, but is likely under repair. A retaining wall structure and fill slope are under construction within the landslide scar below South Lantau Road.

The seepage lines observed on the repaired scar in the November 1993 photographs are no longer visible.

1994 The eastern portion of slope No. 10SW-C/C21 is clearly visible. Slope works (re-surfacing) have been extended to the east as far as the drainage channel separating this feature from the concerned slope and the entire slope has been re-surfaced in this area. The portion of the slope southwest of the 1992 failure in this slope is clearly visible and appears to have been re-surfaced at the same time as the rest of this slope in 1993. The repair works below South Lantau Road appear to be essentially completed as a concrete gravity wall supporting a concrete apron adjacent to the road and a fill slope below (slope No. 10SW-C/FR32). The fill slope has a bench at the crest and there appears to be a break in slope angle mid-way down the feature. The slope face appears to be untrimmed.

The upper portion of the western end of the cut slope has been re-surfaced and the crest drainage channel above has been reconstructed at least as far as the larger of the two 1992 scars. Within this scar, dark streaks are visible in the western (concave) portion, while light streaks are visible on the eastern (convex) portion, suggesting continued seepage at these locations. The portion of the cut slope between about 50 m and 65 m from the eastern extent has been re-surfaced and extended upslope, possibly to the crest drainage channel. The adjacent slope to the east, repaired in 1993, may have also been re-surfaced.

1995 No significant changes since 1994. The cut slopes above South Lantau Road are in partial shadow. Slope No. 10SW-C/FR32 and the debris trail below are partially revegetated.

1996 Slope works (re-surfacing) have been carried out on a 20 m long section of slope No. 10SW-C/C21 west of the portion re-surfaced in 1993, as well as a 15 m long section immediately west of the 1993 scar. Slope No. 10SW-C/FR32 is mostly re-vegetated.

Most of the cut slope appears to have been cleared of unplanned vegetation and portions immediately east and west of the larger 1992 scar have been re-surfaced, with the hard surfacing extending up to the crest drainage channel. The interfaces between the separate applications of hard surfacing appear to provide the present feature boundaries (slopes Nos. 10SW-C/C20, -/C116, -/C117, -/C118 & -/C119) indicated by the GEO Landslide Database, although the crest line of the features is not consistent with that indicated by the photographic record.

August 1998 No significant changes since 1996.

November 1998 Higher altitude photographs. Hazy weather conditions. No significant changes visible since 1996.

A.2 LIST OF AERIAL PHOTOGRAPHS

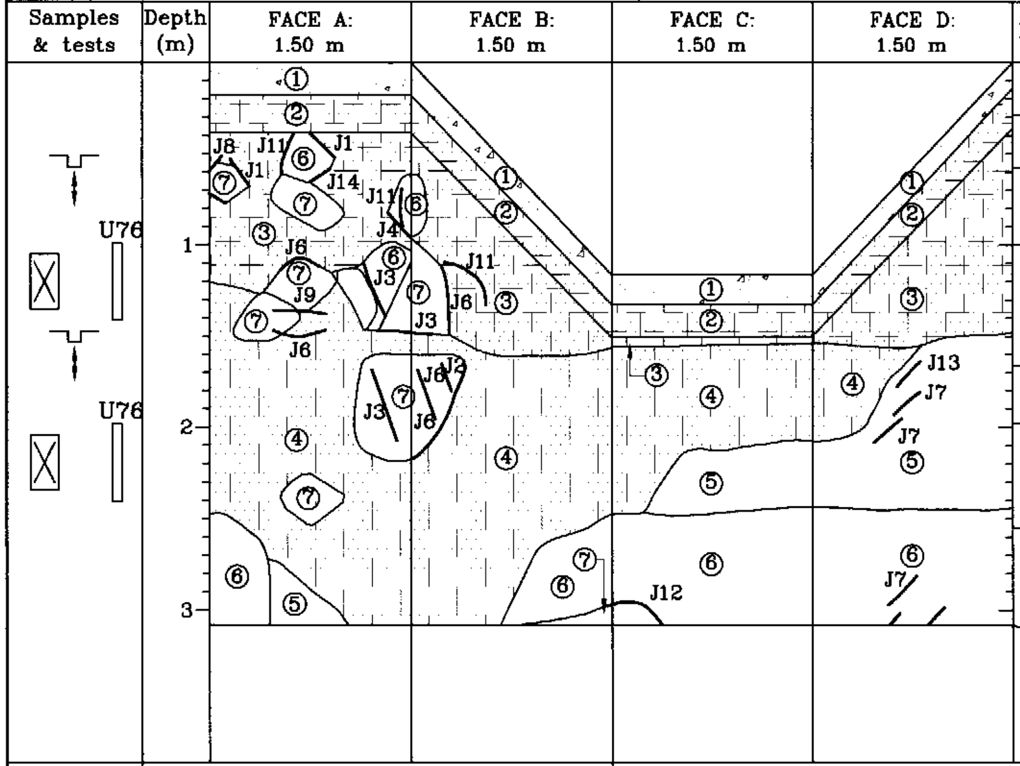
A list of aerial photographs used in this API study is presented below.

YEAR	PHOTOGRAPHS
1963	Y05969 Y05970
1968	Y13941 Y13942
1973	3807 3808 3809
1974	10280 18281
1979	26663 26664
1982	42865 42866 4286
3.10.1984	56147 56148 56149
22.11.1984	57311 57312 57313
1991	A29126 A29127 A29128
1992	CN2986 CN2987 CN2988
9.11.1993	A36243 A36244 A36245
5.12.1993	CN5294 CN5295 CN5296
1994	CN9114 CN9115
1995	CN11508 CN11509
1996	A43481 A43482 A43483
14.8.1998	CN20618 CN20619 CN20620
10.11.1998	CN22054 CN22055 CN22056

APPENDIX B

TRIAL PIT LOGS

Fugro Maunsell Scott Wilson Joint Venture Agreement No. CE 101/98 The 1999 Landslide Investigation Consultancy Detailed Study No. 7 South Lantau Road near Lai Chi Yuen, Lantau	TRIAL PIT RECORD		Sheet 1 of 2
	TRIAL PIT No. TP1	EXCAVATION DATE: from 22/10/1999 BACKFILL DATE: 10/11/1999	
	CO-ORDINATES 817392.025 E , 813335.918 N GROUND LEVEL 104.98 mPD	LOGGED BY: JLKS DATE: 9/11/1999 CHECKED BY: ICM DATE: 14/1/1999	

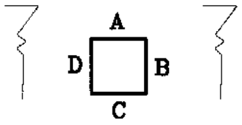


Legend	Grade	Description
1		Medium dense, slightly moist, dark grey, silty gravelly SAND (Top Soil) with many tree roots.
2	V	Extremely weak, slightly moist, dark brown, completely decomposed SYENITE with tree roots (Firm, slightly clayey sandy SILT)
3	V	Extremely weak, moist, dark brown, completely decomposed SYENITE (Firm, clayey sandy SILT) with cobbles/boulders of grade IV/III and grade III materials and many tree roots.
4	V/IV	Extremely weak to weak, slightly moist, brown mottled with reddish-brown and white, completely to highly decomposed SYENITE. (Firm to stiff, sandy SILT) Locally mixed with hard, moist, dark brown silty CLAY (Residual Soil) penetrated by tree roots.
5	IV	Weak, slightly moist, brown mottled with some reddish-brown, grey and white, streaked with black, highly decomposed SYENITE.
6	IV/III	Weak to moderately strong, slightly moist, light yellowish-brown mottled with grey and black, highly to moderately decomposed SYENITE. Surface stained black and coated with soft, moist, dark brown silty CLAY (Residual Soil) penetrated by tree roots.
7	III	Moderately strong, slightly moist, light yellowish-brown spotted with grey and black, moderately decomposed SYENITE. Surface stained black and coated with soft, moist, dark brown silty CLAY (Residual Soil).

Continued to Sheet 2 of 2

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
⊥	UNDISTURBED SAMPLE HORL. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
☒	BLOCK SAMPLE
⊓	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



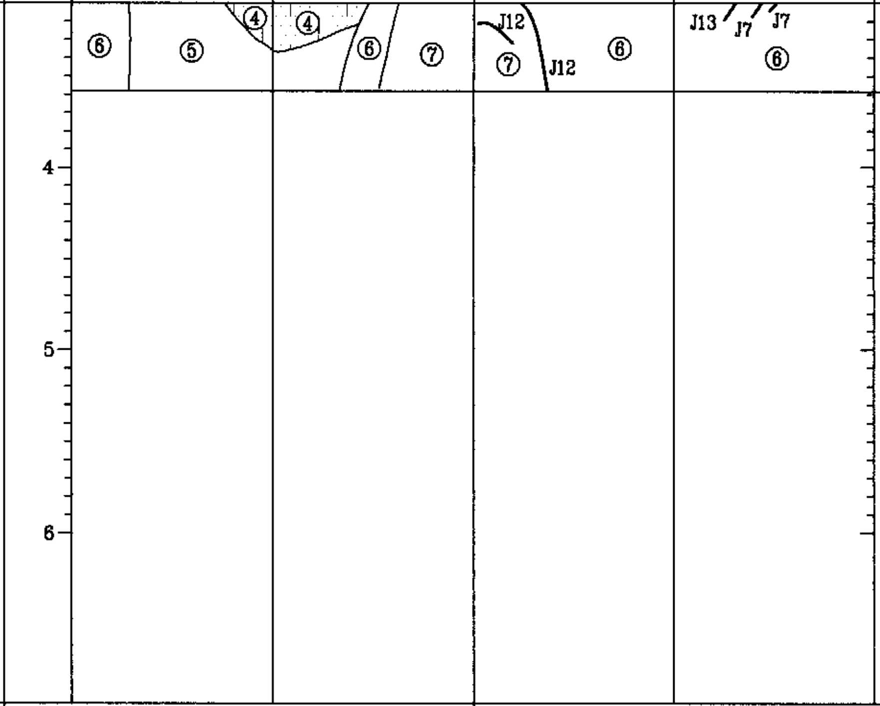
KEY

NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture Agreement No. CE 101/98 The 1999 Landslide Investigation Consultancy Detailed Study No. 7 South Lantau Road near Lai Chi Yuen, Lantau	TRIAL PIT RECORD		Sheet 2 of 2
	TRIAL PIT No. TP1	EXCAVATION DATE: BACKFILL DATE:	from 22/10/1999 10/11/1999
	CO-ORDINATES 817392.025 E , 813335.918 N GROUND LEVEL 104.98 mPD	LOGGED BY: JLKS CHECKED BY: ICM	DATE: 9/11/1999 DATE: 14/1/2000

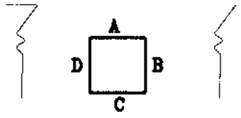
Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description
								Continued from Sheet 1 of 2 Trial pit complete at 3.0m depth (ave.)



Joint Description
J1 = 333 ~ 340/76 ~ 78
J2 = 290/78
J3 = 248 ~ 255/70 ~ 72
J4 = 265/48
J6 = 018 ~ 035/70 ~ 82
J7 = 074 ~ 084/60 ~ 88
J9 = 352 ~ 000/40 ~ 48
with clay infill

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
⇣	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORL. (U100/U78)
▯	UNDISTURBED SAMPLE VERT. (U100/U78)
⊠	BLOCK SAMPLE
⏊	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
The 1999 Landslide Investigation Consultancy
Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

TRIAL PIT RECORD

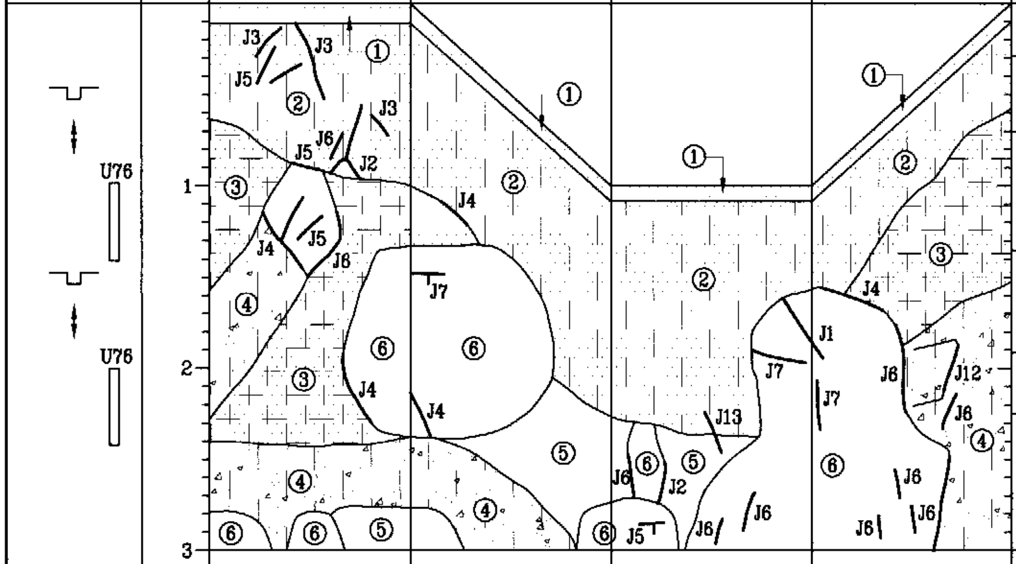
TRIAL PIT No. TP2

CO-ORDINATES 817392.517 E , 813340.751 N
GROUND LEVEL 101.56 mPD

Sheet 1 of 1

EXCAVATION DATE: from 22/10/1999
BACKFILL DATE: 9/11/1999
LOGGED BY: JLKS DATE: 8/11/1999
CHECKED BY: ICM DATE: 14/1/2000

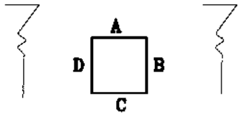
Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m



Legend	Grade	Description
1		Medium dense, slightly moist, dark grey, silty gravelly SAND with tree roots. (Top Soil)
2	V	Extremely weak, slightly moist, dark brown, completely decomposed SYENITE with sub-angular cobbles of grade III material. (Hard, slightly clayey sandy SILT).
3	V/IV	Extremely weak to weak, moist, dark brown mottled with reddish-brown, black and white, completely to highly decomposed SYENITE with boulders of grade III material. (Firm, clayey sandy SILT). Joints infilled with dark brown, silty clay penetrated by tree roots.
4	IV	Weak, slightly moist, dark brown mottled with reddish-brown, black and white, highly decomposed SYENITE. (Stiff, gravelly sandy SILT). Joints surface stained black and infilled with dark brown, silty clay.
5	IV/III	Weak to moderately strong, slightly moist, brown mottled with reddish-brown and grey, highly to moderately decomposed SYENITE.
6	III	Moderately strong, slightly moist, light brown mottled with grey and white, moderately decomposed SYENITE. Joints infilled with dark brown, silty clay penetrated by tree roots. Trial pit complete at 2.5m depth (ave.)

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
—	UNDISTURBED SAMPLE HORL. (U100/U78)
▯	UNDISTURBED SAMPLE VERT. (U100/U78)
⊠	BLOCK SAMPLE
┬	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

J1 = 320 ~ 335/80 ~ 82 clay
J2 = 282 ~ 286/70 ~ 82 black, clay
J3 = 209 ~ 236/60 ~ 80 black, clay
J4 = 269 ~ 292/54 ~ 70 white & black, clay
J5 = 173 ~ 166/42 ~ 62 clay
J6 = 025 ~ 045/82 ~ 88 white & black, clay
J7 = 052 ~ 068/65 ~ 82 black, clay

Fugro Maunsell Scott Wilson Joint Venture
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South Lantau Road near Lai Chi Yuen, Lantau

TRIAL PIT RECORD

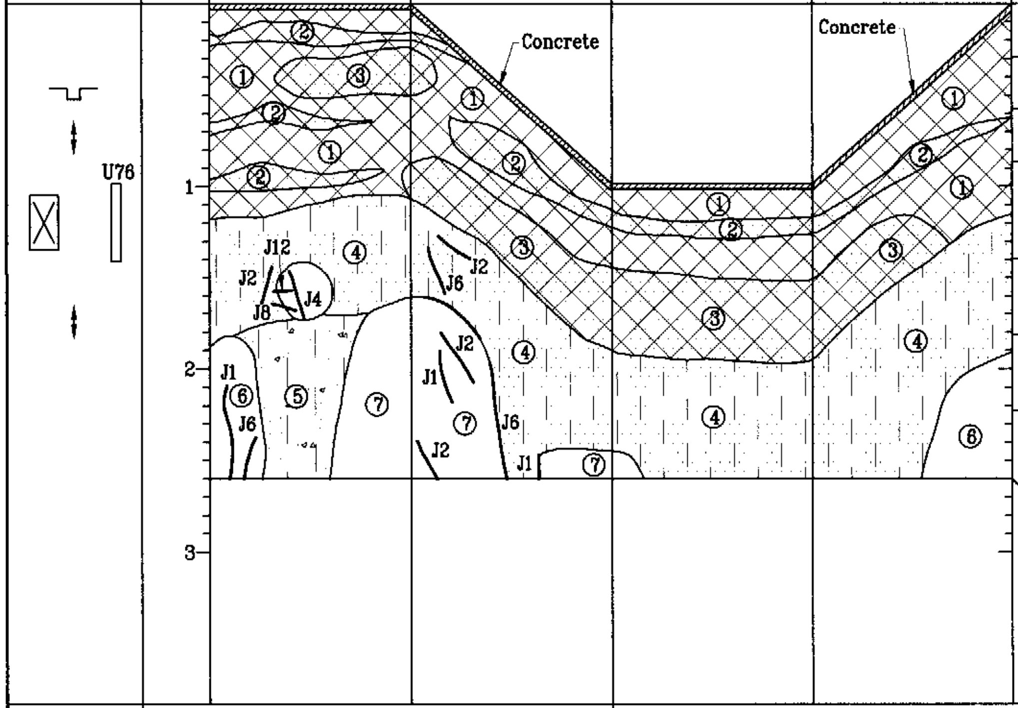
Sheet 1 of 1

TRIAL PIT No. TP3

CO-ORDINATES 817390.672 E , 813355.014 N
GROUND LEVEL 88.68 mPD

EXCAVATION DATE: from 20/10/1999
BACKFILL DATE: 1/11/1999
LOGGED BY: JLKS DATE: 28/10/1999
CHECKED BY: ICM DATE: 14/1/2000

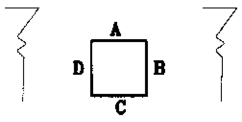
Samples & tests | Depth (m) | FACE A: 1.50 m | FACE B: 1.50 m | FACE C: 1.50 m | FACE D: 1.50 m



Legend	Grade	Description
1		Soft, moist, dark brown spotted with dark grey and reddish-brown, sandy SILT with some tree roots. (Fill)
2		Soft, moist, dark grey, very sandy clayey SILT with many tree roots and some decaying leaves. (Fill)
3		Medium dense, moist, brown mottled with yellowish-brown, silty fine to coarse SAND. (Fill)
4	V/IV	Extremely weak to weak, slightly moist, yellowish-brown mottled with reddish-brown and spotted with black and white, completely to highly decomposed SYENITE with occasional tree roots. (Firm, slightly clayey sandy SILT)
5	IV	Weak, yellowish-brown mottled with black, white and reddish-brown, highly decomposed SYENITE. (Firm to stiff, slightly gravelly sandy SILT)
6	IV/III	Weak to moderately strong, slightly moist, light yellowish-brown mottled with black and white, highly to moderately decomposed SYENITE. Joints surface stained reddish-brown, black and white.
7	III	Moderately strong, light yellowish-brown mottled with grey and white, moderately decomposed SYENITE. Joints stained black and infilled with some kaolin. Trial pit complete at 2.0m depth (ave.)

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORL. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
☒	BLOCK SAMPLE
⊥	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



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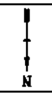

NORTH ARROW

REMARKS

J1 = 300 ~ 316/83 ~ 85
J2 = 270 ~ 283/72 ~ 85
J4 = 275/65
J6 = 028 ~ 040/65 ~ 83
J8 = 220/50
J12 = 205/82

Fugro Maunsell Scott Wilson Joint Venture
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South Lantau Road near Lai Chi Yuen, Lantau

TRIAL PIT RECORD

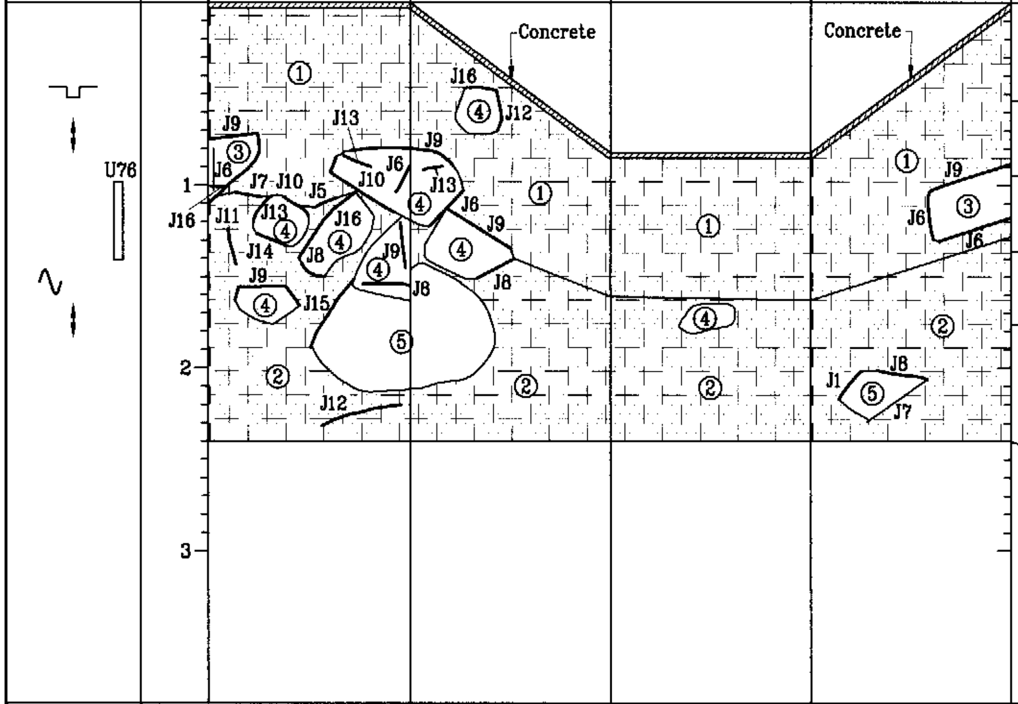
Sheet 1 of 1

TRIAL PIT No. TP4

CO-ORDINATES 817389.927 E , 813361.837 N
GROUND LEVEL 83.37 mPD

EXCAVATION DATE: from 20/10/1999
BACKFILL DATE: 1/11/1999
LOGGED BY: JLKS DATE: 29/10/1999
CHECKED BY: ICM DATE: 14/1/2000

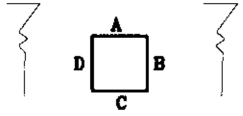
Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m



Legend	Grade	Description
1	V	Extremely weak, moist, reddish-brown mottled with yellowish brown and black, completely decomposed SYENITE with some cobbles/boulders and some tree roots. (Soft to firm, clayey sandy SILT).
2	V/IV	Extremely weak to weak, wet, reddish-brown mottled with light brown and black, highly to completely decomposed SYENITE. (Firm, clayey sandy SILT)
3	IV	Weak to moderately strong, yellowish-brown mottled with reddish-brown and black, highly to moderately decomposed SYENITE.
4	III	Moderately strong, light brown mottled with light grey and white, moderately decomposed SYENITE. Joints stained black and white. Some joints infilled with yellowish-brown clay.
5	III/II	Moderately strong to strong, light grey spotted with yellowish-brown and white, moderately to slightly decomposed SYENITE. Joints surface stained black and infilled with yellowish brown clay. Trial pit complete at 2.0m depth (ave.)

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORL. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
⊠	BLOCK SAMPLE
⊓	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Seepage noted at 1.5m depth (Face A & B)

J5 = 174 ~ 180/50 ~ 55
J6 = 025 ~ 045/80 ~ 85
J8 = 225 ~ 240/25 ~ 40
J9 = 010/25
J10 = 286 ~ 290/40 ~ 50
J11 = 300/65
J12 = 180 ~ 200/85 ~ 86
J13 = 040 ~ 046/60 ~ 70
J14 = 190/30
J15 = 100 ~ 120/50 ~ 15

Fugro Maunsell Scott Wilson Joint Venture
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Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

TRIAL PIT RECORD

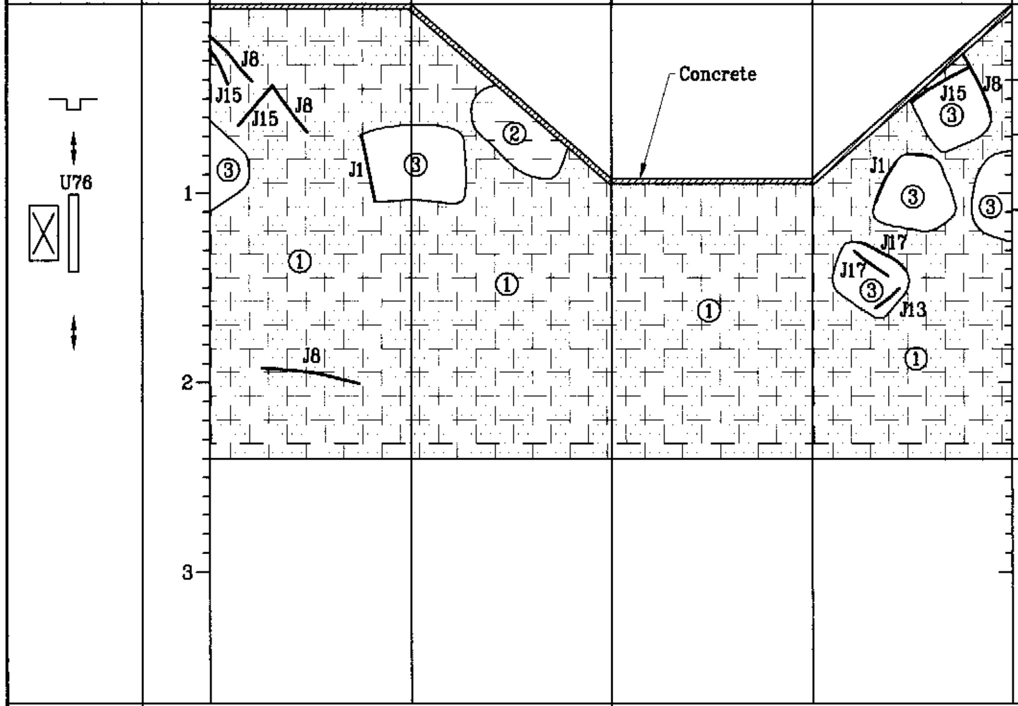
Sheet 1 of 1

TRIAL PIT No. TP5

CO-ORDINATES 817389.736 E , 813368.091 N
GROUND LEVEL 79.17 mPD

EXCAVATION DATE:		from	20/10/1999
BACKFILL DATE:			2/11/1999
LOGGED BY:	JLKS	DATE:	29/10/1999
CHECKED BY:	ICM	DATE:	14/1/2000

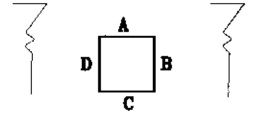
Samples & tests | Depth (m) | FACE A: 1.50 m | FACE B: 1.50 m | FACE C: 1.50 m | FACE D: 1.50 m



Legend	Grade	Description
1	V/IV	Extremely weak to weak, slightly moist, reddish-brown with yellowish-brown, completely to highly decomposed SYENITE with cobbles/boulders of grade III material. (Firm, clayey sandy SILT)
2	VI	Soft to firm, moist, dark brown, sandy CLAY with many tree roots. (Residual Soil)
3	III	Moderately strong, slightly moist, light brown mottled with grey and black, moderately decomposed SYENITE. Joints surface stained black and infilled with dark brown silty clay.
		Trial pit complete at 2.0m depth (ave.)

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORI. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
☒	BLOCK SAMPLE
⊔	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

J1 = 304 ~ 338/65 ~ 82 black
J8 = 210 ~ 240/32 ~ 60 black, clay infill
J13 = 052/55
J15 = 089 ~ 110/55 ~ 65 black, clay infill
J17 = 020 ~ 030/40 ~ 45 black

Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
The 1999 Landslide Investigation Consultancy
Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

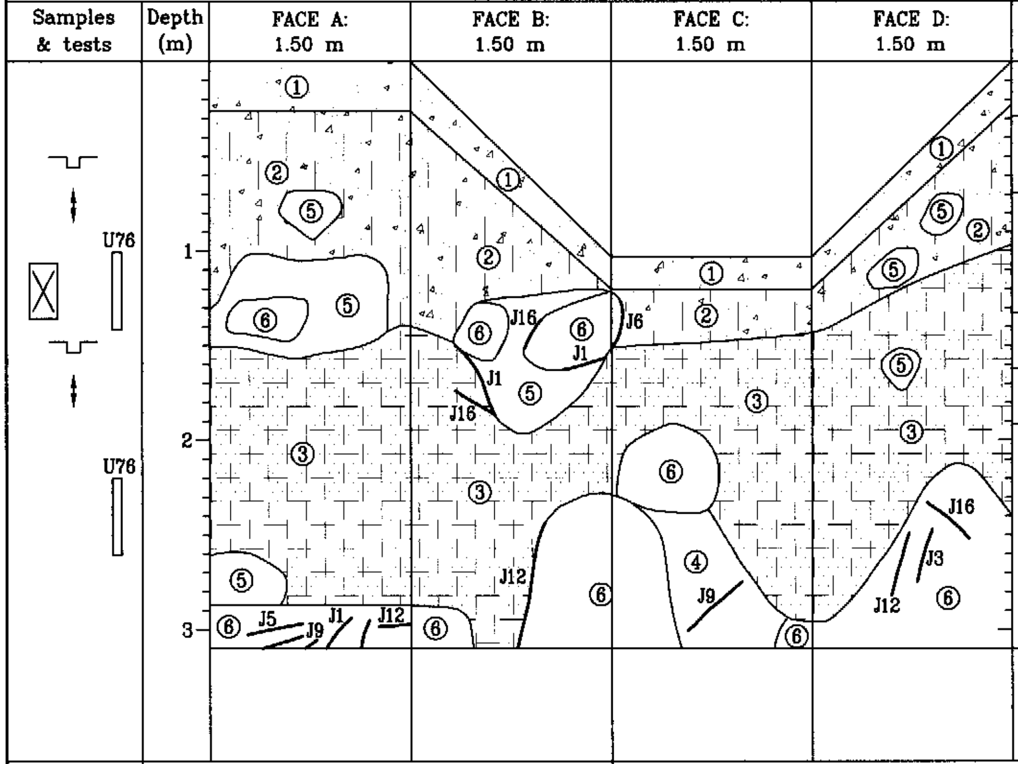
TRIAL PIT RECORD

Sheet 1 of 2

TRIAL PIT No. TP6

CO-ORDINATES 817408.805 E , 813345.513 N
GROUND LEVEL 95.99 mPD

EXCAVATION DATE: from 21/10/1999
BACKFILL DATE: 4/11/1999
LOGGED BY: JLKS DATE: 3/11/1999
CHECKED BY: ICM DATE: 14/1/2000

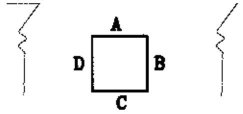


Legend	Grade	Description
1		Dense, slightly moist, grey, slightly gravelly silty fine to coarse SAND with many tree roots. (Top Soil/Colluvium)
2	V	Extremely weak, slightly moist, dark brown, completely decomposed SYENITE with many tree roots. (Firm, slightly clayey sandy SILT)
3	V/IV	Extremely weak to weak, slightly moist, dark brown mottled with reddish-brown, grey and white, completely to highly decomposed SYENITE. (Firm to stiff, clayey sandy SILT). Locally mixed with extremely weak, moist, dark brown, completely decomposed SYENITE with some tree roots. (Soft to firm, sandy silty CLAY)
4	IV	Weak, slightly moist, dark brown mottled with reddish-brown and black, highly decomposed SYENITE. (Stiff, gravelly sandy SILT)
5	IV/III	Weak to moderately strong, slightly moist light yellowish-brown mottled with white, highly to moderately decomposed SYENITE.
6	III	Moderately strong, slightly moist, light yellowish-brown mottled with white and black, moderately decomposed SYENITE.

Continued to Sheet 2 of 2

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
—	UNDISTURBED SAMPLE HORI. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
☒	BLOCK SAMPLE
⊤	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
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Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

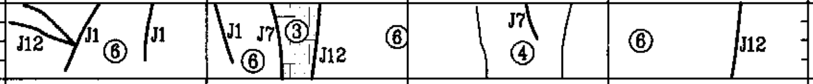
TRIAL PIT RECORD

Sheet 2 of 2

TRIAL PIT No. TP6

CO-ORDINATES 817408.805 E , 813345.513 N
GROUND LEVEL 95.99 mPD

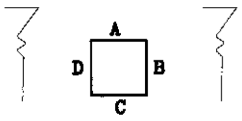
EXCAVATION DATE: from 21/10/1999
BACKFILL DATE: 4/11/1999
LOGGED BY: JLKS DATE: 3/11/1999
CHECKED BY: ICM DATE: 14/1/2000



Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description
	3.1							Continued from Sheet 1 of 2 Trial pit complete at 3.0m depth (ave.)
	4							Joint Description J1 = 305 ~ 325/68 ~ 85 J3 = 240/75 J5 = 180 ~ 190/45 ~ 50 J6 = 024 ~ 042/74 ~ 85 J7 = 082/70 J9 = 324 ~ 006/52 ~ 64 J12 = 195 ~ 220/72 ~ 85 J13 = 038/64 J15 = 095/50 J16 = 102 ~ 108/24 ~ 28 with clay infill.
	5							
	6							

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
—	UNDISTURBED SAMPLE HORI. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
⊠	BLOCK SAMPLE
⊓	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
The 1999 Landslide Investigation Consultancy
Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

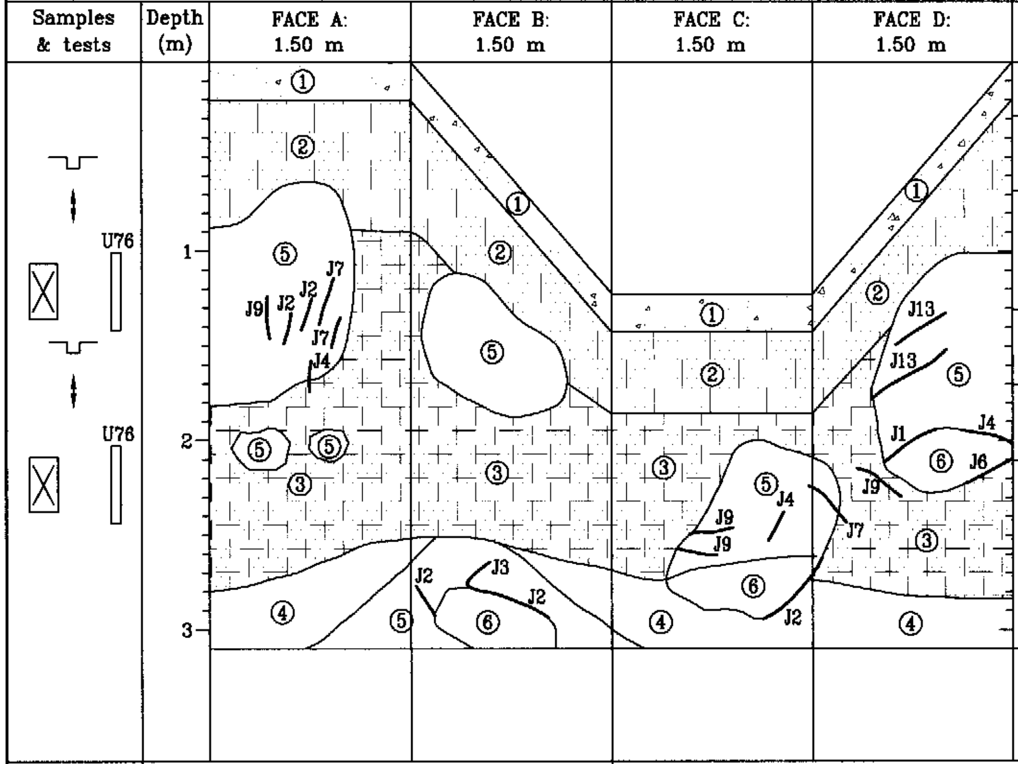
TRIAL PIT RECORD

Sheet 1 of 2

TRIAL PIT No. TP7

CO-ORDINATES 817378.491 E , 813349.116 N
GROUND LEVEL 97.58 mPD

EXCAVATION DATE: from 21/10/1999
BACKFILL DATE: 6/11/1999
LOGGED BY: JLKS DATE: 5/11/1999
CHECKED BY: ICM DATE: 14/1/2000

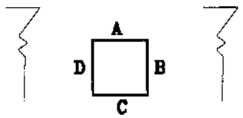


Legend	Grade	Description
1		Medium dense, slightly moist, grey, slightly gravelly fine to coarse SAND with many tree roots. (Top Soil/Colluvium)
2	V	Extremely weak, slightly moist, dark brown, completely decomposed SYENITE with some tree roots. (Firm, clayey sandy SILT)
3	V/IV	Extremely weak to weak, slightly moist, brown mottled with red and light brown, completely to highly decomposed SYENITE (Hard, sandy SILT) Locally mixed with extremely weak, moist, dark brown, completely decomposed SYENITE with some tree roots. (Soft, slightly sandy silty CLAY)
4	IV	Weak, slightly moist, light brown mottled with dark brown, reddish-brown and black, highly decomposed SYENITE (Firm to stiff, gravelly sandy SILT).
5	IV/III	Weak to moderately strong, slightly moist, light brown mottled with white and dark brown, highly to moderately decomposed SYENITE.
6	III	Moderately strong, slightly moist, lightly moist, light brown mottled with black and white, infilled with dark brown clay.

Continued to Sheet 2 of 2

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
⇕	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORL. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
☒	BLOCK SAMPLE
⊓	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
The 1999 Landslide Investigation Consultancy
Detailed Study No. 7
South Lantau Road near Lai Chi Yuen, Lantau

TRIAL PIT RECORD

Sheet 2 of 2

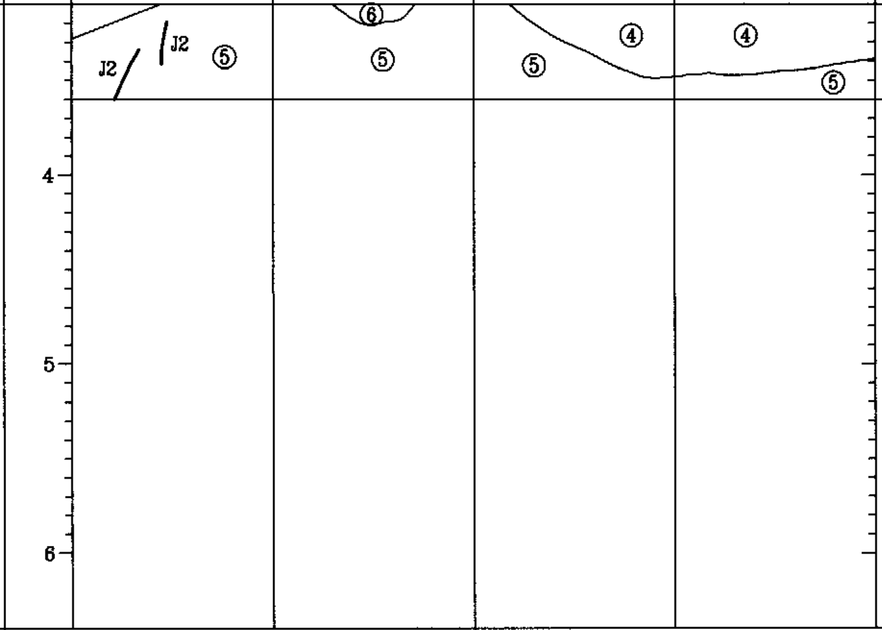
TRIAL PIT No. TP7

EXCAVATION DATE:	from	21/10/1999
BACKFILL DATE:		6/11/1999

CO-ORDINATES 817378.491 E , 813349.116 N
GROUND LEVEL 97.58 mPD

LOGGED BY:	JLKS	DATE:	5/11/1999
CHECKED BY:	ICM	DATE:	14/1/2000

Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description



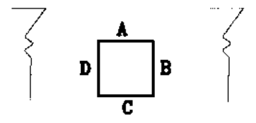
Continued from Sheet 1 of 2

Trial pit complete at 3.0m depth (ave.)

Joint Description
J2 = 280 ~ 296/72 ~ 85
J3 = 248/80
J4 = 250 ~ 280/65 ~ 70
J6 = 030/80
J7 = 060 ~ 068/85 ~ 86
J9 = 008/38 ~ 58
J13 = 048 ~ 060/60 ~ 62
J17 = 034/42
Stained dark brown & with clay infill

SYMBOL	SAMPLES/TESTS/WATER
●	SMALL DISTURBED SAMPLE
⫯	BULK DISTURBED SAMPLE
⊥	UNDISTURBED SAMPLE HORL. (U100/U78)
▯	UNDISTURBED SAMPLE VERT. (U100/U78)
⊠	BLOCK SAMPLE
⊔	IN-SITU DENSITY TEST
▲	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS