DETAILED STUDY OF 20 AUGUST 2005 LANDSLIDE BEHIND NURSES' QUARTERS BLOCK A, QUEEN MARY HOSPITAL, POK FU LAM

GEO REPORT No. 242

Fugro Scott Wilson Joint Venture

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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This report is largely based on GEO Landslide Study Report No. LSR 10/2006 produced in March 2007

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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

R.K.S. Chan
Head, Geotechnical Engineering Office
March 2009

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FOREWORD

This report presents the findings of a detailed study of slope distress (Incident No. 2005/08/0464) that occurred at around midnight on 20 August 2005 on the natural hillside about 80 m upslope from the Nurses' Quarters Block A, Queen Mary Hospital, Pok Fu Lam.

The key objectives of the study were to document the facts about the incident, present relevant background information and establish the probable causes of this distress. The scope of the study comprised aerial photograph interpretation, desk study, ground investigation, laboratory testing, topographic survey and field mapping. Recommendations for follow-up actions are reported separately.

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

Y C Koo
Project Director
Fugro Scott Wilson Joint Venture

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

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1. INTRODUCTION

At around midnight on 20 August 2005, a landslide (Incident No. 2005/08/0464) occurred on the natural hillside behind the Nurses' Quarters Block A of Queen Mary Hospital, Pok Fu Lam Road, when the Amber Rainstorm and Landslip Warnings were in force. The incident involved a distressed area of about 1,000 m^2 and downslope displacement by about 1 m. The slope movement severed a section of a pressurised water main supplying a service reservoir to the north of the landslide. The rupture of the water main was brought to the attention of the Water Supplies Department (WSD) by a sudden drop in water level in the service reservoir and subsequent investigation identified the landslide as being the cause of this.

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

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of failure. The scope of the study comprised aerial photograph interpretation, desk study, ground investigation, laboratory testing, topographic survey and field mapping. Recommendations for follow-up actions are reported separately.

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

(a) review of relevant documentary records relating to the development history of the site,

(b) aerial photograph interpretation,

(c) topographic survey and detailed field mapping,

(d) ground investigation works and laboratory testing,

(e) analysis of rainfall records, and

(f) diagnosis of the probable causes of failure.

2. THE SITE

2.1 Site Description

The landslide occurred on southwest-facing natural hillside about 80 m upslope of the Nurses' Quarters Block A of Queen Mary Hospital and downslope of High West (Figure 1 and Plate 1). The catchment surrounding the landslide has a plan area of about 14,000 m^2 and is defined by rounded spurs to the north and south with an open hillslope in between (Figure 2). The landslide occurred at the approximate location of a change in slope, with moderately steep gradients (30° to 35°) above the main scarp and moderate

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gradients (20° to 25°) below (Figure 3). Several drainage features lie within the catchment, including one that discharges into the crown of the August 2005 landslide. The catchment is covered by a dense tree canopy, with moderately dense undergrowth.

2.2 Maintenance Responsibility

The landslide lies in an area of unallocated Government land. The exception is a thin strip of land (Lot No. GLA-THK 557/SHMS/82E_10) traversing the distressed area (Figure 2), which is associated with the pipeline feeding the service reservoir to the north of the landslide (Section 2.3). According to the Lands Department, this lot was allocated temporarily to the WSD on 7 July 2004. The temporary allocation expired on 31 January 2005.

2.3 Water-carrying Services

A covered service reservoir lies about 70 m to the north of the August 2005 landslide and a 150 mm diameter pressurised asbestos water main that supplies the reservoir traverses the landslide scar (Figure 2). The pipeline was supported above ground level by concrete plinths spaced at approximately 5 m intervals. At the time of the landslide, the pipeline was in service although works were ongoing for the replacement of the existing water main (see Section 4.6).

3. SITE HISTORY AND PAST INSTABILITY

3.1 Development History of the Site

The development history of the site has been established from aerial photograph interpretation (API) based on the available aerial photographs between 1924 and 2004, together with a review of relevant documentary records. A detailed account of the API is presented in Appendix A and the relevant details are shown in Figure 4.

Works at the site of Queen Mary Hospital were ongoing in 1924 and by 1949 the main hospital buildings, including Nurses' Quarters Block A and the associated cut slopes, had been built. The covered service reservoir above the hospital complex and the connecting pipelines were also completed by 1949. One pipeline supplying water into the service reservoir and another, which feeds water to the hospital complex, were installed.

Between 1949 and 1963, the alignment of the pipeline supplying the service reservoir had been modified, with the section located above the present-day Nurses' Quarters Block B being moved upslope by approximately 10 m. The reason for the realignment of the pipeline is not known.

Between 1968 and 1972, an electricity pylon was constructed along the northern spur of the catchment. The pylon was removed between 1990 and 1991.

No other works of significance have been undertaken within the subject catchment.

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3.2 Maintenance History of the Pipeline

There are no maintenance records for the pipeline in the WSD. In addition, WSD have no past water main leak/burst records for the pipeline prior to 1996. However, two incidents of minor leakage were recorded by WSD in January 1999 and March 2000 respectively, in the section of the pipeline between the service reservoir and the hospital to the north of the distressed area (Figure 2). There are no records of water main leaks/bursts for the pipeline within the distressed area.

In mid-2004, works commenced under WSD Contract No. CE 3/WSD/02 for the construction of a new pipeline to replace the old existing pipeline supplying the service reservoir (Section 4.5). The works were ongoing at the time of the August 2005 landslide and the existing pipeline was still in service at the time the incident was reported.

3.3 Past Instability

In the catchment surrounding the August 2005 landslide, three areas of possible relict instability (depressions L1 to L3) have been identified by API, which consist of depressions (probably former landslide scars) located above the main scarp of the August 2005 landslide (Figure 4). These depressions are first noted in the 1949 aerial photographs and were probably in existence prior to 1924, but the poor resolution of the 1924 aerial photographs prevented accurate identification.

Depression L1 comprises a cluster of small depressions located immediately to the north of the August 2005 landslide that effectively form one large depression with an overall width of about 25 m. Depression L2 is about 20 m wide and is located about 60 m to the northeast of the August 2005 landslide. A prominent rock outcrop adjoins the southern flank of this depression. Depression L3 lies along the northern spur of the catchment between depressions L1 and L2 and is less prominent, with rounded edges, suggesting that it is an older relict landslide feature.

Other minor scarps and breaks of slope are observed within the catchment in the 1949 and 1963 aerial photographs, suggesting past movement, shallow instability and/or erosion. In particular, minor scarps were observed below depression L2 at an elevation approximately coincidental with the main scarp of the August 2005 landslide and along the drainage line below the toe of the August 2005 landslide.

After the late 1960's, the vegetation cover across the hillside is so dense that detailed observations by API are not possible, but in the 1972 photographs a small reflective area observed through the tree canopy suggests the possibility of erosion and/or slight retrogression of the southern flank of depression L1 (Figure 4).

Field mapping by FSW has confirmed the observations made from API and has also identified the presence of other areas of possible relict instability (Section 6). The large depression and possible relict landslide scar to the north of the August 2005 landslide (L1 on Figure 4) actually comprises five separate depressions (R1 to R5 on Figure 5). Another two smaller depressions (R6 and R7) are located above the main scarp of the August 2005

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landslide (Figure 5), which lies in an area where breaks in slope and possible minor scarps were observed from API.

In the area of depression L2, a 20 m wide single depression interpreted as a relict landslide scar was identified on site (R9 on Figure 5). In the area of depression L3, a shallow concavity and drainage feature were identified (R8 on Figure 5).

4. PREVIOUS STUDIES AND WORKS

4.1 Geotechnical Area Studies Programme

The Geotechnical Area Studies Programme (GASP) Report No. 1 covers the area of Hong Kong Island and Kowloon and provides geotechnical information for regional appraisal and strategic planning purposes. The Physical Constraints Map presented in the report indicates that the natural hillside in the vicinity of the landslide site is covered with colluvium and that the area is of ‘high’ geotechnical limitations (i.e. GLUM Class III).

4.2 Natural Terrain Landslide Inventory

In the mid 1990’s, the GEO compiled an inventory of historical landslides on the natural terrain of Hong Kong based on API using high-altitude (>8,000 feet) aerial photographs. The inventory, referred to as the Natural Terrain Landslide Inventory (NTLI), contained about 30,000 landslides, none of which were identified in the catchment surrounding the August 2005 landslide.

4.3 Enhanced Natural Terrain Landslide Inventory

In 2004, work commenced on the Enhanced Natural Terrain Landslide Inventory (ENTLI) project using low-altitude (i.e. <8,000 feet) aerial photographs to improve the identification of landslides and update the existing NTLI. Four relict landslides have been identified in the catchment area surrounding the August 2005 landslide as part of the ENTLI (Figure 4). ENTLI landslides nos. 11SWCX191 and 11SWCX194 correspond to landslide scars L1 and L2, respectively, which were identified in the 1949 aerial photographs under the current study. ENTLI landslides nos. 11SWCX193 and 11SWCX198 correspond to areas of possible relict instability identified in the 1963 aerial photographs (Section 3.3).

Given the close proximity of the existing hospital buildings to the historical natural terrain landslides identified in the ENTLI, the catchment containing the relict landslides was classified as a Historical Landslide Catchment (HLC) under the ENTLI project. The hillside affected by the August 2005 landslide incident is located within the HLC.

4.4 Study by Fugro (Hong Kong) Ltd in 1982

In 1982, Fugro (Hong Kong) Ltd were appointed by the Architectural Office Maintenance Branch of the Building Development Department, to carry out a geotechnical investigation of the previously registered Slope No. 11SW-C/C74 (i.e. the central portion of

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present Slope No. 11SW-C/C73), which is located at the toe of the hillside below the hillside affected by the August 2005 landslide. The report concluded that the soil slope was substandard and recommended cutting back the slope to 45°. In addition, the report indicated the existence of adversely orientated rock joints in the rock portion of the slope and recommended rock bolts and shotcrete to stabilise the adverse joints. The proposed works were also recommended for adjacent Slopes Nos. 11SW-C/C73, 11SW-C/C75 and 11SW-C/C76 although there are no records to indicate that detailed stability assessments had been carried out for the adjacent slopes. The works were completed between 1983 and 1984.

After the completion of the works, the four features were grouped together and registered as Slope No. 11SW-C/C73.

4.5 Landslip Preventive Measures (LPM) Programme

Slopes Nos. 11SW-C/C70, 11SW-C/C72 and 11SW-C/C73 are located at the toe of the landslide catchment (Figure 2), and have all been investigated and upgraded under the LPM Programme. LPM Stage 3 Study reports were prepared by Maunsell Geotechnical Services Ltd. in 1997, Halcrow Asia Partnership Ltd. in 1998 and Fugro (Hong Kong) Ltd. in 2001, for Slopes Nos. 11SW-C/C70, 11SW-C/C72 and 11SW-C/C73, respectively. The reports do not refer to any instability on the natural hillsides above the cut slopes.

The Stage 3 Study reports indicated that all three features comprised substandard soil and rock slopes and recommended upgrading by soil nail and raking drain installation in soil slopes, and by rock slope stabilisation measures such as rock bolt installation and shotcrete in rock portions of the slopes. In addition, the soil portion of Slope No. 11SW-C/C72 was recommended to be cut back to 30°. The works were completed between 1998 and 2003.

The effects of previous slope formations and slope trimming works on the August 2005 landslide were probably negligible, given the lack of any obvious evidence of slope distress on the natural hillsides immediately above the cut slopes.

4.6 Pipeline Rehabilitation Works

Maunsell Scott Wilson Joint Venture (MSW) was the consultant engaged under WSD Agreement No. CE 6/2001 for the Replacement and Rehabilitation of Water Mains Stage 1, Phase 1B, Package 1 – Hong Kong and Islands – Design and Construction. The existing pressurised water main, which supplies the service reservoir and traverses the distressed area, was due for replacement under this Agreement. Replacement works were to comprise the construction of a new ductile iron pipeline along the alignment of the existing, old, asbestos pipeline (Figure 2 and Plate 2). The new pipeline was to be supported above ground level by concrete plinths in accordance with WSD standard drawings.

General details of the proposed works, including pipe replacement above Queen Mary Hospital and a copy of the key plans showing the extent of the works, were submitted to GEO's Island Division by MSW on behalf of WSD on 20 March 2003, with additional information submitted in April and July 2003. No site-specific designs or investigations were submitted for the works behind Queen Mary Hospital, as the above ground pipeline did not

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involve any realignment or slope cutting and was not located on or at the crests of registered slopes and/or walls. For these reasons, GEO's Island Division had no specific geotechnical comments on the proposed pipeline replacement works above Queen Mary Hospital.

Works for the replacement of the existing pressurised water main above Queen Mary Hospital were ongoing at the time of the August 2005 landslide. Costain-China Harbour-Aarsleff Joint Venture was the contractor under WSD Contract No. CE 3/WSD/02, Replacement and Rehabilitation of Water Mains Stage 1, Phase 1 – Mains on Hong Kong & Lantau Islands. Works started at the south end of the pipeline in June 2004. Although the new pipeline was in place, the existing, old pipeline was still in service at the time the August 2005 landslide was reported.

A 15 m-long section of both the existing and replacement pipelines was severely deformed as a result of the August 2005 landslide (Figure 5 and Plates 2 and 3), following which works on the new pipeline were suspended. A section of plastic pipeline bridging the failed section of existing pipeline was installed by WSD as a temporary measure following the August 2005 landslide.

5. THE AUGUST 2005 INCIDENT

At midnight on 20 August 2005, a sensor in the service reservoir above Queen Mary Hospital recorded a sudden drop in water level. On 22 August 2005, the contractor for the pipeline replacement works (Section 4.4) inspected the pipeline serving the service reservoir and discovered that a 15 m-long section had been cracked and severely deformed, and ruptured locally. On 23 August 2005, the contractor identified an area of distress upslope of the broken pipeline and informed the WSD (Figure 5 and Plates 2 & 3). The WSD reported the landslide incident to the GEO on 24 August 2005 and FSW inspected the landslide site in that afternoon. Following the identification of distress on the hillside above the hospital, the ground and first floor level of the Nurses' Quarters Block A at the toe of the affected hillside were evacuated for a period of about 4 months.

The landslide comprised a semi-circular area of distressed ground approximately 30 m wide by 40 m long that had moved downslope by about 1 m. The main scarp of the landslide was 17 m long and located about 20 m upslope of the pipeline (Figure 5 and Plates 4 to 6). The vertical displacement across the main scarp varied from 150 mm at the northern and southern ends to about 800 mm in the central portion. The horizontal displacement across the main scarp varied from 150 mm at the northern and southern ends to about 800 mm in the central portion. Several persistent tension cracks, 100 mm to 200 mm wide and up to 1 m deep, and secondary scarps with 500 mm to 600 mm horizontal and vertical displacement, were identified slightly above and downslope of the main scarp (Figure 5 and Plates 7 & 8). Below the pipeline, an area of hummocky ground indicative of possible ground bulging was identified (Figure 5 and Plates 9 & 10).

The main component of slope movement above the pipeline is in a south southwest (190° to 210°) direction, while below the pipeline the movement tends to be in a southwest direction (Figure 5).

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Inspection of the pipelines further to the north of the severely deformed area revealed a 50 mm wide tensile fracture of the existing asbestos water main and hairline cracks (1 mm to 2 mm wide) at the base of one of the concrete plinth supports to the ductile iron pipeline (Figure 5 and Plates 11 and 12). On 8 December 2005, an additional hairline fracture developed in the existing asbestos pipeline about 8 m away from the 50 mm tensile fracture (Figure 5). The pipeline was also broken at the southern boundary of the August 2005 landslide and at about 5 m to the south of the landslide.

During the 24 to 31 August 2005 inspections, no surface water flows or seepage were observed in the area of the landslide or along the drainage feature at the toe of the distressed area. However, strong water flows (each about 6 litres per minute) were observed from some of the raking drains installed in Slope No. 11SW-C/C72 at the toe of the hillside below the landslide site, and seepage flows within an area of standing water were also noted at the crest of the cut slope (Figure 5).

6. FIELD MAPPING

Detailed field mapping of the landslide and surrounding area was undertaken by FSW between September and December 2005. Details of the pertinent observations made during field mapping are shown in Figure 5.

The catchment is defined by rounded spurs to the north and south with an open hillslope in between (Figure 5). The catchment is about 90 m wide at the toe and reduces in width in an upslope direction as the rounded spurs converge into a single point about 100 m above the main scarp of the landslide. The open hillslope between the spurs has a general southwesterly aspect. A subtle concave change in slope at an elevation of about 200 mPD separates the open hillslope into a slightly steeper (30° to 35°) upslope portion and gentler (20° to 25°) lower portion. The main scarp of the August 2005 landslide is approximately coincidental with the concave change in slope.

The area above the catchment to the August 2005 landslide largely comprises steeply inclined rock cliffs that expose Grade II/III fine ash tuff, with local areas of fine to coarse ash tuff. The tuff is slightly micaceous in parts and locally comprises hornfels indicating contact metamorphism has occurred. The tuff comprises persistent joints (possible sheeting joints) dipping adversely at 25-40°/225°-267° in some locations. Along the lower parts of the drainage lines to the north and south of the subject catchment, coarse ash tuff is exposed.

Based on the materials exposed in the main scarps of the relict landslides and along the drainage lines within the landslide catchment, a thin mantle of colluvium 0.5 m to 1 m thick overlies the open hillslope in the upper portion of the catchment. In the lower portion of the catchment, the colluvium locally thickens to an estimated maximum of about 3 m to 4 m.

Seven drainage features (DL1 to DL7), which probably form locations of concentrated surface water flow during rainstorms, lie within the catchment area (Figure 5). These features are shallow and poorly defined in the upper reaches of the catchment above an elevation of about 195 mPD to 200 mPD. In the lower portion of the catchment, the drainage features become more incised and locally expose Grade III/IV fine ash tuff between elevations 170 mPD and 180 mPD. Drainage feature DL3 flows into the crown of the August 2005

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landslide. These drainage features were dry during field mapping between September and December 2005. Flow from four of the raking drains installed along Slope No. 11SW-C/C72 at the toe of the catchment gradually reduced after September 2005. No flow or standing water was noted between December 2005 and March 2006. Since June 2006, seepage and standing water have been observed again (see Section 5) at the crest of Slope No. 11SW-C/C72. In August 2006, flows of about 2 litres per minute were observed from each of three raking drains within Slope No. 11SW-C/C72.

Nine depressions interpreted as relict landslide scars (R1 to R9) were identified during the field mapping, which were probably in existence prior to 1924 as determined from the API (Section 3.3). Five of the scars (R1 to R5) occur as a landslide cluster within the large relict scar L1 identified in the 1949 aerial photographs (Figure 5).

Scar R1 lies immediately to the northwest of the main scarp of the August 2005 landslide and comprises a sharp, well-defined, semi-circular depression that is 5 m to 10 m wide by 15 m long by 2 m to 3 m deep. The main scarp has a southwesterly aspect and exposes 1 m thick colluvium over Grade IV/V fine ash tuff. A strong eutaxitic fabric is visible within the tuff that dips at an angle of 45º in a southerly direction (185º). A drainage feature (DL4) lies downslope of scar R1 that passes through the toe of the August 2005 landslide and converges with drainage feature DL3 (Figure 5).

Scar R2 lies about 10 m upslope of R1 and has a similar aspect to scar R1, but is shallower (1.5 m to 2 m deep) and not as well-defined, with slightly rounded edges. Grade IV/V fine ash tuff was exposed towards the base of the scar, within which a foliation dipping at 77° in a south-southwesterly direction (196°) was observed, similar to that noted in scar R1.

Scar R3 adjoins the northern flank of scar R2 and comprises a poorly-defined, steeply inclined (50°) and shallow (1 m) scar about 5 m wide by 10 m long. Scar R3 has a west-southwesterly aspect orientated towards the centreline of scar R4.

Scar R4 lies immediately to the north of scars R1 to R3 and comprises a well-defined, reasonably sharp, semi-circular depression about 15 m to 20 m wide by 25 m long by 4 m to 5 m deep (Figure 5). The main scarp has a southwesterly aspect and exposes about 1 m of colluvium over Grade III/IV fine ash tuff. A band of Grade II/III fine ash tuff approximately 1.5 m to 2 m thick forms the release surface along the northern flank of the scar with steeply inclined joints (80° to 90°) dipping in a south-southwesterly direction (187° to 197°). The northern flank of scar R4 is coincidental with the rounded spur forming the northern catchment boundary.

Scar R5 comprises a shallow (2 m deep), reasonably well-defined, semi-circular depression that lies directly above scar R4 and possibly represents retrogression of the main scarp of scar R4. A large boulder of Grade III fine ash tuff is exposed in the northern flank of scar R5 and groups of smaller boulders lie along the spur of the northern catchment boundary above and below the scar. A drainage feature (DL5) lies below scar R5 that passes through the main scarp of scar R4 and converges with the drainage feature DL4 below scar R1. Two other drainage features (DL6 and DL7) lie downslope of scar R4 that flow sub-parallel with the rounded spur of the northern catchment boundary.

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Scar R6 is about 7 m wide and comprises a planar surface exposing a thin mantle of colluvium between 0.5 m and 1 m thick overlying Grade IV/V fine ash tuff. The scar is controlled by relict jointing dipping at an angle of 50° in a west-southwesterly direction (250°). Beneath the scar lies an elongated lobe of material about 5 m wide by 15 m long that forms a localised rounded minor spur within the open hillslope that extends upslope of scar R6 and separates drainage feature DL4 from scars R1 to R5 (Figure 5).

Scar R7 is about 10 m wide and comprises a very rounded, ill-defined, shallow, semi-circular depression located above the central and southern portions of the August 2005 landslide. Scar R7 has an overall south-southwesterly aspect and a drainage feature (DL3) leads to the crest of the scar. The drainage feature appears to bifurcate above the main scarp of the August 2005 landslide into drainage lines DL3a and DL3b, which converge again towards the toe of the distressed area (Figure 5).

Scar R8 is about 20 m wide and comprises a very rounded, ill-defined, shallow, semi-circular depression located above relict scars R1 to R5. Scar R8 has an overall south-southwesterly aspect. Drainage feature DL3 lies below scar R8, which leads to the crest of the relict scar R7.

Scar R9, lies about 60 m upslope of the August 2005 landslide and comprises a sharp, well-defined main scarp about 4 m to 5 m deep by 20 m to 25 m wide by 25 m long. The flanks of the scar are rounded and not as well-defined as the main scarp. Steeply inclined joints dipping at 54° to 87° in a south-southwesterly (197° to 218°), westerly (267° to 283°) and northwesterly (328° to 242°) directions were identified in the main scarp. A large outcrop of Grade II/III fine ash tuff adjoins the southern flank of the scar, which is also coincidental with the rounded spur forming the southern catchment boundary. An ephemeral drainage (DL2) lies below scar R9. In the lower reaches of the catchment, a second drainage feature (DL1) flows sub-parallel to drainage line DL2 at an offset of between 5 m and 15 m (Figure 5).

7. SITE INVESTIGATION

7.1 Previous Ground Investigation

Previous relevant ground investigation (GI) works comprised four phases of investigation that were undertaken along the toe of the distressed hillside (Figure 6).

Two drillholes (BH1 and BH2) were sunk along the toe of the southern spur by Bachy Soletanche in August 1996 for the investigation of slope No. 11SW-C/C70 (Figure 6). Drillhole BH1 encountered 2.4 m of colluvium over 7 m of Grade IV and Grade V fine ash tuff with Grade III bedrock of meta-sandstone and fine ash tuff at a depth of 9.4 m. Fine- to medium-grained granite was encountered at a depth of 14.7 m. Drillhole BH2 encountered about 3 m of colluvium over 6.5 m of Grade IV/V fine ash tuff with Grade III bedrock of coarse ash tuff at a depth of 9.5 m. No granite was encountered in drillhole BH2.

Four drillholes (BH1 to BH4) were undertaken along the toe of the open hillside below the August 2005 landslide by Gold Ram Engineering Ltd. in January 1998 for the investigation of slope No. 11SW-C/C72 (Figure 6). Drillholes BH1 and BH2 encountered fill and colluvium to a depth of about 2 m over Grade II/III tuff bedrock. Grade II granite was

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encountered in drillhole BH1 at a depth of 5.7 m. Drillholes BH3 and BH4 encountered 4 m to 5 m of Grade V tuff and Grade IV tuff, with some local fill material, over Grade II tuff. Grade II granite was encountered in drillhole BH4 at a depth of 6.3 m. The tuff was generally fine-grained, but local bands of fine to coarse ash tuff were encountered.

Six drillholes were undertaken across slope No. 11SW-C/C73 by Enpack (HK) Ltd. in March 2001 for the investigation of slope No. 11SW-C/C73. Drillholes DH1 to DH3 are located in close proximity to the area of distressed hillside (Figure 6). Drillholes DH1 to DH3 encountered 2 m to 4.5 m of Grade V tuff over about 1.5 m of Grade IV and IV/V tuff, with Grade III fine ash tuff bedrock at a depth of 3.7 m to 6 m. In drillhole DH1, Grade II granite was encountered at a depth of 9.8 m.

Four drillholes were undertaken below the toe of the southern end of slope No. 11SW-C/C73 by Geotechnics & Concrete Engineering (H.K.) Ltd. in January 2005, of which drillholes BH2 and BH3 are considered relevant to the present study (Figure 6). Drillholes BH2 and BH3 encountered about 2 m of fill overlying Grade III fine ash tuff in BH2 and Grade III/IV fine ash tuff in BH3. Grade II/III granite was encountered in drillhole BH2 at a depth of 3.5 m and in drillhole BH3 at a depth of 5.2 m.

7.2 Current Ground Investigation

7.2.1 Introduction

As part of the landslide study, GI works comprising 3 drillholes (BH1 to BH3), seven trial trenches (TT1 to TT7), four trial pits (TP1 to TP4) and four surface strips (S1 to S4) were carried out by Fugro Geotechnical Services Ltd. between October and November 2005 (Figure 6), under the supervision of FSW. In addition, two drillholes (D1 (L) and D2 (L)) and two trial pits (TP1 (L) and TP2 (L)) were carried out by Lam Geotechnics Limited in August 2006, under the supervision of FSW.

7.2.2 Drillholes

Drillholes BH1 to BH3 were positioned in the central to upper portions of the landslide to investigate the depth and nature of slope-forming materials and potential shear surfaces (Figure 6). The drillholes were advanced using rotary boring techniques with air-foam as the flushing medium. Continuous Mazier samples were retrieved from the soil strata in drillholes BH1 and BH2.

Drillhole BH1 encountered 1 m thick colluvium over 7.1 m thick Grade V and some Grade IV/V fine ash vitric tuff, over Grade II fine ash vitric tuff bedrock. Drillhole BH2 encountered 8.1 m thick Grade V fine ash tuff over 1.2 m thick Grade IV fine ash tuff, over Grade III fine ash tuff bedrock. No colluvium was found in drillhole BH2. Grade III tuff bedrock was encountered at a depth of 9.8 m in drillhole BH3. Two piezometers were installed in drillhole BH1 at depths of 7.5 m and 13.5 m for groundwater monitoring. Inclinometers, which penetrated at least 5 m into bedrock, were installed in each of drillholes BH2 and BH3.

Mazier samples retrieved from drillholes BH1 and BH2 were split for detailed

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inspection. For drillhole BH2 at the mid-portion of the August 2005 landslide, a disturbed zone of about 0.5 m thickness, comprising yellowish brown, slightly sandy silt with some small to medium gravel size fragments of tuff was identified between 2.3 m to 2.8 m depth within CDT (Plate 13). At depths of 3.7 m and 5.9 m respectively, 50 mm to 150 mm wide seams of silty infill material were present within the CDT (Plates 14 and 15). Small voids up to 5 mm wide were present within the infill seams. At a depth of 8.7 m, a 30 mm wide seam of greyish brown and white, slightly sandy, silt with some flecks of mica and small to medium rounded gravel of manganese stained tuff and root fragments was present within the HDT (Plate 16). At a depth of 8.85 m, the Grade IV tuff was brecciated with some infill material indicating possible previous minor disturbance by ground movement. A possible infill seam comprising silty material was also present at a depth of 8.1 m, but this area corresponded to the top of the Mazier sample and may represent soil disturbance due to drilling.

Similar observations of infill materials and soil disturbance were made from the inspections of Mazier samples from drillhole BH1 above the main scarp of the August 2005 landslide. A 450 mm thick seam of slightly sandy silt with some small to medium gravel size fragments of tuff and occasional plant fragments was identified between 2.6 m and 3.1 m depth (Plate 17). Thinner seams (40 mm to 100 mm wide) of silty infill material were also identified at depths of 3.7 m, 5.9 m and 7.3 m. A 300 mm zone of no recovery indicating the presence of extremely weak material or a possible void was identified above the infill seam (50 mm wide) at 7.3 m depth (Plate 18).

Drillholes D1 (L) and D2 (L) were located above and adjacent to relict scars R8 and R9 respectively (Figures 5 and 6). Drillhole D1 (L) encountered 4.3 m of relict colluvium above 9.5 m of CDT and C/HDT with corestones of H/MDT. Bedrock was encountered at 15.35 m below ground level and consists of slightly decomposed coarse ash crystal tuff with occasional quartz veins and layers of eutaxitic and fine ash tuff. Drillhole D2 (L) encountered 3.1 m of relict colluvium above 1.8 m of completely to highly decomposed basalt and slightly decomposed basalt. Below the basalt, C/HDT was encountered at depths of 4.9 m to 6.05 m and 10.6 m to 13.6 m with corestones/coreslabs of M/SDT encountered between the more decomposed materials. Bedrock is encountered at 13.6 m below ground level and consists of predominantly slightly decomposed fine ash tuff becoming eutaxitic fine ash tuff at a depth of 15.7 m. Drillholes D1 (L) and D2 (L) indicate that the spur above the reservoir and the landslide site is covered with relict colluvium.

7.2.3 Trial Trenches

Trial trenches TT1 to TT7 were positioned across the distressed area of the August 2005 landslide to investigate the depth of movement and the nature of slope-forming materials (Figure 6).

Trial trench TT1 positioned across the main scarp identified 1.5 m to 2.5 m thick colluvium overlying Grade IV tuff. The colluvium contained boulders and large, semi-intact blocks of Grades III/IV and IV/V tuff within a firm to stiff, yellowish and orangish brown, slightly sandy silt matrix (Figure 7 and Plate 19). The blocks of tuff within the finer colluvium matrix were very disturbed with open and infilled 2 mm to 15 mm-wide cracks.

The surface of the Grade IV tuff beneath the colluvium had a stepped profile that was

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controlled by a low to moderately inclined (15° to 30°), undulating joint set intersected by steeply inclined (50° to 85°) joints (Figure 7). A seam of slightly sandy silt with brecciated tuff fragments was present between the colluvium and Grade III/IV tuff below (Figure 7 and Plate 20). The seam is located at a maximum of 3 m depth below ground level and increased in thickness from about 50 mm in the upslope face to about 400 mm in the downslope face. This feature is probably a shear plane associated with the August 2005 landslide.

A steeply inclined (60º), 300 mm wide shear plane was identified beneath the main scarp (Figure 7 and Plate 21). The shear plane consisted of brown, slightly sandy, silt with some sub-angular gravel and cobble fragments of Grade IV/V tuff. The material was loose in parts with some voids and had several roots passing through it that appeared to be aligned with the shear plane. The interface between the shear plane and the surrounding material was quite distinct in the upper portion, but became less distinct with depth and could not be identified reliably beyond a length of about 2 m (Plate 21). A steeply inclined 1 m drop in the Grade IV tuff was approximately coincidental with the main scarp and appeared to have influenced the location of the main scarp (Figure 7).

Two tension cracks (50 mm to 100 mm wide) were identified above the main scarp in Face B of the trial trench (Figure 7 and Plate 22), which converged into one larger tension crack (300 mm wide) in Face D of the trial trench.

Trial trench TT2 was located across one of the secondary scarps in the middle of the distressed area, just upslope of the pipeline (Figure 6). Trial trench TT2 identified colluvium of variable thickness up to about 1 m thick overlying Grade V tuff. A zone of recent disturbance (50 mm to 100 mm wide) comprising steeply inclined, sub-parallel and open cracks (5 mm to 15 mm wide), was identified in Face B of trial trench TT2, approximately coincidental with the secondary scarp at the ground surface (Feature 1 in Figure 8 and Plate 23). Additional evidence of recent movement in the form of persistent (up to 2 m long) and open cracks (5 mm to 10 mm wide with no infill) (Feature 2 in Figure 8), and older movement in the form of infilled cracks (Feature 3 in Figure 8), were identified within the trial trench. In particular, a zone of intense disturbance was identified at a depth of between 1.5 m and 2.5 m in face C of the trial trench where numerous open joints and fractures through intact tuff were observed (Feature 4 in Figure 8). The upper and lower limits of the disturbed zone in face C were coincidental with 1 m to 1.5 m long and 25 mm to 70 mm wide cracks (Figure 8 and Plate 24). The open cracks were controlled by moderately inclined joints (20° to 30°) dipping in a general westerly direction (255° to 286°). Manganese staining was observed across some of the joint surfaces in the lower part of the trial trench.

Trial trenches TT3 to TT5 were undertaken in the area of the displaced soil mass below the pipeline (Figure 6). The trial trenches identified 1 m (TT3 and TT5) to 3 m (TT4) thick colluvium overlying Grades IV and V tuff. Trial trench TT4 was undertaken across one of the secondary scarps (Figure 6), but no distinct subsurface slip plane was observed. Instead, a 300 mm wide zone of soft and weak material with micro-fractures was identified within the colluvium. Trial trenches TT3 and TT5 were undertaken across the bulging front at the toe of the landslide. No distinct movement plane was identified, but zones of soft/weak material and localised subsurface voiding were identified within the colluvium layer. Within the Grades IV and V tuff underlying the colluvium, there was evidence of disturbance up to 3 m

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deep, with impersistent, 2 mm to 5 mm wide voids along joint surfaces and joint infill typically 2 mm to 3 mm thick, but locally up to 130 mm thick.

Trial trench TT6 positioned across the east flank of the distressed area (Figure 6) identified about 1 m thick colluvium overlying Grades IV and V tuff. The colluvium within face D of the trial trench (the face closest to the landslide) was noticeably wetter and softer than in the other faces. No clear evidence of recent movement was identified within the trial trench. Evidence of past movement in the form of infill (up to 150 mm thick) along steeply inclined joints (65° to 71°) was observed in face B of the trial trench to a depth of at least 3 m, i.e. to the base of trial trench TT6 (Figure 9 and Plates 25 and 26). The steeply inclined joints dipped in a general southwesterly direction (205° to 225°) and at the base of the trial trench concentrated manganese deposits were present along the joint (Plate 27). The joint infill at the base of face B could be traced through faces C and D of the trial trench, forming a laterally persistent seam (Figure 9 and Plates 28 and 29).

In addition to the primary zones of joint infill, evidence of secondary shearing and joint infill to smaller blocks of tuff were observed, which indicates the overall disturbed nature of the tuff (Plates 30 and 31).

Trial trench TT7, positioned across a tension crack along the northern edge of the distressed area (Figure 6), identified two distinct layers of colluvium overlying Grade III and IV tuff. Each colluvium layer was between 0.3 m and 0.9 m thick, with a combined thickness of about 1.5 m (Figure 10). A steeply inclined (60° to 70°), 150 mm to 200 mm wide tension crack passed through both colluvium layers in the lower part of the trench (Figure 10 and Plate 32). The tension crack was partially infilled with loose, organic material and had numerous roots passing along it. The tension crack narrowed with depth and flattened out to become a void at the interface between the base of the lower colluvium layer and the underlying Grade IV tuff (Plates 32 and 33). In face C of the trial trench, the void was 50 mm to 100 mm wide (Figure 10 and Plate 33).

In the lower corner of trial trench TT7 between faces B and C at 1.2 m to 2.5 m depth, a zone of intensely disturbed Grade IV tuff was identified (Figure 10 and Plate 34). In this area, recent movement in the form of open cracks (20 mm to 50 mm wide) and shearing through intact tuff (5 mm to 20 mm wide) with no infill, and older movement, in the form of infilled cracks were observed. Extensive manganese staining was present across joint surfaces in this area.

7.2.4 Trial Pits

Trial pits TP1 and TP2 were positioned beyond the area associated with the August 2005 landslide (Figure 6) to investigate the nature and condition of materials outside the distressed area. Trial pits TP3 and TP4 were carried out at the base of trial trenches TT2 and TT6 respectively. Trial pits TP1 (L) and TP2 (L) were positioned within relict scar R9 (Figures 5 and 6).

Colluvium about 1 m thick was encountered in both of the trial pits, overlying Grade V fine ash tuff in trial pit TP1 and Grade IV fine to coarse ash tuff in trial pit TP2. Evidence of past minor slope movement in the form of disturbed tuff with joint infill was present in both

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trial pits to a depth of about 2.5 m in trial pit TP1 and to the base of the trial pit (3.5 m) in the upslope face of trial pit TP2 (Plate 35). Trial pits TP3 and TP4 encountered up to 1 m thick CDT with open tension cracks and relict joints indicating that the disturbed materials extended to greater than 4 m below ground level at these locations.

Trial pits TP1 (L) and TP2 (L) encountered 1.2 m and 2.5 m of colluvium respectively above C/HDT with relict joints. Highly to moderately decomposed coarse ash tuff was encountered at 2.7 m below ground level in trial pit TP1 (L).

7.2.5 Surface Strips

Strips S1 to S4 were positioned within and above some of the relict landslides scars present on site to investigate the possible existence of tension cracks (Figure 6).

Strips S1 and S3 were positioned below the main scarp of the relict landslide scar R4 and R2 respectively. Both strips exposed Grade IV fine ash tuff at the base of the steeply inclined main scarps grading into colluvium along the floor of the landslide scars.

Strip S2 was positioned above the relict landslide scar R3 and strip S4 above the relict landslide scars R6 and R7. Both strips exposed colluvium.

No evidence of tension cracks was identified in any of the slope strips.

7.3 Groundwater Monitoring

Monitoring of groundwater in standpipes and piezometers installed in existing drillholes (with Halcrow buckets in DH2 and BH2 (B)), together with drillholes undertaken for the current study has been carried out periodically since January 2006. A summary of the manual monitoring records is presented in Table 1.

Some of the piezometer and standpipe installations were fitted with automatic groundwater monitoring devices (including one Levelogger and five LevelTroll units) in January 2006. A summary of the installations is presented in Table 2. It should be noted that the automatic monitoring devices were removed from the drillholes between 29 March 2006 and 10 July 2006 during the emergency slope stabilisation works, which included soil nail and raking drain installations within the landslide area (Section 8). Monitoring data obtained from 4 January to 29 March and from 11 July to end-August 2006 are presented in Appendix B.

Drillholes BH1 (B) and BH2 (B) undertaken along the toe of the southern spur (Figure 6) had a single standpipe installed at the base of each of the drillholes at depths of 17 m and 15 m respectively. No monitoring records were identified for drillhole BH1 (B) and field inspection by FSW identified that the standpipe was blocked. For drillhole BH2 (B), the highest water level was recorded on 24 June 2006 at a depth of 11.4 m within Grade III coarse ash tuff.

Drillholes BH1 (GR) to BH4 (GR) undertaken along the toe of the open hillside below the August 2005 landslide (Figure 6) had a single standpipe installed towards the base of each

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of the drillholes at 6 m to 10 m depths mostly within Grade III tuff. Drillhole BH3 (GR) had an additional standpipe installed at 4.7 m depth within Grade IV/V fine ash tuff. The highest previously recorded groundwater was at 3.8 m for drillhole BH2 (GR). Recent monitoring has identified that the standpipe in drillhole BH1 (GR) is blocked and drillhole BH2 (GR) could not be located due to the disturbance from the emergency slope works. For drillhole BH3 (GR), the highest recorded water levels were at 4.1 m depth for both upper and lower standpipes on 29 July 2006, following a period of rain on 27 to 28 July 2006, and on 5 August 2006. The standpipe in drillhole BH4 (GR) remained dry until 16 July 2006 when the water level was recorded at 0.5 m depth after a rainstorm on the same day. Similar readings were recorded following a period of rain on 27 to 28 July 2006, and on 5 August 2006.

Drillholes DH1 (E) to DH3 (E) undertaken across Slope No. 11SW-C/C73 (Figure 6) had single piezometers installed in superficial materials at 3 m to 8 m depths. Standpipes were also installed within rock in drillholes DH2 (E) and DH3 (E) at 10.7 m and 19 m depths, respectively. No water was encountered in the piezometers installed in drillholes DH1 (E) to DH3 (E). Both the piezometer and the standpipe in drillhole DH3 (E) are now blocked following the emergency slope stabilisation works. Recent monitoring did not encounter any water in the piezometers installed in drillholes DH1 (E) and DH2 (E). The highest groundwater level for the standpipe in drillhole DH2 (E) was at a depth of 8 m measured in early March 2006 (Table 1).

Drillhole BH1 undertaken in November 2005 above the main scarp of the August 2005 landslide had piezometers installed in soil and rock at 7.5 m and 13.5 m depths, respectively. Recent monitoring recorded the highest water level at a depth of about 12.8 m for the lower piezometer up to the start of May 2006, after which time the piezometer was blocked (presumably by grout from nearby soil nail installations). The upper piezometer was dry throughout the monitoring period.

7.4 Movement Monitoring

In October 2005, CEDD's Survey Division commenced periodic monitoring of seven movement stations (M1 to M7) installed across the distressed hillside associated with the August 2005 landslide and the eight movement stations (P1 to P8) installed along the section of replacement pipeline affected by the landslide (Figure 6). Monitoring up to the end of March 2006 have not recorded significant settlement or horizontal displacement (Appendix B), although there were no significant rainstorms during that period. Monitoring was discontinued in April 2006 when the emergency slope stabilisation works commenced.

The Survey Division also carried out monitoring of the inclinometers installed down to depths of 16.75 m and 15.23 m in drillholes BH2 and BH3, respectively, and which are located in the area of distressed hillside above the pipeline (Figure 6). Monitoring up to the end of March 2006 did not record any significant movements. However, monitoring in drillhole BH3 between June and 21 July 2006 recorded movements in an upslope direction of 11 mm (+/- 7.5 mm) between ground level and 14.8 m depth, and movements towards the southeast (i.e. in the downslope direction of the pipeline) of about 10 mm (+/- 7.5 mm) at 10 m depth. These movements might be related to ground disturbance caused by the soil nail installation works, which were on-going near the installations at that time.

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7.5 Laboratory Testing

Laboratory testing was carried out by Gammon Construction Limited in February 2006 on selected soil samples. The following tests were undertaken:

(a) single-stage and multi-stage isotropically consolidated undrained triaxial compression tests with pore pressure measurement, and

(b) direct shear box tests (on 100 mm diameter specimens).

Consolidated undrained triaxial tests were undertaken on samples of colluvium and Grade IV/V tuff (Table 3). Test results for colluvium presented in the form of a p′-q plot generally showed a reasonable straight-line relationship with shear strength parameters of c′ = 0 kPa and ϕ'= 33°, the exception being the results from one multi-stage test that yielded shear strength parameters of c′ = 12 kPa and ϕ' = 33° (Figure 11). Triaxial test results for Grade IV/V tuff presented in the form of a p′-q plot showed a greater degree of scatter with lower-bound parameters of c′ = 0 kPa and ϕ' = 38° and upper-bound parameters of c′ = 15 kPa and ϕ' = 41° (Figure 12).

Direct shear box tests were undertaken on samples of colluvium (Table 4). A plot of normal stress against shear stress yields best-fit shear strength parameters of c′ = 2 kPa and ϕ' = 34°, which are in line with the triaxial test results for colluvium (Figure 13). Samples of the joint infilling materials could not be obtained for laboratory testing due to the loose nature of the soils.

8. SOIL NAILING WORKS

Follow-up emergency slope stabilisation works to the August 2005 landslide area and the surrounding hillside, which comprise 12 m to 16 m long, 32 mm diameter soil nails at 2 m spacing, commenced in February 2006. Based on soil nail drilling records, in the location slightly upslope of the distressed area at an elevation of about 207 mPD, soil was typically encountered to a drilling depth of between 8 m and 12 m. In the central portion of the distressed area at an elevation of about 191 mPD, soil was typically encountered to a drilling depth of between 11 m and 14 m. Towards the base of the distressed area at an elevation of about 183 mPD, only soil was encountered during the drilling of the 16 m long soil nails. As the process of drilling of soil nail is not subject to stringent control as opposed to ground investigation or insitu testing, it would not be credible to rely on the relatively crude drilling records to determine precisely where rockhead lies. However, these records may be used to assist in establishing where rockhead or boulder is not encountered. It appears that there are no abrupt changes in the thickness of soil within the distressed area.

During the works, excessive grout loss corresponding to more than ten times the theoretical grout volume was recorded for three of the soil nail locations. These soil nails are located in the distressed area of the slope associated with the August 2005 landslide. The drilling records for two of the soil nails that experienced excessive grout loss in the distressed area indicate a very weak zone with possible voiding at a depth of 9 m to 11 m measured along the soil nails, i.e. at about 7 m to 9 m depths below ground level. In addition, grout loss

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corresponding to between five and ten times the theoretical grout volume was recorded for thirty seven soil nail locations. Of these, ten are located in the distressed area of the slope associated with the August 2005 landslide.

9. GEOLOGY, GEOMORPHOLOGY AND HYDROGEOLOGY OF THE SITE

According to the Hong Kong Geological Survey Sheet 1:20,000 scale geological map, Series HGM20 Sheet No. 11, the August 2005 landslide site is underlain by fine ash vitric tuff of the Ap Lei Chau Formation (Figure 14). A superficial layer of debris flow deposits, comprising unsorted sand, gravel, cobbles and boulders with a clay/silt matrix, covers the site. The fine ash tuff is underlain by eutaxite and fine-grained granite, which outcrop about 150 m to the northeast and southwest of the site respectively.

Regionally, the tuffs and eutaxites have been folded into a series of northwest-southeast striking anticlines and synclines, which have been subsequently intruded by granite. The nearest anticlinal axial trace is located through Sai Ko Shan to the northeast of the landslide site (Figure 14). Three major photolineaments have been identified from API in the vicinity of the site (Figure 15). A north-south trending photolineament is located about 250 m to the west of the landslide site and appears to be associated with the valleys extending through to Belchers Bay to the north and to Kong Sin Wan in the south, although the photolineament appears to be offset by a fault trending WSW-ENE through the Chinese Christian Cemetery to the north of Queen Mary Hospital. Although not indicated in Figure 14, this major north-south photolineament may be a fault with an associated zone of weakness, and if present this zone may be a factor in the change of relief present in the area. It is also possible that this feature may have influenced the surrounding geology, including that at the landslide site, in terms of joint orientations, joint persistence and so on.

A WNW-ESE trending photolineament appears to control the drainage line within the catchment to the north of the landslide site, and a NNW-SSE trending photolineament is evident controlling the area of rock outcrops above and to the east of the landslide site (Figure 15). These two photolineaments are likely to be associated with some of the more significant joint sets within the area.

Based on field observations and the GI data, superficial materials at the landslide site comprise colluvium between 0.5 m and 3 m thick overlying Grade V and IV/V fine ash tuff to a depth of about 10 m. In the lower reaches of the catchment, the colluvium becomes concentrated along topographic depressions, where it has an estimated thickness of between 3 m and 4 m. In the upper reaches of the catchment, the thickness of saprolite thins to less than 5 m and in places is totally absent.

In the area of the August 2005 landslide, the upper 3.5 m of Grade V and IV/V tuff is very disturbed. Recent movement in the form of open tension cracks up to 300 mm wide were observed to a depth of 1.5 m and open joints and fractures between 2 mm and 15 mm wide were observed to a depth of 3 m in the trial trenches. Older movement in the form of steeply inclined joints with up to 150 mm of infill was observed to a depth of 3.5 m to 4 m in the trial trenches. Further evidence of past movement in the form of joint infill 30 mm to 150 mm thick was observed in the Mazier samples at depths of up to 8 m.

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Bedrock at the landslide site predominantly comprises fine ash tuff with local areas of fine to coarse ash tuff, the exception being along the lower southerly spur, where coarse ash tuff was encountered in drillhole BH2. In addition, the tuff is slightly micaceous in parts and locally comprises hornfels indicating that contact metamorphism has occurred. Coarse ash tuff was not encountered in any of the other drillholes in the area, but was encountered in the lower portions of the drainage lines to the north and south of the landslide catchment during field mapping. This suggests that the coarse ash tuff possibly occurs in laterally impersistent lenses across the site. Grade II/III granite was encountered beneath the fine ash tuff in some of the existing drillholes along the toe of the hillside indicating an undulating profile beneath the fine ash tuff. A section across the toe of the hillside is presented in Figure 16.

A geomorphological plan of the site is shown in Figure 15. The August 2005 landslide occurred within a local catchment, which is smaller than the broader hillside catchments to the north and south of the landslide site. In addition, it contains relatively poorly developed drainage lines as compared to the well-defined, incised drainage lines within the adjoining hillside catchments.

The landslide catchment is located on the southern flank of a west-trending spur, which is interpreted as a remnant of an older landform. This spur is undermined on the northern flank by an incised drainage line, which could be structurally controlled given its distinct west northwest trend. In addition, the hillsides to the north and south of the landslide site are characterised by large areas of north northwest-south southeast trending rock outcrops with colluvium and talus deposits on the less steep ground below. In contrast, the southern flank of the spur and the landslide catchment form a more subdued depression with several possible relict landslides near the top of the landslide catchment (i.e. scars R4 and R9, Figure 5) and colluvium below.

The hydrogeology of the site is considered to be complex given the nature of the geology, geomorphology and distribution of superficial materials. Given the relatively thick soil mantle within the landslide catchment, it is considered that most precipitation falling onto the hillside would result in surface infiltration into the colluvium and saprolite. In addition, a greater degree of infiltration can be expected in the distressed area associated with the August 2005 landslide, where concentrated surface water flow along drainage feature DL3 was directed into the head of the distressed area (Figure 5). Taking into consideration the presence of laterally persistent tension cracks up to 1.5 m deep, it is considered that surface water would probably enter into the near-surface materials readily at this location, although it is not certain when these cracks developed. The numerous cracks and open joints observed within the near-surface materials would further promote water ingress into the ground.

Following direct infiltration, groundwater is likely to flow through the landslide catchment towards the crest of Slope No. 11SW-C/C72 at the toe of the hillside. During August and September 2005 and from May to September 2006, strong water flows were observed from some of the raking drains installed in Slope No. 11SW-C/C72 at the toe of the hillside below the landslide site, and seepage flows were observed within an area of standing water at the crest of the cut slope (Figure 5). These observations indicate groundwater flow at or close to the bedrock near the crest of the cut slope. Monitoring records of installations indicate the main groundwater table along the toe of the catchment to be at a depth of about 4.5 m. It is possible that the granite-tuff contact below the cut slope (Figures 3 and 15) forms a less permeable horizon, which leads to higher groundwater in the bedrock at this location.

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This in turn could lead to higher groundwater levels within the bedrock and saprolite further upslope below the August 2005 landslide. However, groundwater was measured at a depth of about 11.5 m to 12.8 m below the main scarp of the August 2005 landslide (Figure 3 and Section 7.3), which suggests that the main groundwater table was located within bedrock and was therefore relatively deep below the distressed zone during the monitoring period.

10. KINEMATIC ANALYSIS

A stereoplot of joint measurements taken during field mapping and GI works has identified four principal joint sets, J1 to J4, and four secondary joint sets, J5 to J8 (Table 5 and Figure 17). Joints J1 and J2 are low angle joints (17° to 22°) dipping in a southeasterly direction (140°) and a westerly (267°) direction respectively. Joints J3 and J4 are steeply inclined joints (69° to 74°) dipping in a westerly direction (280°) and a southwesterly (227°) direction respectively. The secondary joints J5 to J8 are all steeply inclined joints (60° to 88°) dipping in various directions.

Stereographic projection of the joint set data on an equal-area stereoplot assuming a slope angle of 35º and a dip direction of the hillside of 215º, shows that the hillside could be liable to plane failure (for joint set J2) for a low effective friction angle of around 20º, even discounting any potential effect of groundwater pressure (Figure 18). The potential for wedge failure does exist between joint sets J3 and J8, but this mode of failure has not been observed in the relict landslide scars identified on site.

Based on the site observations, the basal plane of movement might have been, at least in part, controlled by a combination of low angle joint sets J1 and J2, which is in line with the findings of the kinematic analysis. Furthermore, steep joints, in particular joint sets J4 and J6, appear to control the formation of the back scarps of most of the relict landslides.

11. RAINFALL ANALYSIS

Rainfall data were obtained from GEO automatic raingauge, No. H03, located at Block 44, Baguio Villa, Pok Fu Lam about 1,000 m to the south of the landslide site (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory and the GEO.

The daily rainfall recorded by the raingauge in July and August 2005, together with the hourly rainfall from 19 to 21 August 2005, is shown in Figure 19.

Table 6 shows the maximum rolling rainfall intensities and their estimated return periods for different durations for the 19 to 21 August 2005 rainstorm. Based on Lam & Leung (1994), the maximum 31-day rolling rainfall of 1122 mm was the most severe with an estimated return period of 29 years. Based on Evans & Yu (2001), the maximum 24 hour rolling rainfall of 364 mm was the most severe with an estimated return period of 24 years at raingauge No. H03.

The maximum rolling rainfall of the 19 to 21 August 2005 rainstorm recorded by raingauge H03 has been compared with records of previous rainstorms (Figure 20). The

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August 2005 rainstorm was the most severe in terms of medium to long duration rainfall in excess of 20 hours.

12. DISCUSSION

12.1 Nature of the Landslide

The August 2005 landslide comprised limited slope movement of an approximately 1,000 m^2 area of distressed natural hillside above Queen Mary Hospital without complete detachment. The movement has resulted in the formation of a 17 m long main scarp and a distressed area comprising laterally persistent tension cracks, minor scarps, hummocky ground and subtle breaks of slope. Across the main scarp, a maximum of about 0.8 m of horizontal and vertical displacement has occurred.

Below the main scarp, a 300 mm wide shear plane was identified. The shear plane was steeply inclined and could be traced over a length of about 2 m, where it appeared to converge with a silty seam at a depth of about 2 m below original ground level (Figure 7). The silty seam lies between a layer of bouldery colluvium and Grade IV fine ash tuff. The silty seam of disturbed material along the shear plane tracked along the surface of the Grade IV tuff, the profile of which is controlled by shallow to moderately inclined joints intercepted by steeply inclined joints, forming a stepped profile. The seam contained brecciated fragments of tuff in a silty matrix, indicating that the material had been sheared and reworked. The seam appears to be a pre-existing shear plane that has been reactivated in the August 2005 landslide. This postulation is supported by the presence of pre-existing tension cracks passing through the upper colluvium layer, which end abruptly above the seam, with no evidence of the tension cracks extending into the underlying Grade IV tuff. Furthermore, relict instability has been identified immediately above the main scarp of the August 2005 landslide.

In the area slightly downslope of the main scarp, the mechanisms of movement were more complex and not easily characterised. The discrete shear plane noted below the main scarp was no longer present. Instead, movement had predominantly taken place along relict joints within the Grade V and Grade IV/V tuff. Evidence of both recent movement, in the form of 5 mm to 20 mm wide cracks with no infill, and historical movement, in the form of infilled cracks up to 150 mm wide, was identified. Between ground level and a depth of 2 m to 2.5 m, movement had largely taken place along steeply inclined joints. Below 2 m to 2.5 m, movements appeared to flatten out along shallow to moderately inclined joints, but the exact depth to the basal plane of movement was not clear.

About 40 m downslope of the main scarp in the lower portion of the distressed area, ground bulging of 0.5 m to 1 m high was identified within the colluvium. It is not certain if the bulging relates to recent or old, possibly shallow and intermittent slope movements.

Therefore, the majority of recent movement associated with the August 2005 landslide appears to have occurred in the upper portion of the distressed area located between the main scarp and the pipeline. Observations show that the recent movement has manifested as a series of complex, discontinuous and stepped displacements along relict joints within the tuff. Lateral movement has been accommodated by a general opening of sub-vertical joints to more than 3 m depths over a wide area resulting in localised ground bulging and subtle surface deformations.

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The limited mobility of the August 2005 landslide appears to be related to the complex joint-controlled nature of the failure and to the relatively gentle inclination of the hillslope. Movement has predominantly taken place along shallow to moderately inclined (5° to 30°) joints with varied dip directions, stepped and undulating surfaces. This has probably resulted in increased joint interlock within the sliding mass, thereby limiting downslope movements.

The exact depth of movement of the August 2005 landslide is not very well defined. Observations from the trial trenches indicate that much of the recent movement has occurred within 3 m of the ground surface. However, inspection of Mazier samples taken from the drillholes identified joint infill at depths of between 4 m and 8 m, which indicates deeper seated distress that was probably associated with historical movements.

Deformation at the colluvium/weathered rock interface observed near the main scarp of the August 2005 landslide could be caused by regression of the ground movement within the weathered rock below the colluvium.

12.2 Probable Causes of the Landslide

The close correlation between heavy rainfall and the time of the slope movement suggests that the recent distress was triggered by rainfall. There is no evidence or record of any leakage from either the above ground water main or the covered service reservoir prior to the August 2005 landslide. This investigation has established that the geological and hydrogeological setting of the site probably contributed to the failure.

The catchment within which the August 2005 landslide occurred probably has an ongoing process of intermittent slope movement. API and field mapping have identified numerous relict landslide scars, hummocky ground and breaks of slope within the catchment. Pre-existing tension cracks up to 300 mm wide and 1.5 m deep were identified within colluvium. Evidence for both recent movement, in the form of 5 mm to 20 mm wide cracks with no infill, and historical movement, in the form of infilled cracks up to 150 mm wide and 4 m deep were identified in Grade V tuff. Infilled cracks within the fine ash tuff were common in most of the trial trenches indicating a history of disturbance within the tuff.

Adversely orientated relict joints within the fine ash tuff at the landslide site appear to have had a controlling influence on the failure mode. Steeply inclined joints have formed release surfaces, and shallow to moderately inclined joints have formed planes of sliding movement. The presence of infill along joint surfaces has reduced frictional resistance and provided preferential planes of weakness.

The complex hydrogeological setting of the hillside, comprising mainly a thin mantle of colluvium with tension cracks overlying Grade IV/V tuff with open joints is favourable to the build-up of water pressure arising from surface infiltration. Manganese staining on some of the joint surfaces as observed in the trial trenches indicates the presence of water flowing through open joints in the past.

Seven drainage features are present within the landslide catchment, one of which flows directly into the crown of the August 2005 landslide where pre-existing tension cracks were identified. During the prolonged and heavy rainfall in August 2005, concentrated runoff

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would have entered the tension cracks leading to the wetting up of near-surface materials and formation of cleft water pressures within tension cracks and open joints and the possibility of a perched water table at the colluvium/tuff interface. It is likely that this build-up of water pressure during intense rainfall caused the recent slope movement and disrupted the pressurised water-carrying utility pipe.

The possibility of the landslide being affected by leakage of the pipeline traversing the landslide site is remote, given that the majority of movement appears to have occurred above the pipeline. Furthermore, stress relief associated with the formation of relatively small cut slopes at the toe of the hillside, is unlikely to have contributed to the extensive distress higher up on the natural hillside, given the lack of any obvious evidence of distress near the crests of the relatively small cut slopes.

13. CONCLUSIONS

It is concluded that the August 2005 landslide on the natural hillside above Queen Mary Hospital was probably caused by a transient build-up of water pressure in the ground mass following prolonged and heavy rainfall. The rainfall with a return period of 29 years was the most severe in terms of medium to long duration rainfall recorded by the adjacent GEO automatic raingauge, No. H03, since it was installed in 1978.

The failure was, to a large extent, controlled by relict joints within the Grade IV and Grade V fine ash tuff at the landslide site, where the steeply inclined joints formed release surfaces and the shallow to moderately inclined joints formed planes of sliding. The failure appears to have been a reactivation of previous slope movements based on the evidence of pre-existing soil infilled joints and cracks within the near-surface ground mass.

The landslide catchment probably has an ongoing process of intermittent movements as evidenced by the presence of numerous relict landslide scars, hummocky ground, breaks of slope and infilled old cracks in the decomposed tuff. This is likely to result in progressive deterioration of the hillside condition as the distressed ground becomes loosened with more extensive crack formations.

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Table 1 – Records of Manual Groundwater Monitoring

	Drillholes Installed Previously																Drillholes Installed Under Current Study			
Drillhole No.	BH3(GR) Upper		BH3(GR) Lower		BH4(GR)		DH1(E)		DH2(E) Lower				BH2(B)				BH1_P2 (Upper)		BH1_P1 (Lower)	
Piezometer / Standpipe	Standpipe		Standpipe		Standpipe		Piezometer		Standpipe				Standpipe				Piezometer		Piezometer	
Ground Level (m PD)	168.66		168.66		167.45		171.31		170.00				179.11				203.22		203.22	
Piezometer Depth (m bgl)	4.5		10.2		6.00		4.50		10.74				15.00				7.50		13.50	
Piezometer Level (m PD)	164.16		158.51		161.45		166.81		159.26				164.11				195.82		189.82	
Date	Measured Groundwater Level		Measured Groundwater Level		Measured Groundwater Level		Measured Groundwater Level		Measured Groundwater Level		Buckets from 5.5 to 10m @ 0.5m intervals		Measured Groundwater Level		Buckets from 1 to 7m @ 1m intervals		Measured Groundwater Level		Measured Groundwater Level	
	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)	Depth (m)	Level (mPD)
04-Jan-06	4.4	164.3	4.4	164.2	Dry	-	*		*		*		*		*		Dry	-	12.5	190.8
03-Mar-06	4.5	164.2	4.7	164.0	Dry	-	Dry	-	9.7	160.3	8.0	162.0	13.8	165.3	7.0	172.1	Dry	-	12.8	190.6
29-Mar-06	4.6	164.1	4.6	164.1	Dry	-	Dry	-	9.7	160.3	9.5	160.5	14.1	165.1	Dry	-	Dry	-	12.9	190.4
04-May-06	4.6	164.1	4.6	164.1	Dry	-	Dry	-	10.1	159.9	8.5	161.5	11.6	167.5	7.0	172.1	Dry	-	Blocked	
25-May-06	4.5	164.2	4.5	164.2	Dry	-	Dry	-	9.9	160.2	10.0	160.0	11.6	167.5	Dry	-	Dry	-	Blocked	
24-Jun-06	4.1	164.5	4.2	164.5	Dry	-	Dry	-	9.7	160.3	9.5	160.5	11.4	167.7	Dry	-	Dry	-	Blocked	
July	Slope stabilization works ongoing – no records taken																			
18-Aug-06	4.0	164.6	4.2	164.5	4.3	163.11	*		*		*		*		*		*		Blocked	

Notes:
1. * Indicates water levels not able to be measured on this date.
2. Refer to Figure 6 for locations of drillholes.
3. Halcrow buckets were installed in DH2(E) and BH2(B) only.

Table 2 – Summary of Automatic Groundwater Monitoring Devices

G.I.	Drillhole No.	Ground Level (mPD)	Type of Installation	Depth of Pipe below Ground Level (mbgL)	Pipe Top above Ground Level (m)	GWL Monitoring Device	Depth of Device below Ground Level (mbgL)	Date & Time of GWL Monitoring Device Installation / Removal	GWL below Pipe Top at Time of Device Installation (m)	Remarks
Previous Drillholes	BH3(GR)_Upper	168.66	Standpipe	4.50	0.05	MiniTROLL (S/N 17332)	4.00	- 1st installation : 4/1/2006 (13:13) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:30)	4.44 (4/1/2006)	
	BH3(GR)_Lower	168.66	Standpipe	10.20	0.05	BaroTROLL (S/N 17401)	0.70	- 1st installation : 4/1/2006 (13:30) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:30) - Removed : 4/9/2006	4.49 (4/1/2006)	
						MiniTROLL (S/N 17257)	9.50	- 1st installation : 4/1/2006 (13:30) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:30)	4.49 (4/1/2006)	
	BH4(GR)	167.45	Standpipe	6.00	0.03	MiniTROLL (S/N 17635)	5.50	- 1st installation : 4/1/2006 (12:40) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:20)	Dry (4/1/2006)	No pipe cap. Water suspected as having entered piezo from ground surface during rainstorms.
	DH1(E)	168.12	Standpipe	4.60	0.04	MiniTROLL (S/N 17311)	4.00	- 1st installation : 4/1/2006 (14:52) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:55) - Removed : 4/9/2006	Dry (4/1/2006)	
Drillholes in Nov 2005	BH1_P2 (Upper)	203.32	Piezometer	7.50	0.19	MiniTROLL (S/N 17377)	7.00	- 1st installation : 4/1/2006 (15:42) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:45)	Dry (4/1/2006)	
						BaroTROLL (S/N 17397)	1.00	- 1st installation : 4/1/2006 (15:42) - Removed : 29/3/2006 - 2nd installation : 11/7/2006 (13:45)	Dry (4/1/2006)	
	BH1_P1 (Lower)	203.32	Piezometer	13.50	0.19	MiniTROLL (S/N 17826)	13.00	- 1st installation : 4/1/2006 (15:32) - Removed : 29/3/2006	12.69 (4/1/2006)	Blocked at the depth 8.19m below pipe top (Noted on 4/5/2006 groundwater measurement) - REMOVED
Drillholes in Aug 2006	D1	233.75	Standpipe	30.27	0.20	Levelogger (S/N 26777)	29.00	- 1st installation : 6/9/2006 (12:00)	18.40 (6/9/2006)	
	D2_Upper	237.87	Piezometer	5.90	0.15	BaroTROLL (S/N 17401)	5.00	- 1st installation : 6/9/2006 (12:00)	Dry (6/9/2006)	
	D2_Lower	237.87	Piezometer	13.50	0.15	MiniTROLL (S/N 17311)	13.00	- 1st installation : 6/9/2006 (12:00)	Dry (6/9/2006)	

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

GI Station No.	Sample Depth (m)	Material	Test Results: Moisture Content (%)	Initial Bulk Density (Mg/m^3)	Initial Dry Density (Mg/m^3)	Triaxial Compression Test: Type of Test	Confining Pressure (kPa)	p' (kPa)	q (kPa)	Behaviour
TT2	2.0	CDT	11	2.01	1.81	M	30	145	110	Dilative
							60	211	153	
							120	382	267	
	3.0	CDT	15	1.9	1.65	M	40	115	82	Dilative
							80	200	135	
							160	404	261	
TT3	0.5	COLL	20	1.92	1.6	S	25	85	47	Dilative
TT4	0.5	COLL	19	1.89	1.59	S	25	67	38	Dilative
	1.0	COLL	21	1.79	1.48	S	30	69	37	Dilative
	2.0	COLL	21	1.92	1.59	M	25	57	34	Dilative
							50	86	49	
							100	150	84	
TT5	1.5	CDT	15	1.88	1.63	S	35	125	82	Dilative
	2.0	CDT	15	1.83	1.59	S	40	92	54	Dilative
	2.5	CDT	14	1.98	1.74	M	30	87	58	Dilative
							60	146	93	
							120	332	204	
TT6	2.5	COLL	19	2.02	1.7	M	30	83	54	Dilative
							60	160	99	
							120	257	150	
	3.0	COLL	23	1.8	1.46	M	35	68	38	Dilative
							70	100	52	
							140	180	97	
25-DH1 (E)*	3.6-4.6	CDT	Data not available					131.9	90.9	Data not available
								177.2	117.2	
								246.1	160.1	
25-DH3 (E)*	3.6-4.6	CDT						61.7	38.7	
								102.9	59.9	
								204.4	117.4	
25-DH5 (E)*	?	CDT						48.8	32.8	
								70.3	45.3	
								103.	66.3	
	3.6-4.6	CDT						27.4	15.4	
								43.6	23.6	
								76	41	
	5.2-6.2	CDT						70.8	47.8	
								122.9	76.9	
								182.3	111.3	
BH1 (GR)#	1.5-2.5	CDT						43.63	33.63	
								75.51	55.51	
								101.55	71.55	

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

GI Station No.	Sample Depth (m)	Material	Test Results							
			Moisture Content (%)	Initial Bulk Density (Mg/m^3)	Initial Dry Density (Mg/m^3)	Triaxial Compression Test				
						Type of Test	Confining Pressure (kPa)	p' (kPa)	q (kPa)	Behaviour
BH1 (GR)*	5.5-6.5	CDT	Data not available					91.03	70.03	Data not available
								159.93	119.83	
								200.78.	140.78	
	7.5-8.5	CDT						106.62	76.62	
								195.61	135.61	
								273.46	183.46	

Note:

* Triaxial tests were completed by Gold Ram (GR) and Enpack (E) during the GI works for Slopes Nos. 11SW-C/C72 and 11SW-C/C73 respectively.

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Table 4 – Summary of Direct Shear Box Test Results on Colluvium

Trial Trench No.	Sample			Moisture Content (%)	Bulk Density (Mg/M^3)	Dry Density (Mg/M^3)	Normal Stress (kPa)	Shear Stress (kPa)	Soil Description	Soil Type
	No.	Type	Depth (m)							
TT3	4/1	BLK	0.90	18	1.75	1.48	20	13	Light brown, slightly gravelly, sandy SILT	Colluvium
TT3	4/2	BLK	0.90	18	1.78	1.51	30	24	Light brown, slightly gravelly, sandy SILT	Colluvium
TT3	4/3	BLK	0.90	18	1.87	1.58	50	30	Light brown, slightly gravelly, sandy SILT	Colluvium
TT3	4/4	BLK	0.90	18	1.89	1.60	100	58	Light brown, slightly gravelly, sandy SILT	Colluvium
TT4	3/1	BLK	0.50	13	1.65	1.46	20	15	Light brown, slightly gravelly, sandy SILT	Colluvium
TT4	3/2	BLK	0.50	13	1.69	1.50	30	25	Light brown, slightly gravelly, sandy SILT	Colluvium
TT4	3/3	BLK	0.50	13	1.70	1.51	50	30	Light brown, slightly gravelly, sandy SILT	Colluvium
TT4	3/4	BLK	0.50	13	1.58	1.40	100	45	Light brown, slightly gravelly, sandy SILT	Colluvium

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Table 5 – Summary of Joint Set Data

Joint Set No.	Dip Angle (Degrees)	Dip Direction (Degrees)	Remarks
1	17	140	Principal Joint Sets
2	22	267	
3	69	280	
4	74	227	
5	72	044	Secondary Joint Sets
6	88	204	
7	79	324	
8	60	137	

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Table 6 - Maximum Rolling Rainfall at GEO Raingauge No. H03 for Selected Durations Preceding the Landslide on 20 August 2005 and Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (See Notes 3)	Estimated Return Period (Years) (See Notes 2)	
			Lam & Leung (1994)	Evans & Yu (2001)
5 Minutes	8	08:35 on 19 Aug 2005	1	1
15 Minutes	13	08:40 on 19 Aug 2005	1	1
1 Hour	36	22:05 on 19 Aug 2005	1	1
2 Hours	65	22:10 on 19 Aug 2005	1	2
4 Hours	125.5	22:35 on 19 Aug 2005	2	4
12 Hours	193	06:00 on 20 Aug 2005	3	4
24 Hours	364	18:25 on 20 Aug 2005	9	24
48 Hours	474.5	22:30 on 20 Aug 2005	15	20
4 Days	553.5	23:55 on 20 Aug 2005	13	12
7 Days	571.5	23:55 on 20 Aug 2005	9	11
15 Days	800	23:55 on 20 Aug 2005	15	11
31 Days	1122	23:55 on 20 Aug 2005	29	14

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and Appendix B of Evans & Yu (2001)
(3) The landslide is assumed to have occurred around midnight on 20 August 2005.
(4) The nearest GEO raingauge to the landslide site is raingauge No. H03 which is located about 1 km to the south of the landslide site and is operational since September 1978

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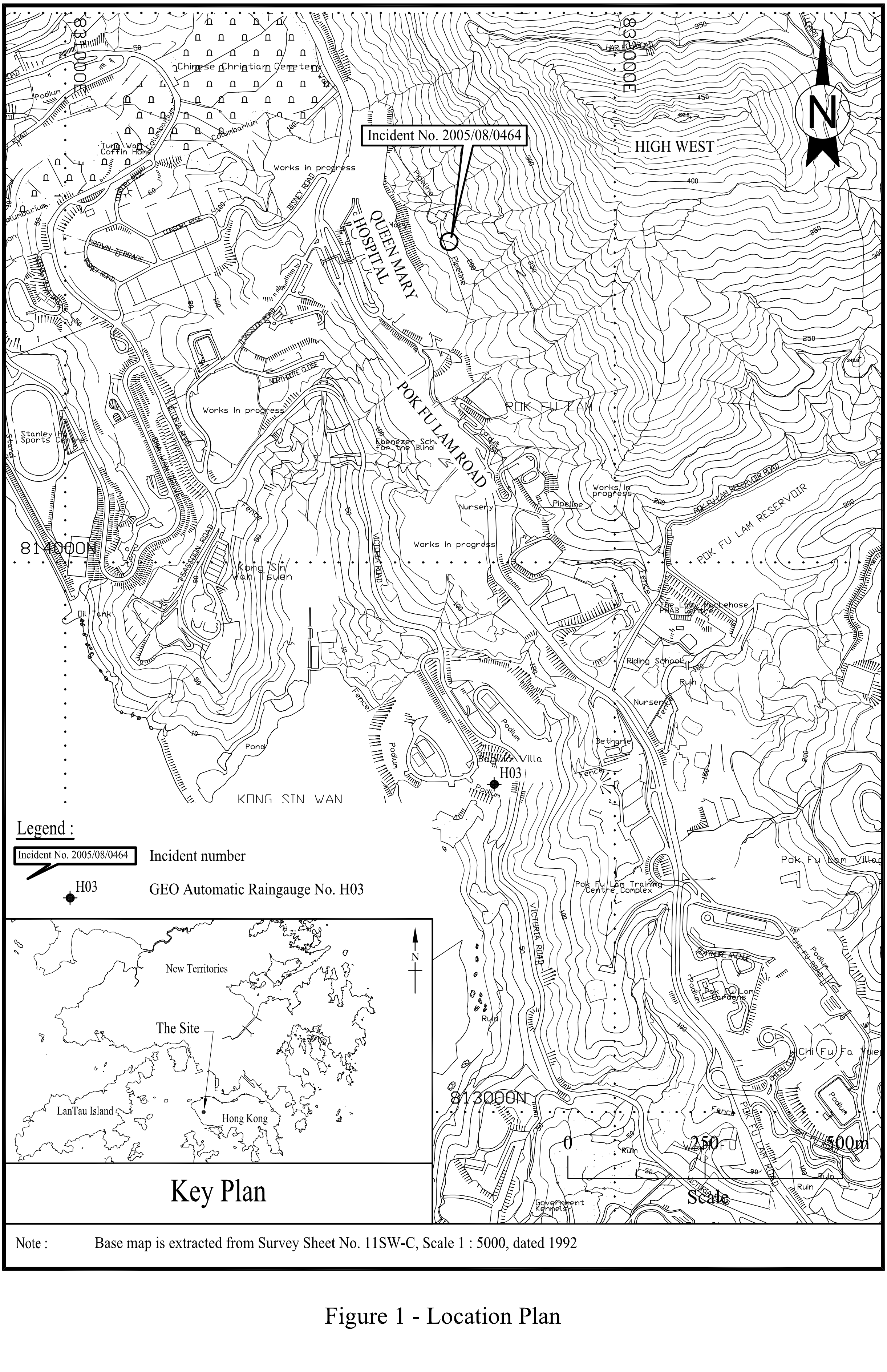

Note : Base map is extracted from Survey Sheet No. 11SW-C, Scale 1 : 5000, dated 1992

Figure 1 - Location Plan

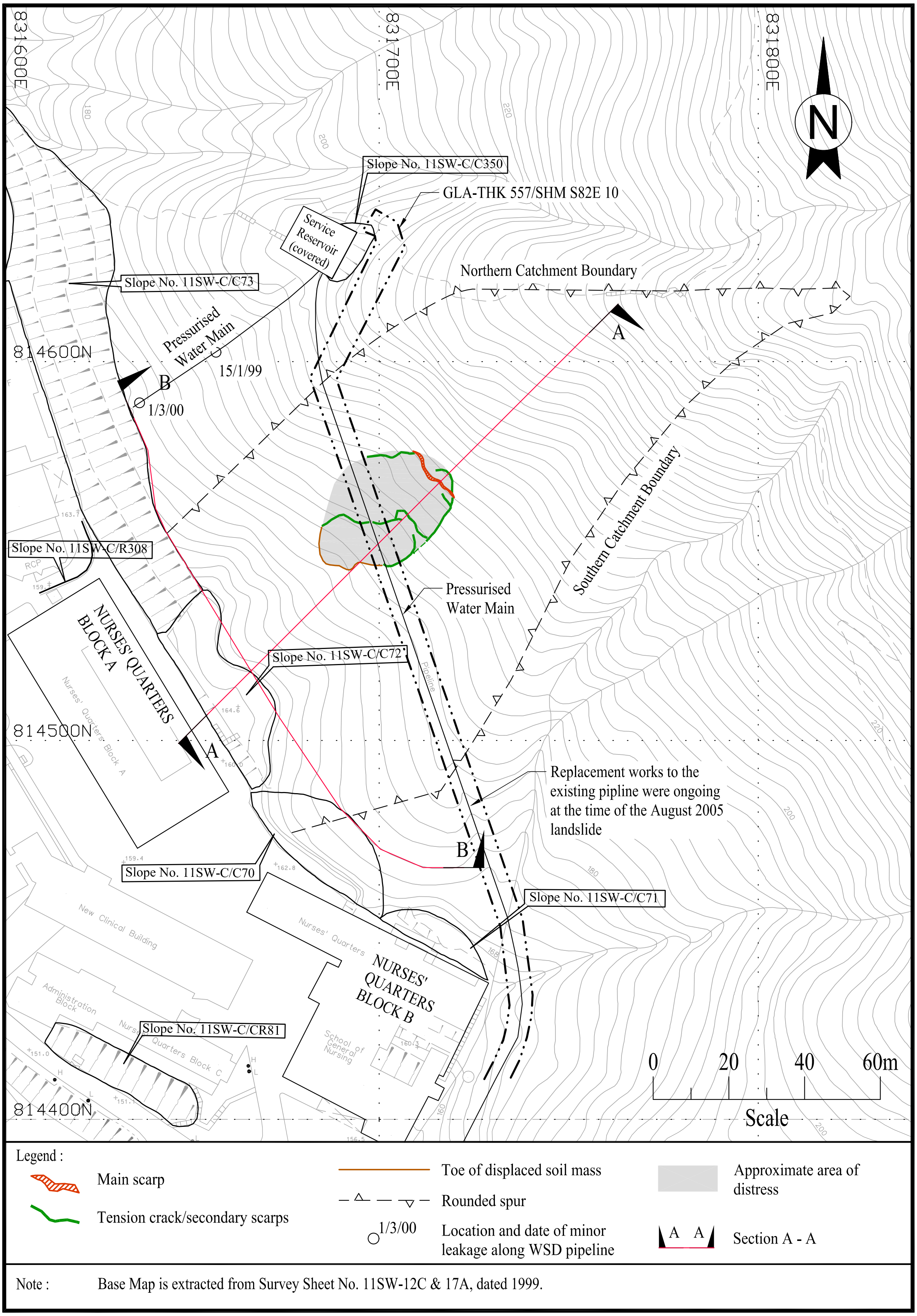

Figure 2 - Site Plan

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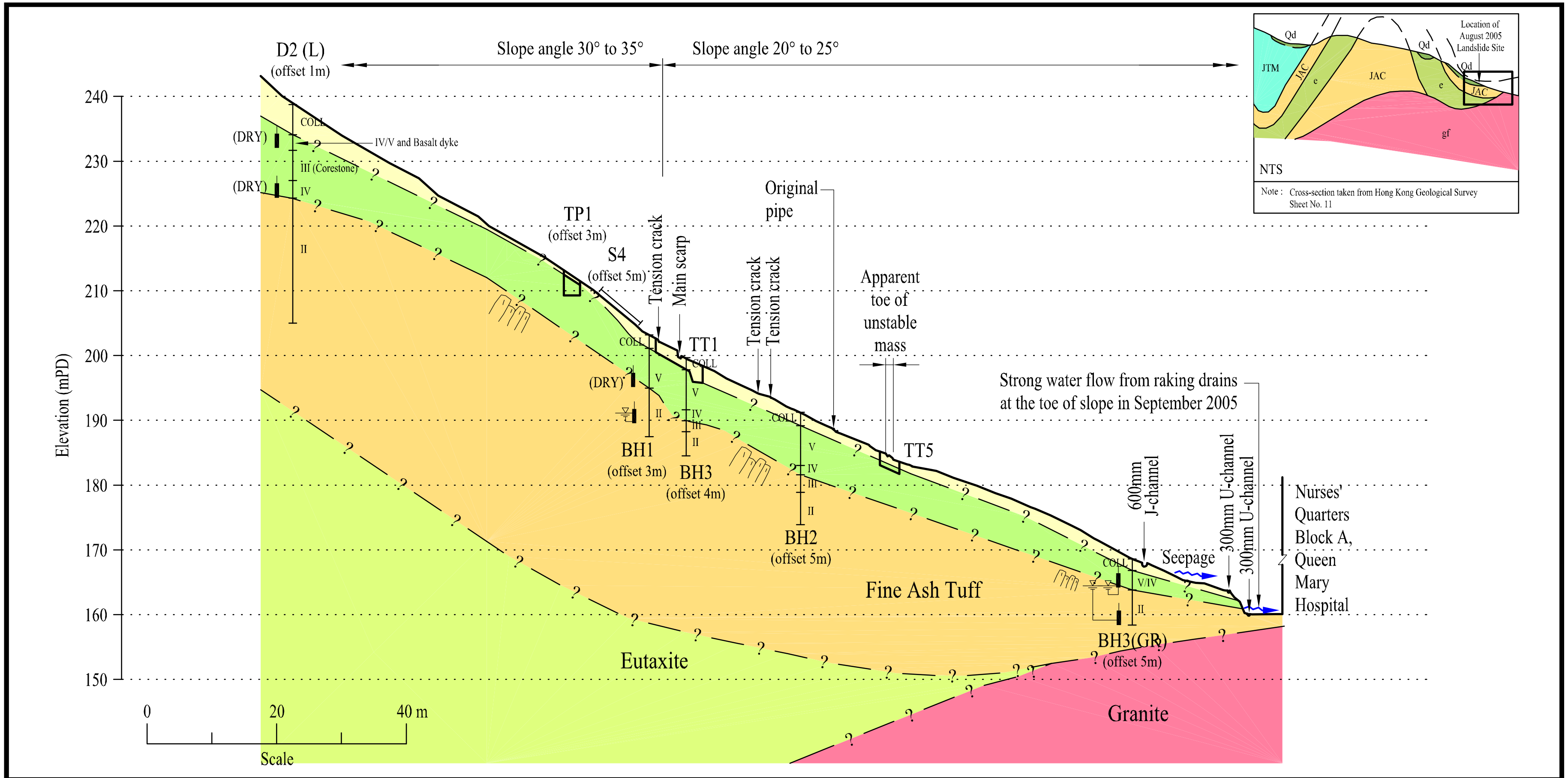

Legend :

— ? —	Possible geological boundary
(yellow)	Colluvium
(green)	Compelety Decomposed Tuff

COLL Colluvium

Weather grades in tuff:

V	Completely decomposed
IV	Highly decomposed
III	Moderately decomposed
II	Slightly decomposed

S4	Vegetation Strip S4 undertaken by FGS in November 2005
TT1	Trial Trench TT1 undertaken by FGS in November 2005
BH1	Borehole BH1 undertaken by FGS in November 2005
TP1	Trial Pit TP1 undertaken by FGS in November 2005
BH1 (GR)	Drillhole BH1 undertaken by Gold Ram Engineering in January 1998
D2 (L)	Drillhole D2 undertaken by Lam Geotechincs Ltd. in August 2006

Notes :

(1) Geological boundaries between fine ash vitric tuff, eutaxite and granite are based on information in the Hong Kong Geological Survey Sheet 1:20000, Series HGM20 Sheet No. 11.

(2) Refer to Figure 6 for location of ground investigation stations.

Figure 3 - Section A - A

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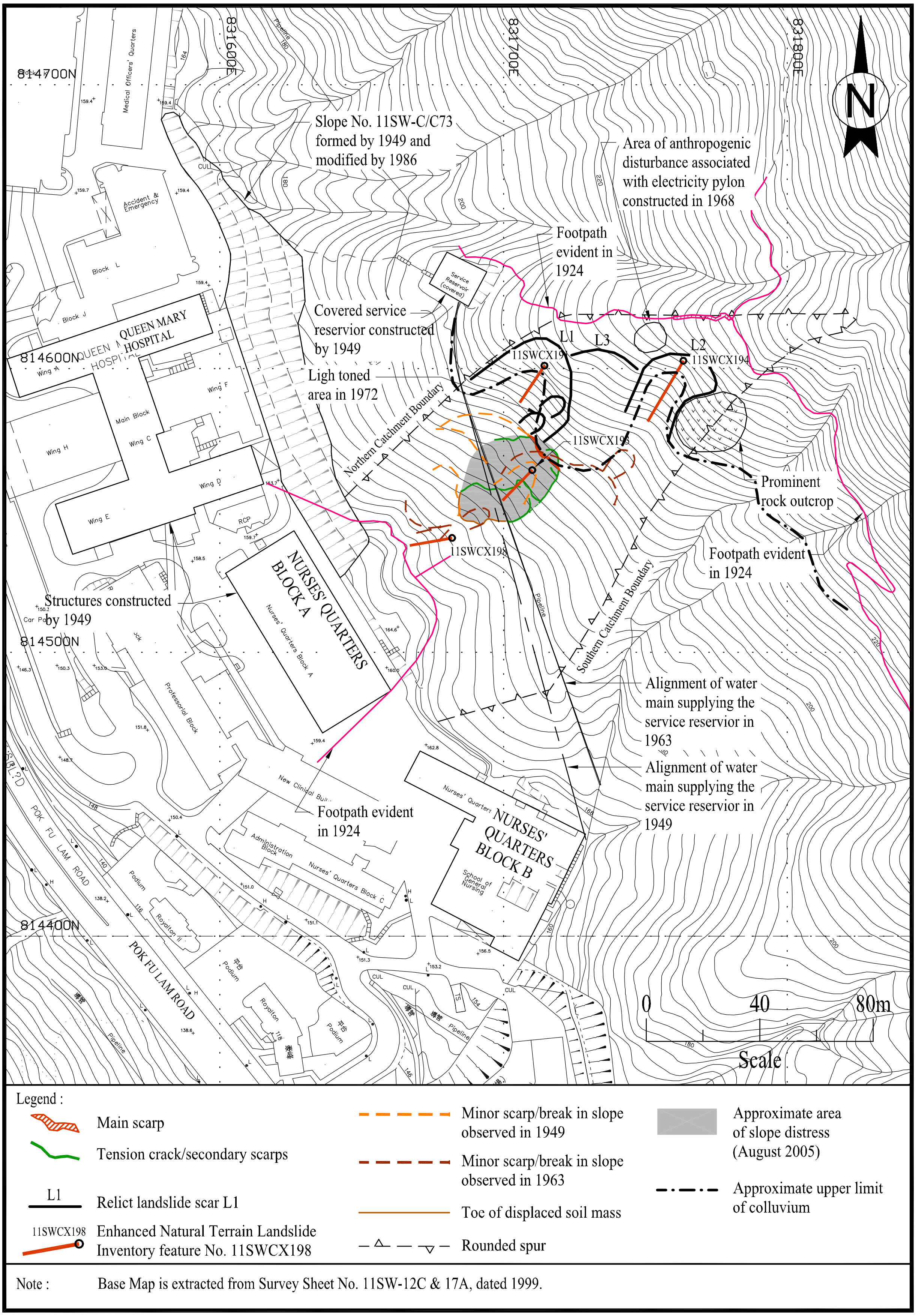

Figure 4 - Plan of Development History and Past Instability

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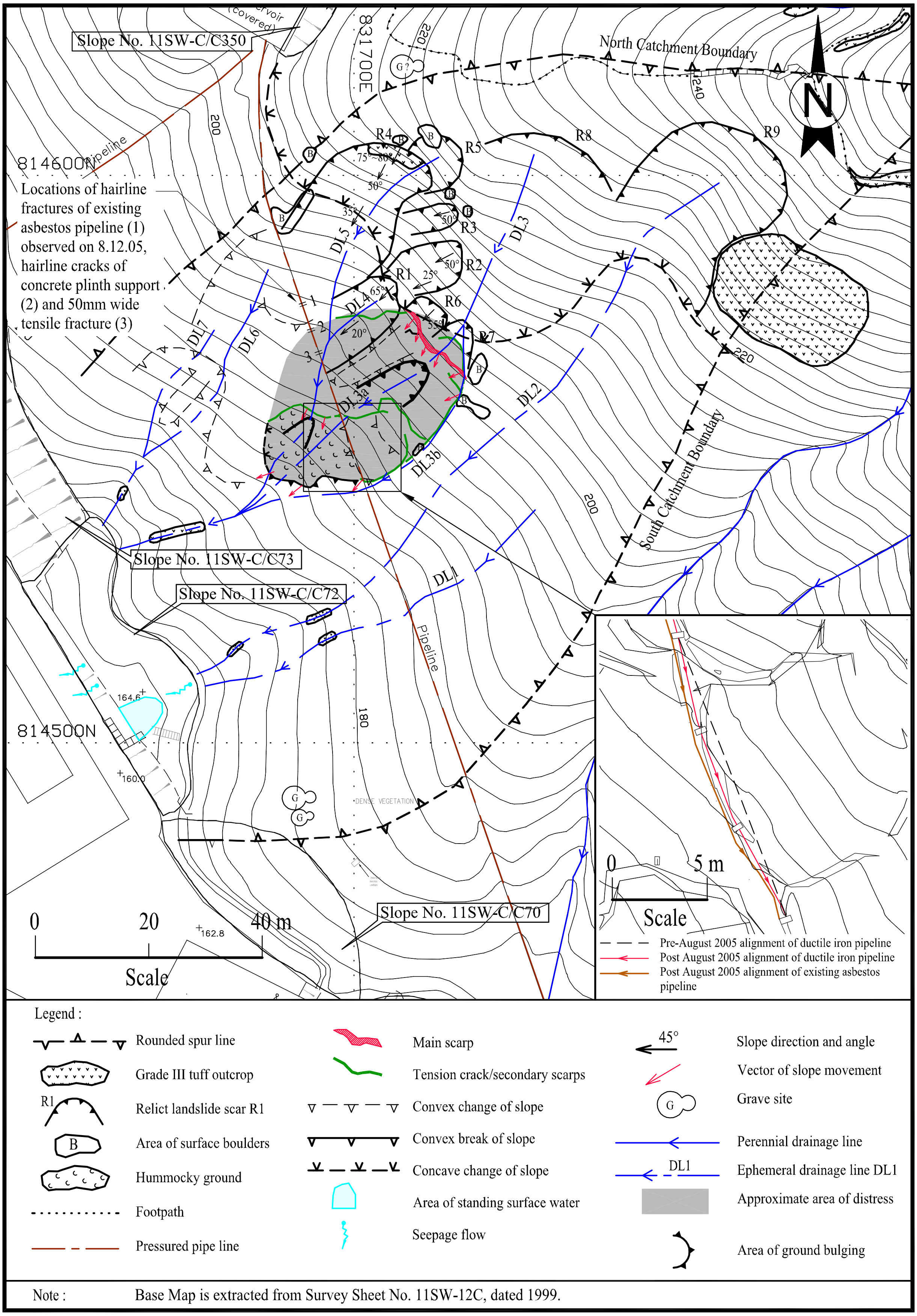

Figure 5 - Detailed Field Mapping Plan

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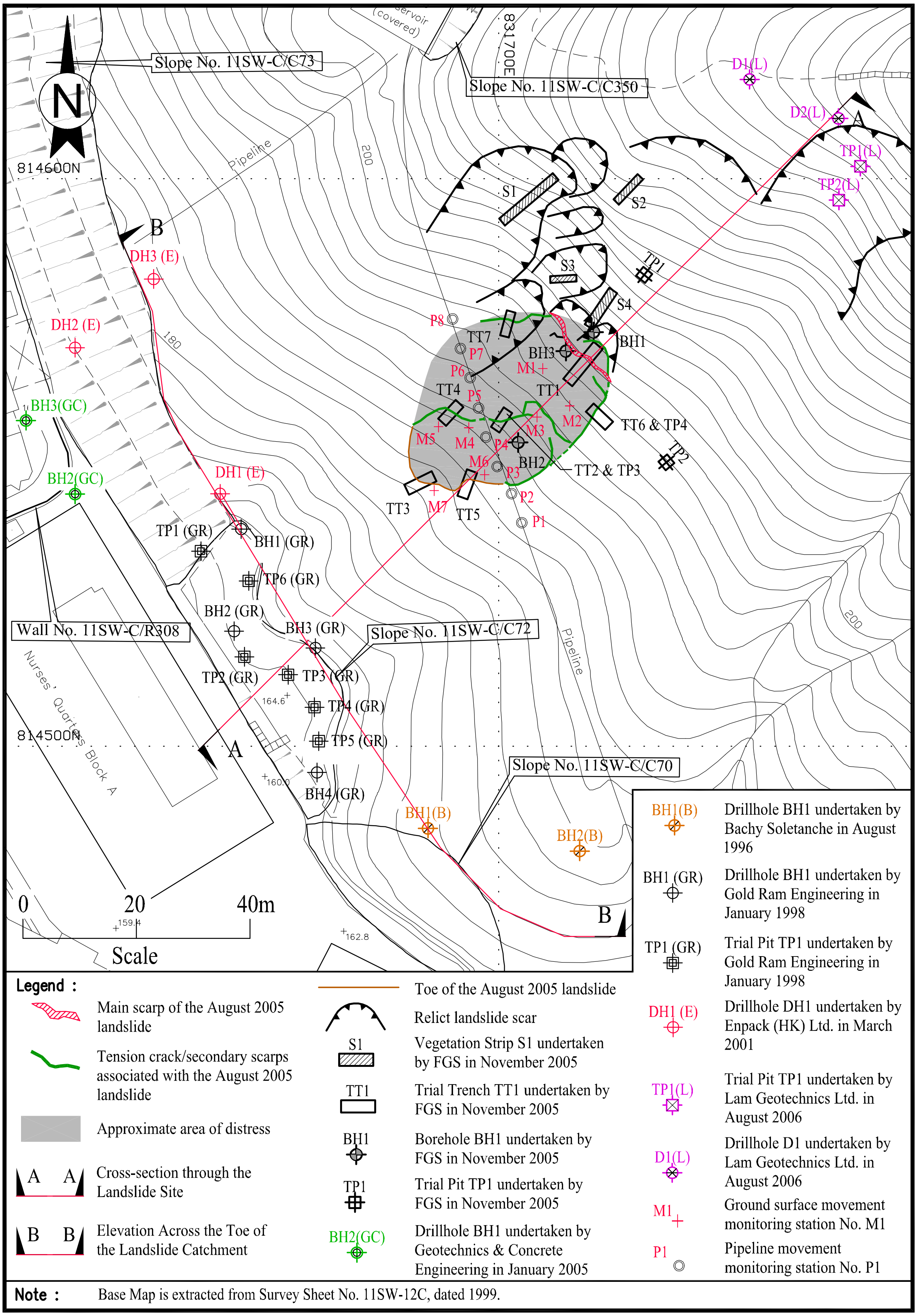

Figure 6 - Ground Investigation Location Plan

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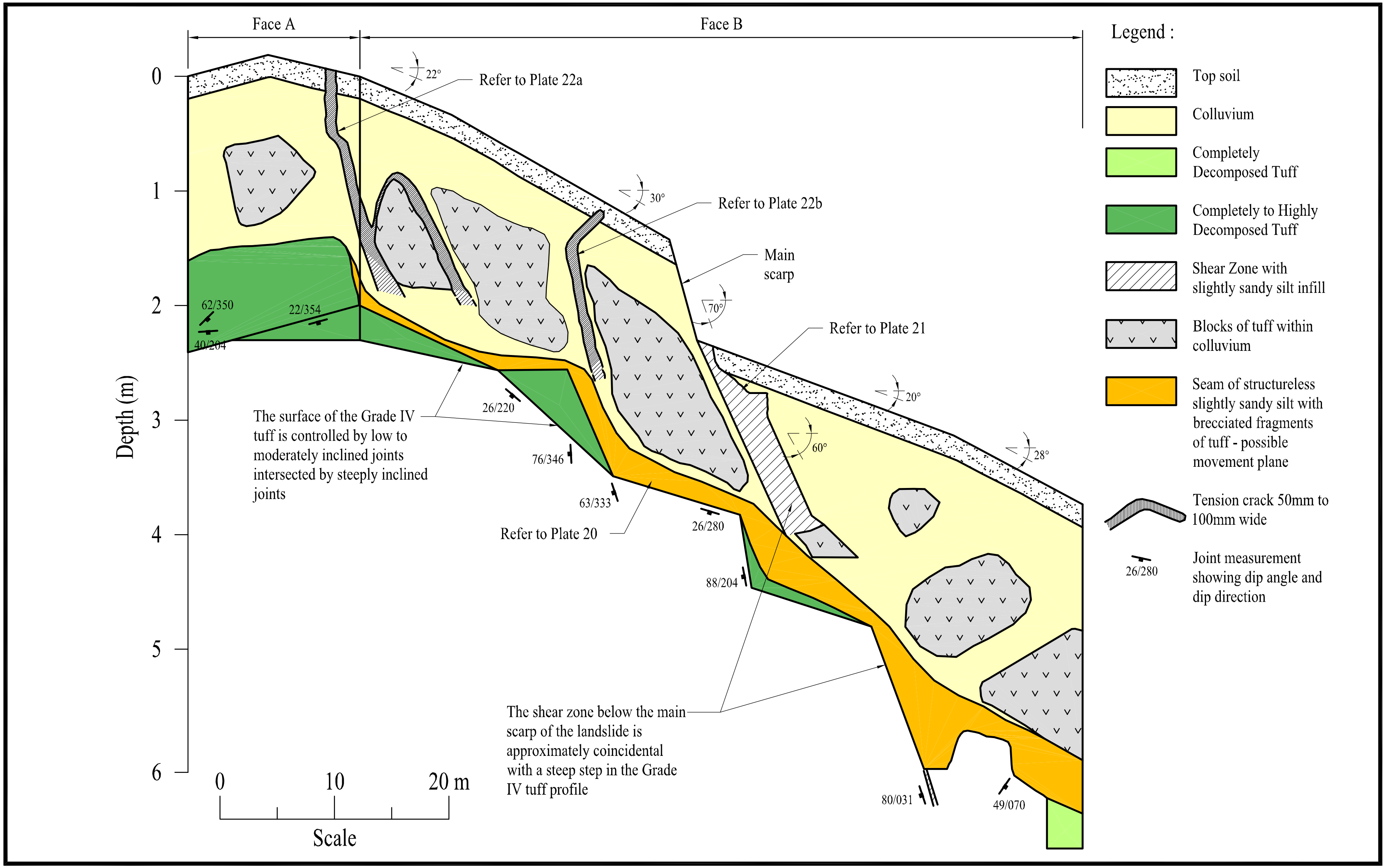

Figure 7 - Trial Trench TT1

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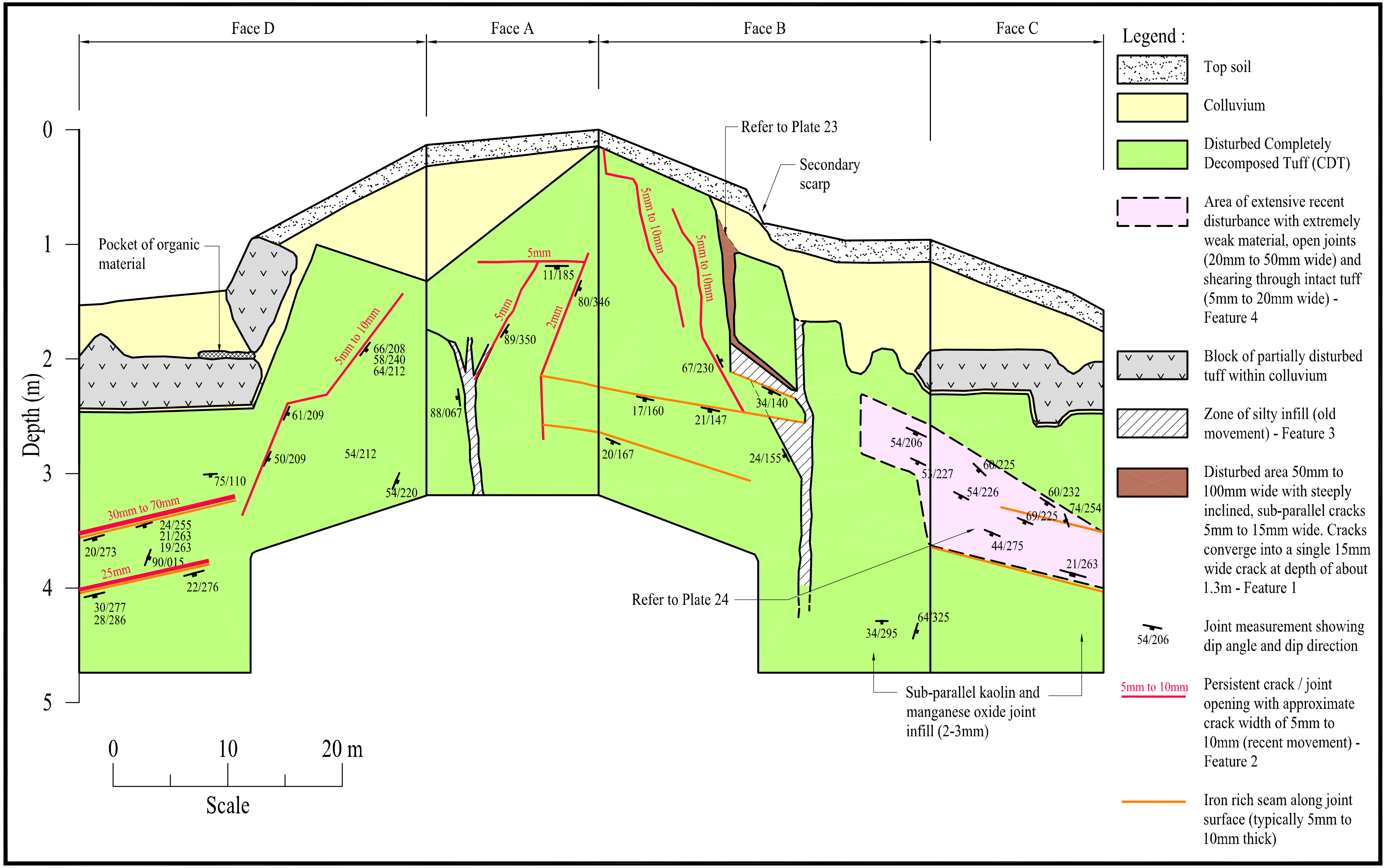

Figure 8 - Trial Trench TT2

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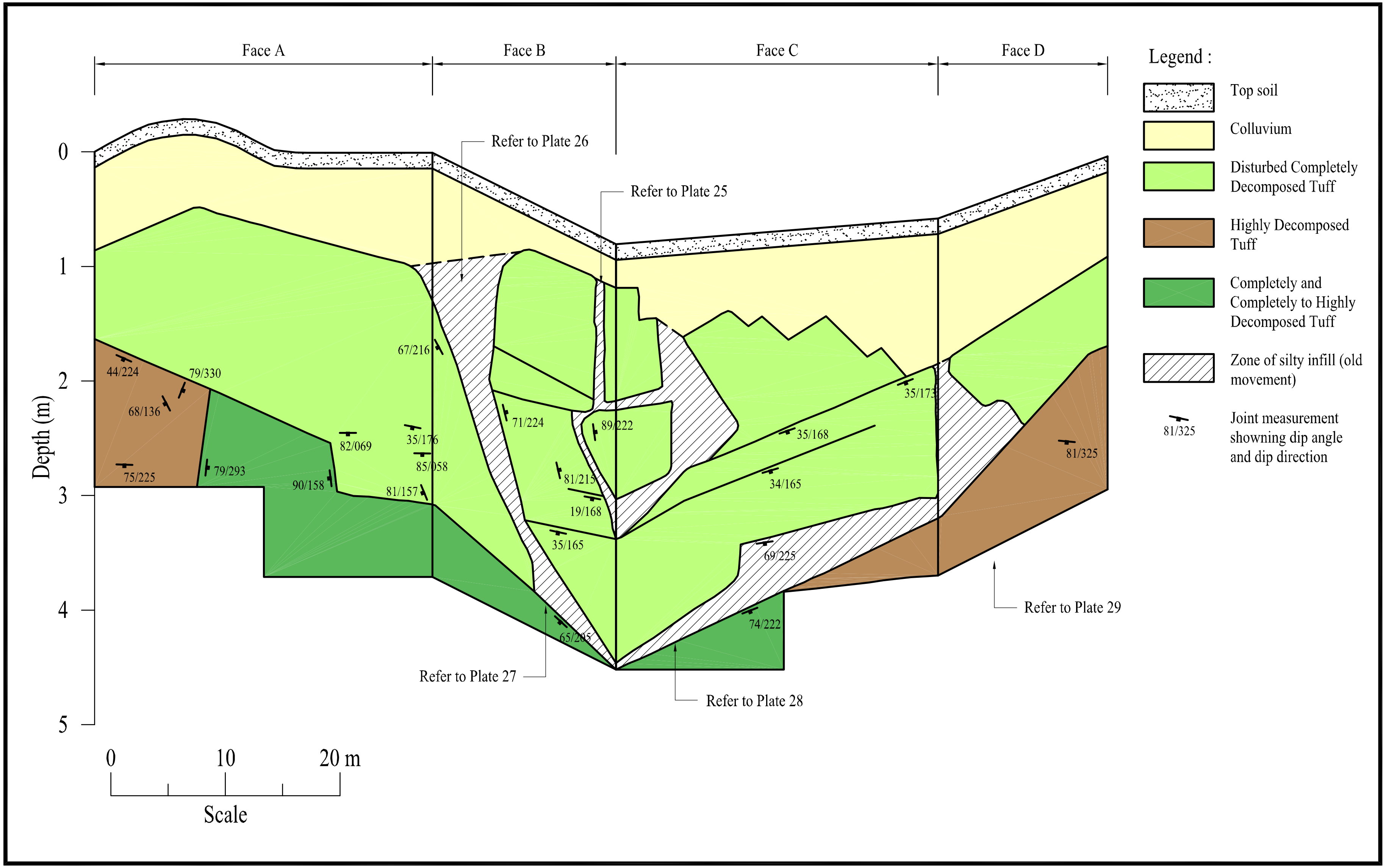

Figure 9 - Trial Trench TT6

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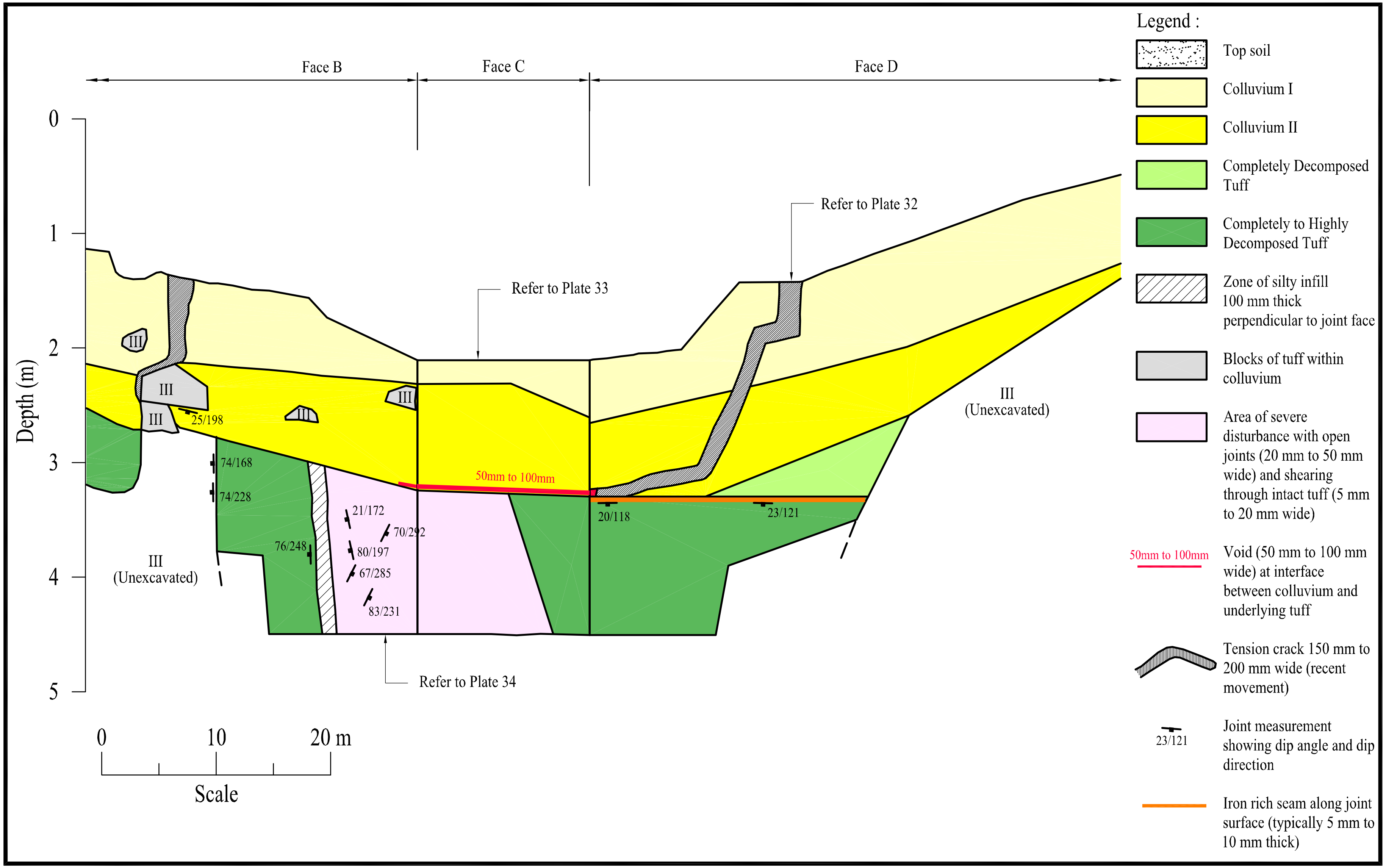

Figure 10 - Trial Trench TT7

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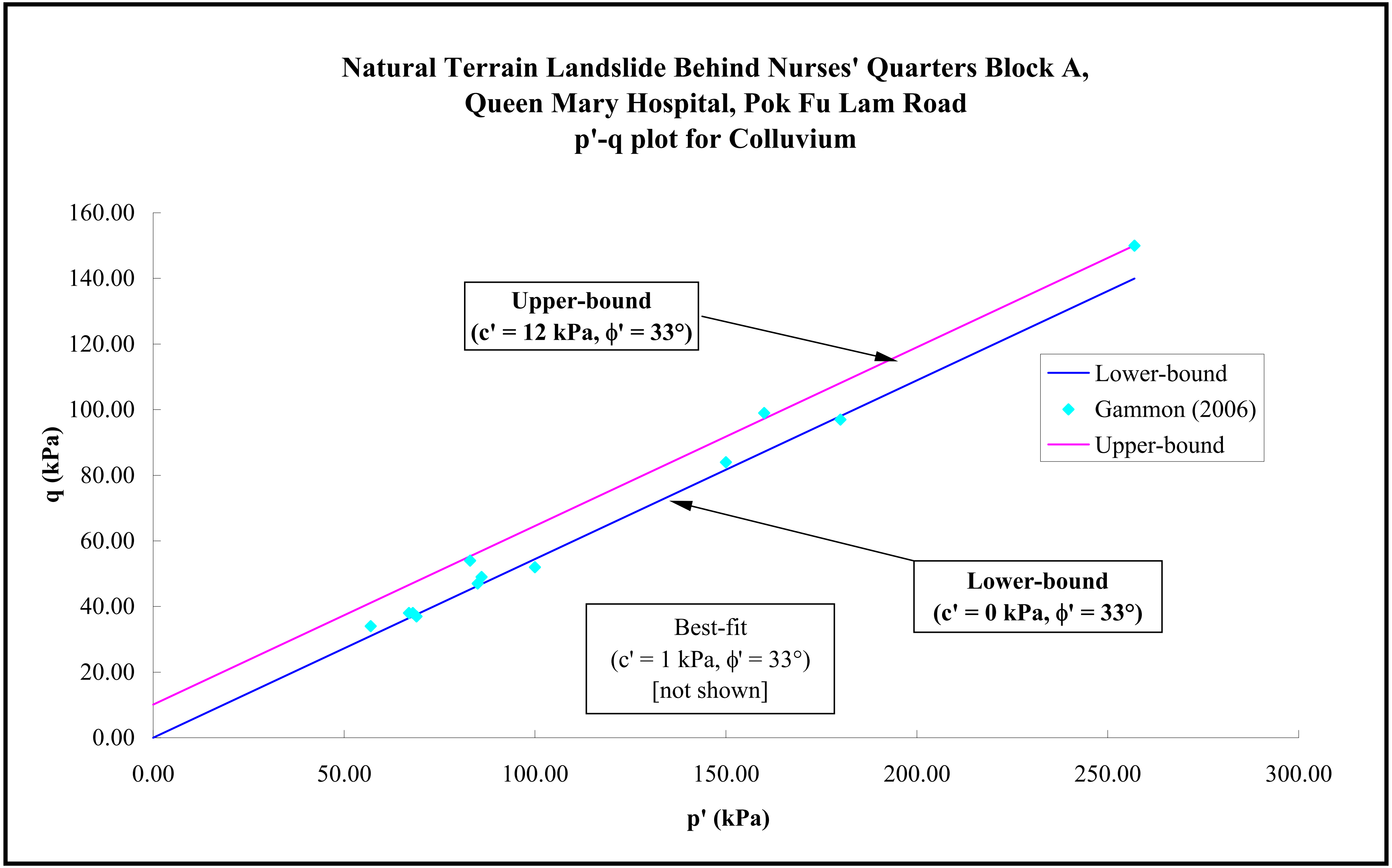

Figure 11 - p'-q Plot for Colluvium

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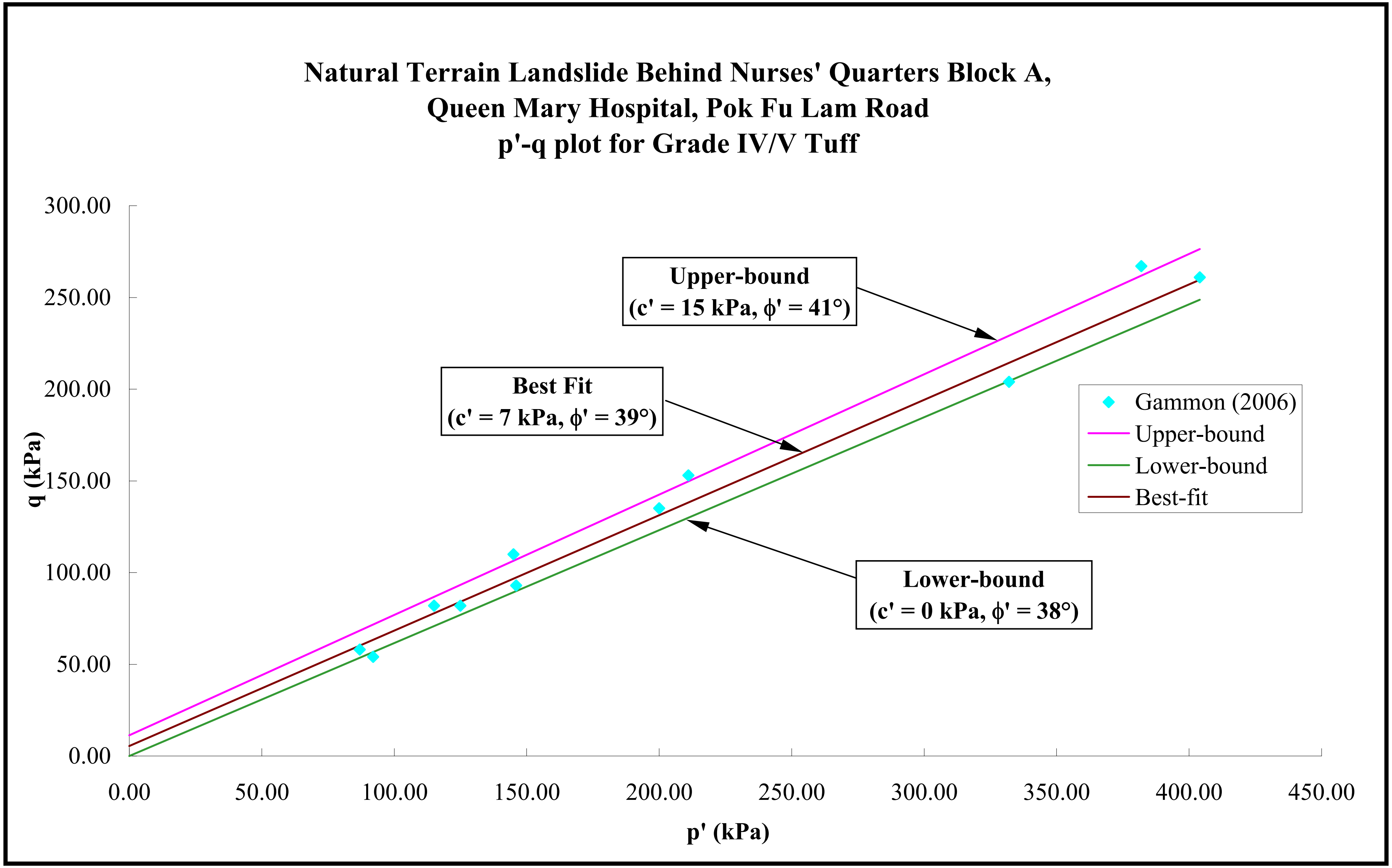

Figure 12 - p'-q Plot for Grade IV/V Tuff

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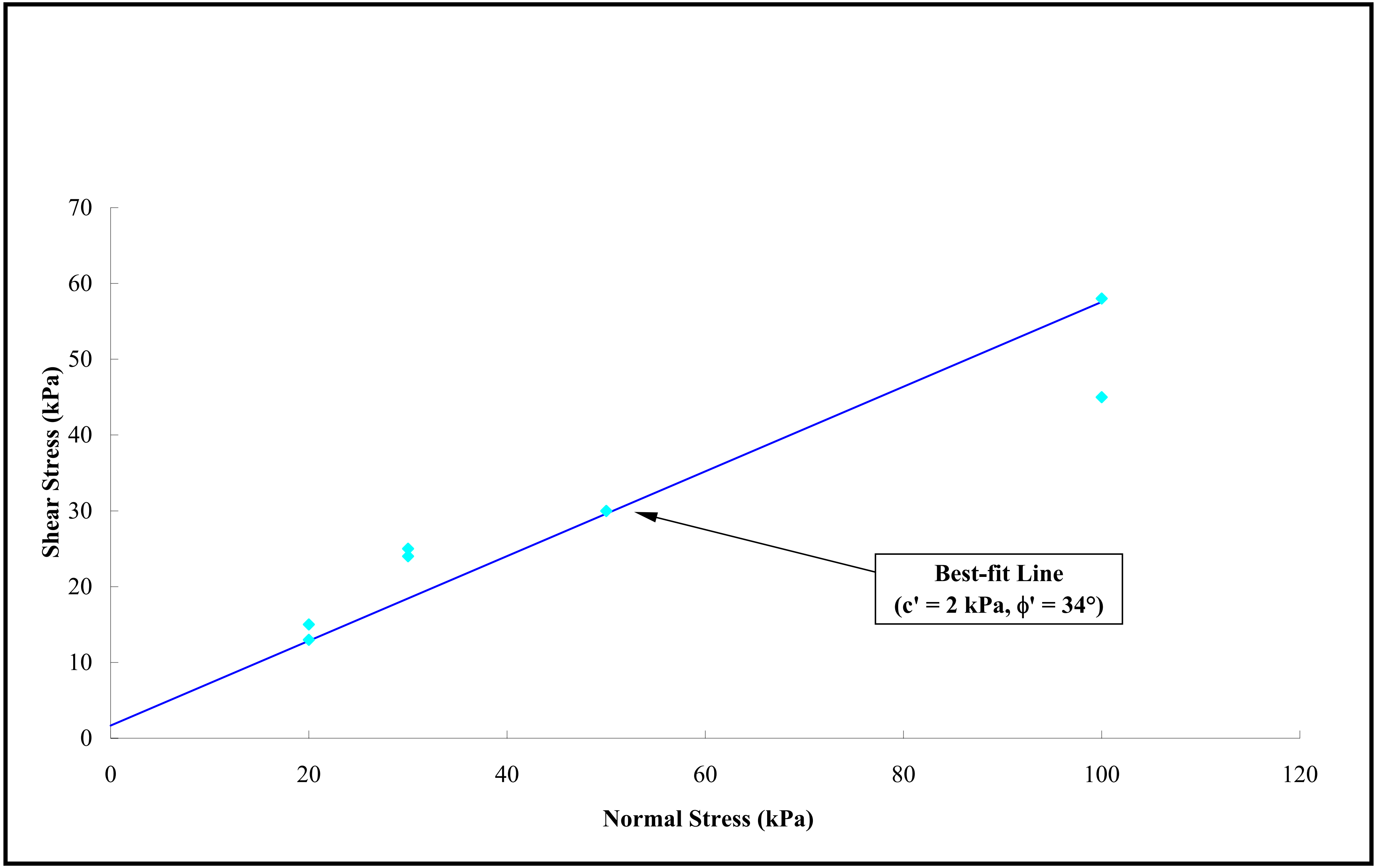

Figure 13 - Shear Box Test Results for Colluvium

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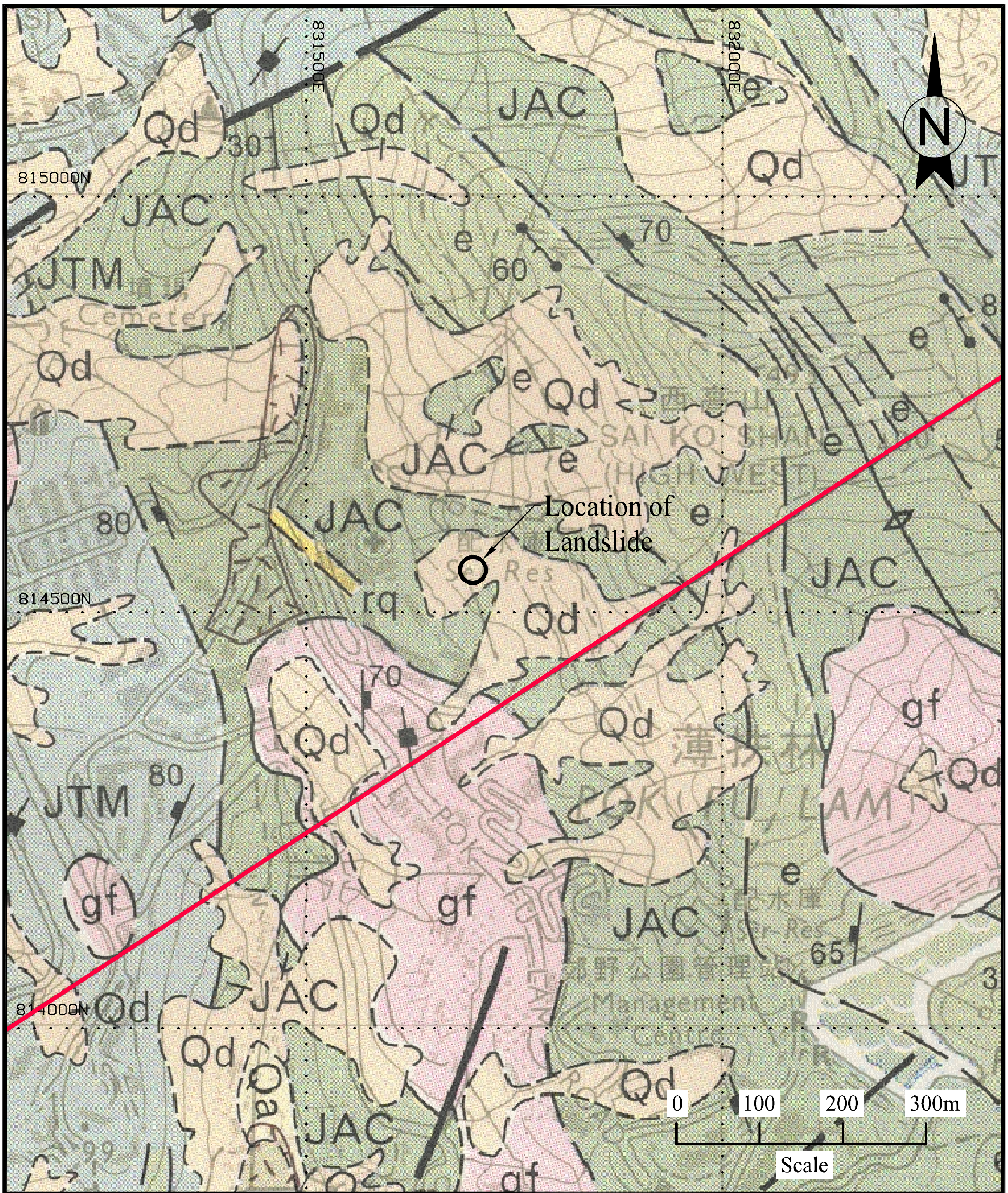

Legend :

JAC	Fine ash vitric tuff	Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix		Fault (Dashed line denotes uncertainty)
rq	Quartzphyric rhyolite	50	Jointing (50° dip)		Photogeological lineament
gf	Fine-grained granite, <2mm		Geological Boundary		Anticline axial trace
e	Eutaxite		Geological Section Line (refer to Figure 3)		

Note : Base Map is extracted from Solid and Superfical Geology Map No. HGM20, Sheet 11, dated 1986.

Figure 14 - Regional Geology Plan

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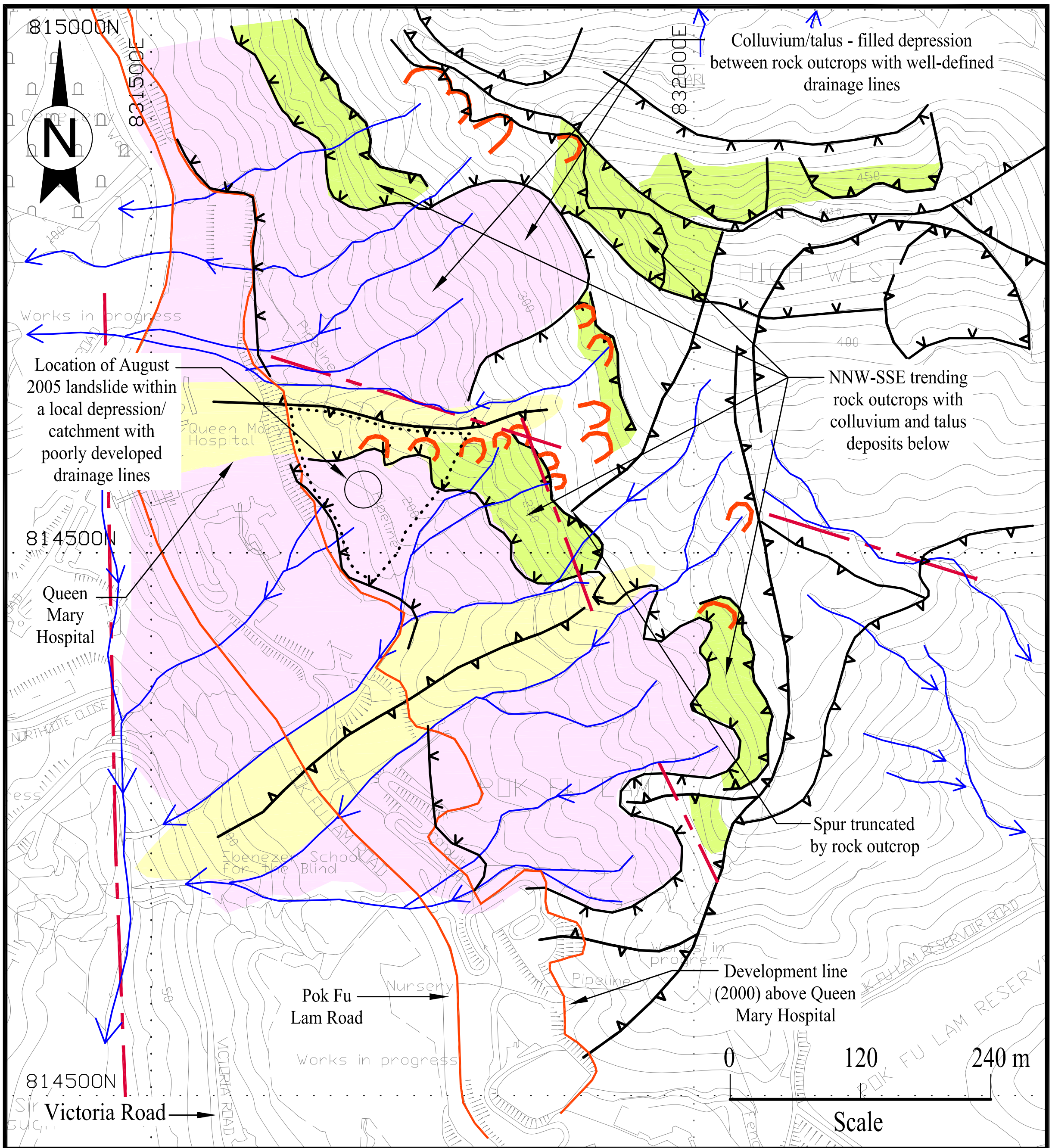

Legend :

- Major ridge or spur
- Major convex break in slope
- Major concave break in slope
- Well-defined, incised drainage lines (predominantly ephemeral)
- Photolineament
- Some possible relict landslide depressions
- Rock at or near to surface (Fall face terrain unit)
- Residual soil /saprolite with some colluvium/talus (Upper convex terrain and transportational midslope terrain)
- Spurs representing possible remnants of older landforms (comprising saprolite and/or colluvium)
- Undifferentiated colluvium and talus (Colluvial midslope terrain)
- Catchment containing the August 2005 landslide

Notes :
(1) Base Map is extracted from Survey Sheet No. 11SW-C, dated 2000.
(2) Based on review of low-level aerial photographs taken in 1963.
(3) Terrain unit descriptions are based on Dalrymple et al (1968).

Figure 15 - Geomorphology Plan

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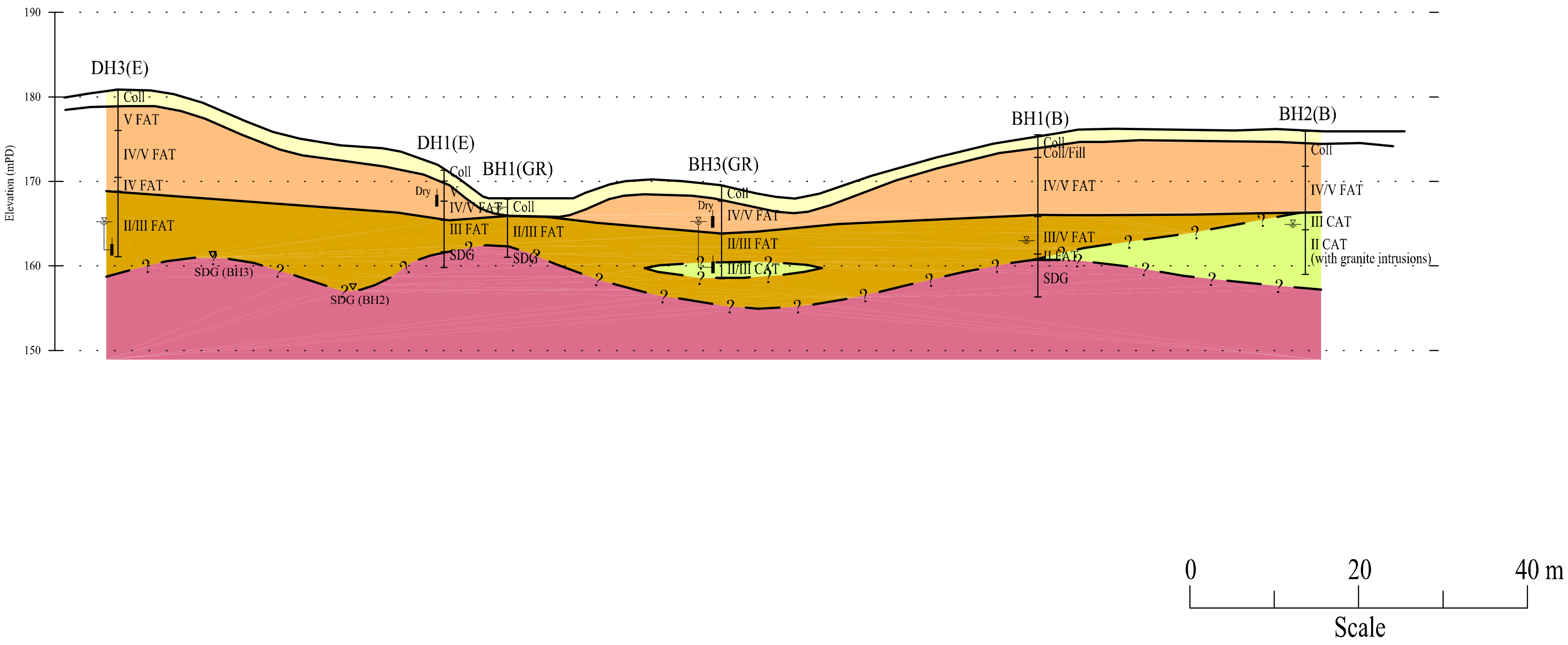

Legend : BH1 Drillhole BH1; Coll Colluvium; V FAT Grade V fine ash tuff; II/III CAT Grade II/III coarse ash tuff; SDG Grade II granite; Colluvium; Grade IV/V fine ash tuff; Grade II/III fine ash tuff; Grade II/III coarse ash tuff; Grade II/III granite

Notes : (1) Refer to Figure 6 for location of elevation and drillholes.
(2) The tuff will have been affected by contact metamorphism above the granite.

Figure 16 - Section B - B

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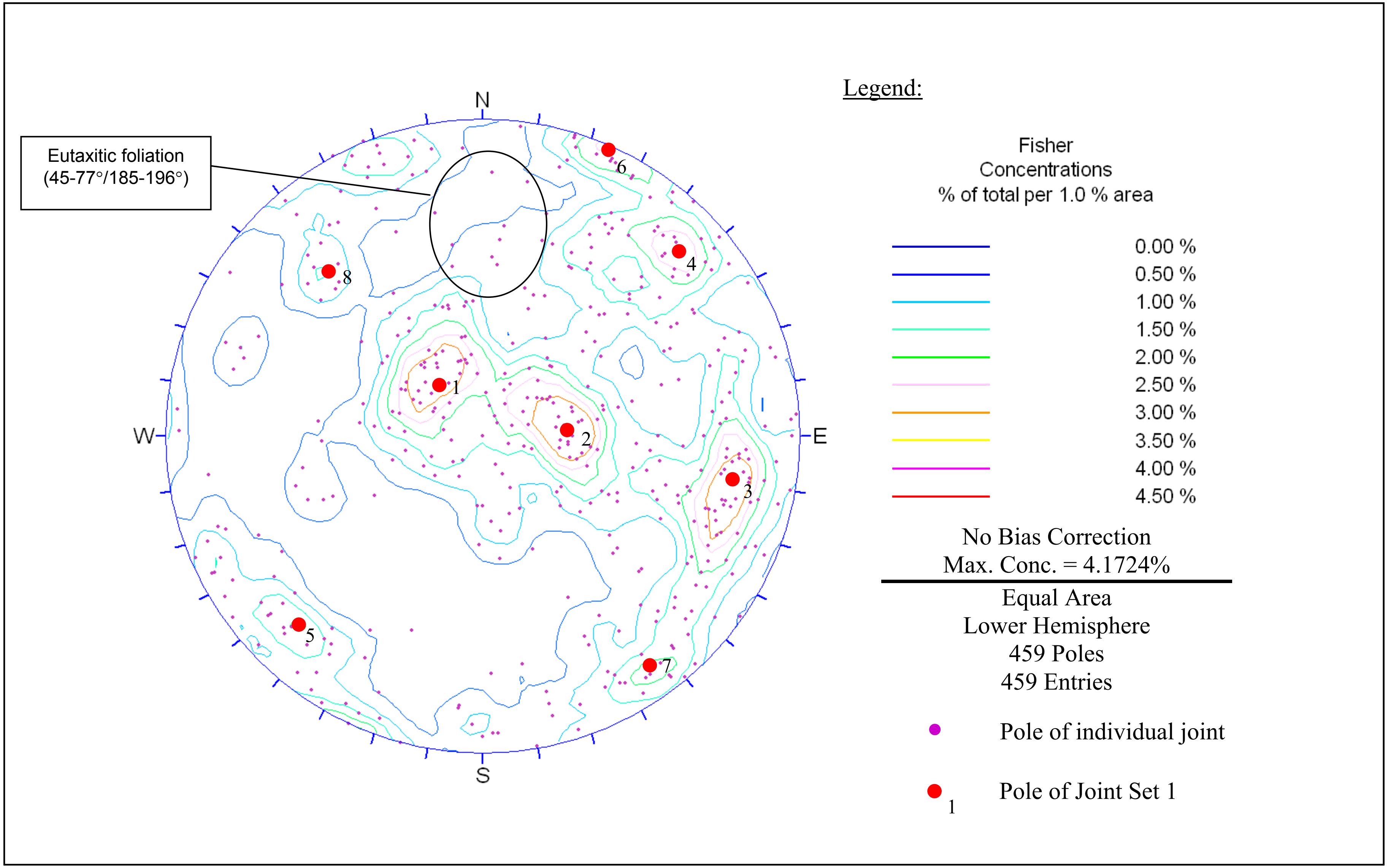

Figure 17 – Pole Concentration Contour for Joint Measurements

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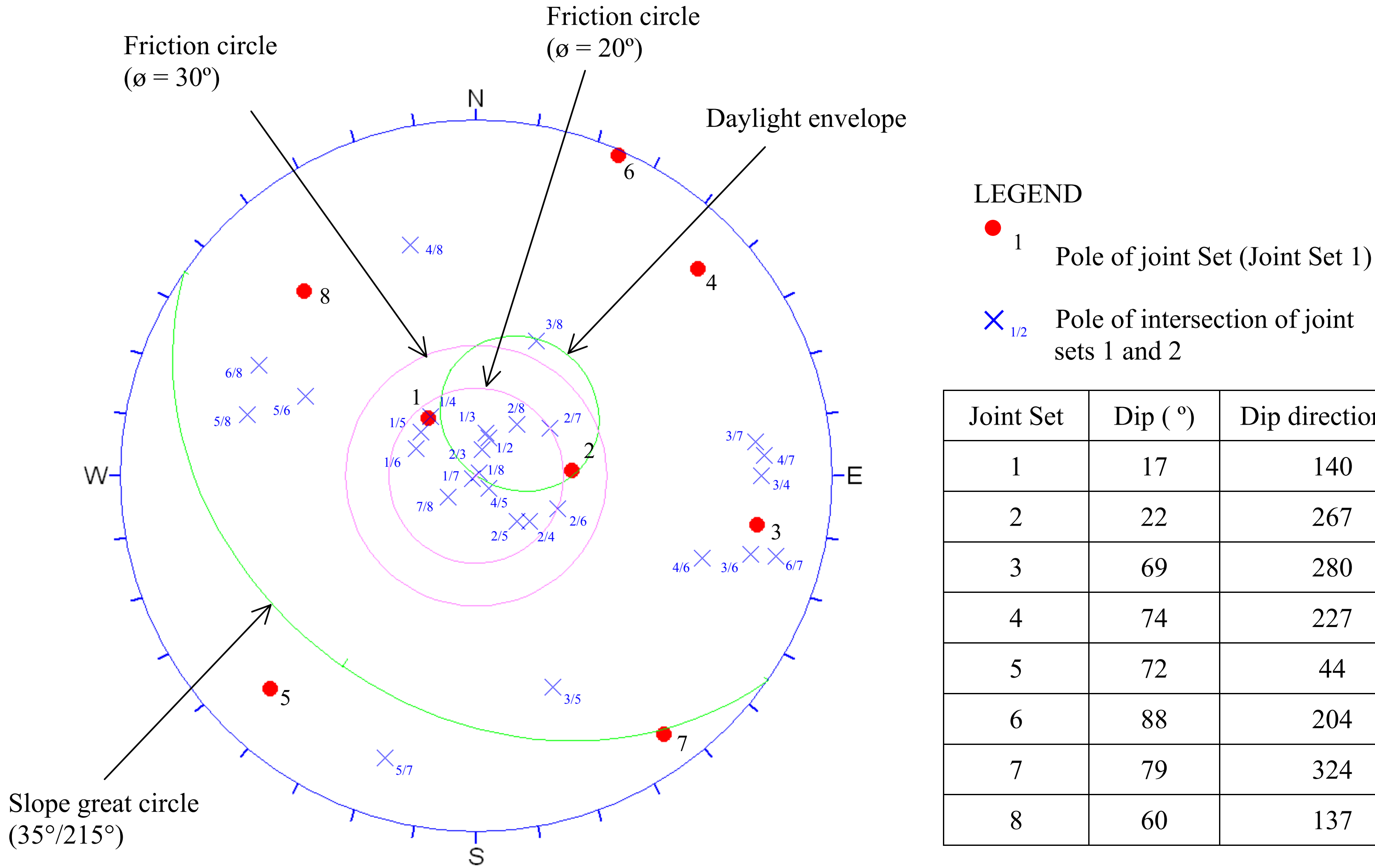

Joint Set	Dip (º)	Dip direction (º)
1	17	140
2	22	267
3	69	280
4	74	227
5	72	44
6	88	204
7	79	324
8	60	137

Figure 18 - Stereographic Projection of Discontinuity Survey Data

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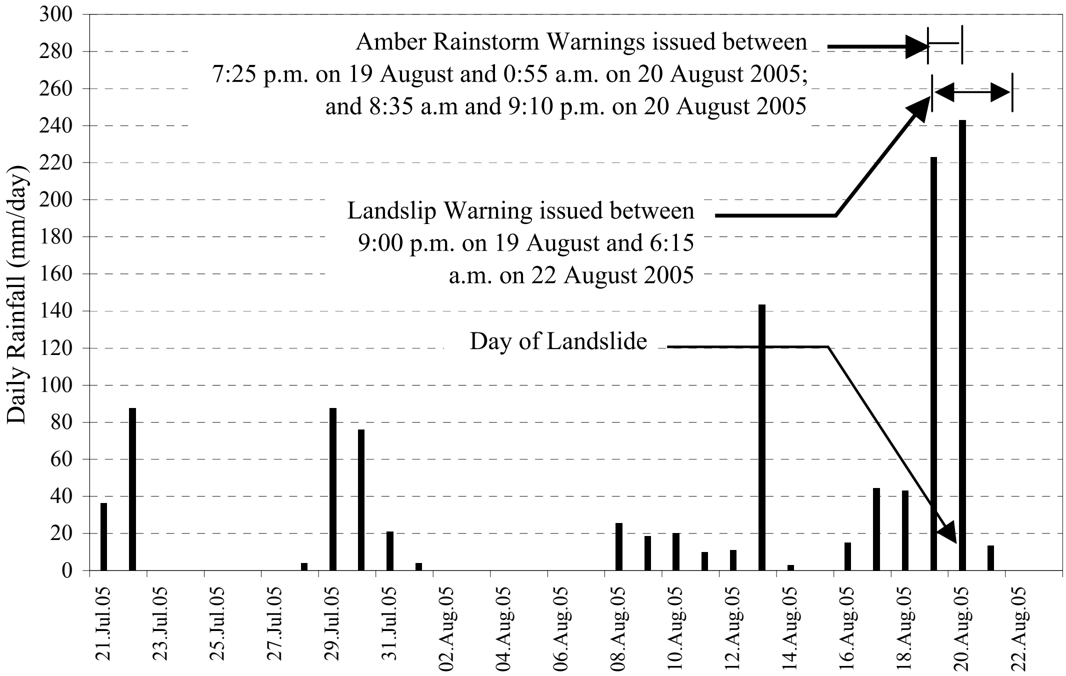
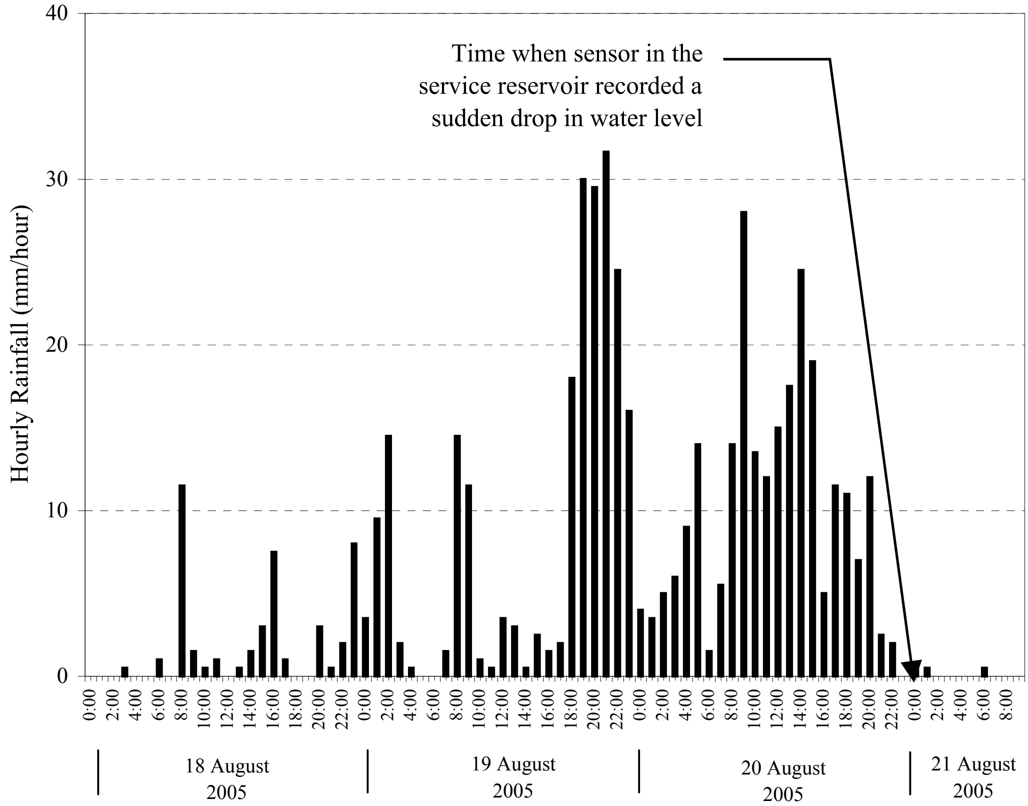


(a) Daily Rainfall Recorded between 21 July and 23 August 2005



(b) Hourly Rainfall Recorded between 18 and 21 August 2005

Figure 19 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. H03

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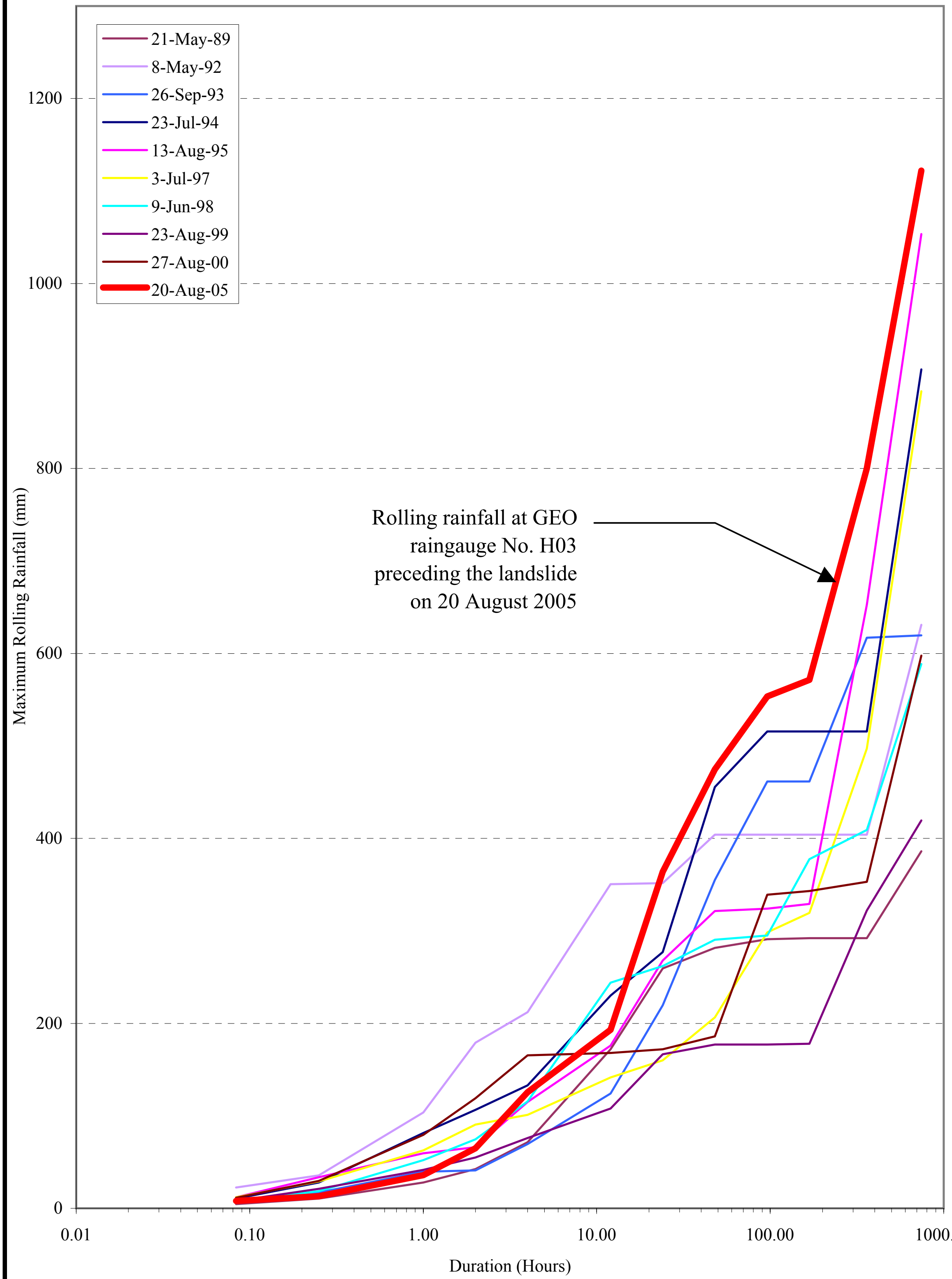

Notes: (1) Rainfall data are evaluated from 5-minute readings from GEO raingauge No. H03 (located about 1 km to the south of the landslide site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. H03 since 12 September 1978 when the raingauge was installed.

Figure 20 - Maximum Rolling Rainfall for Rainstorms at GEO Raingauge No. H03

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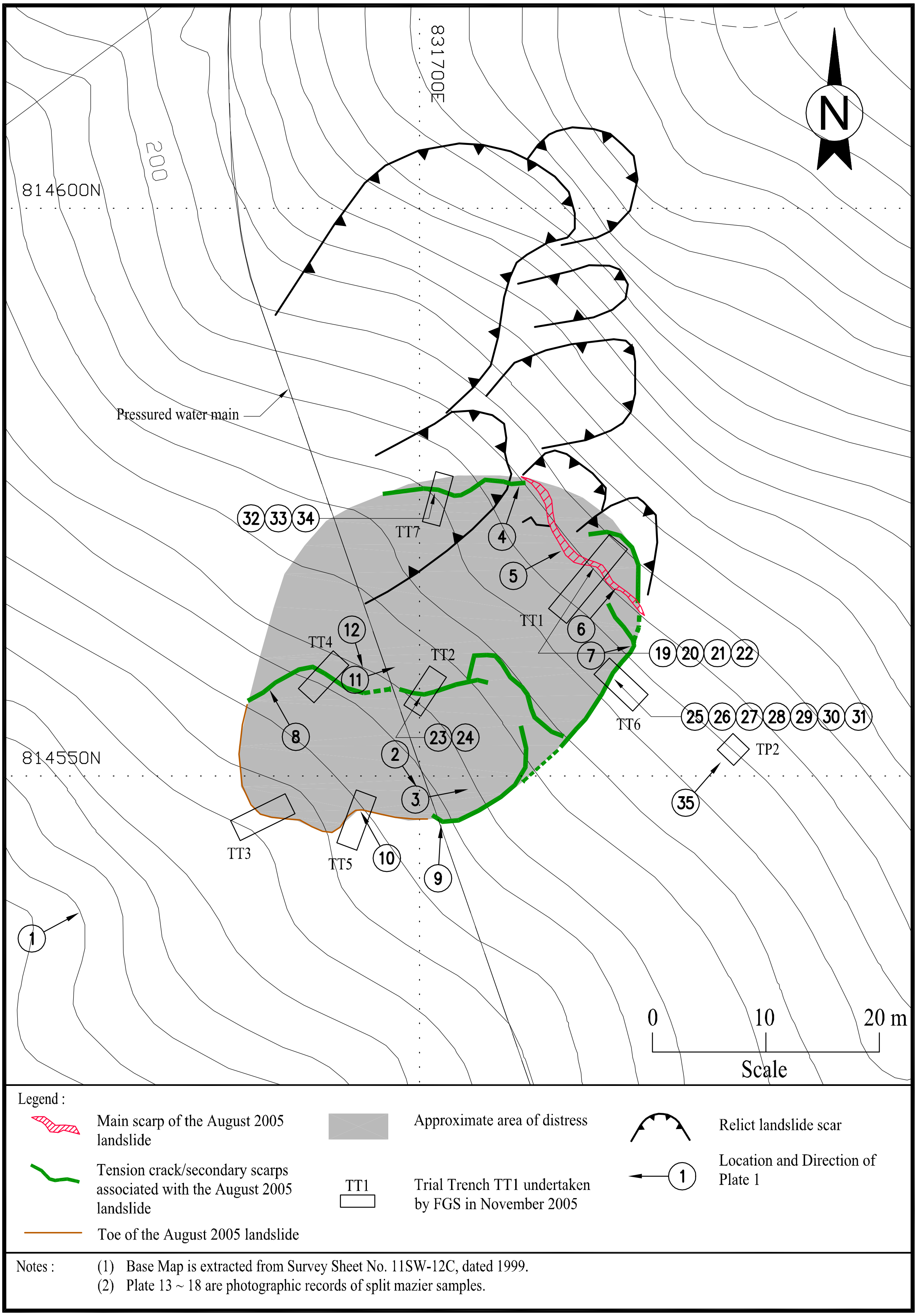

Figure 21 - Locations and Directions of Photographs

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Plate 1 – General View of the August 2005 Landslide Site
(Photograph taken on 13 September 2005)

Note: See Figure 21 for location and direction of photograph.

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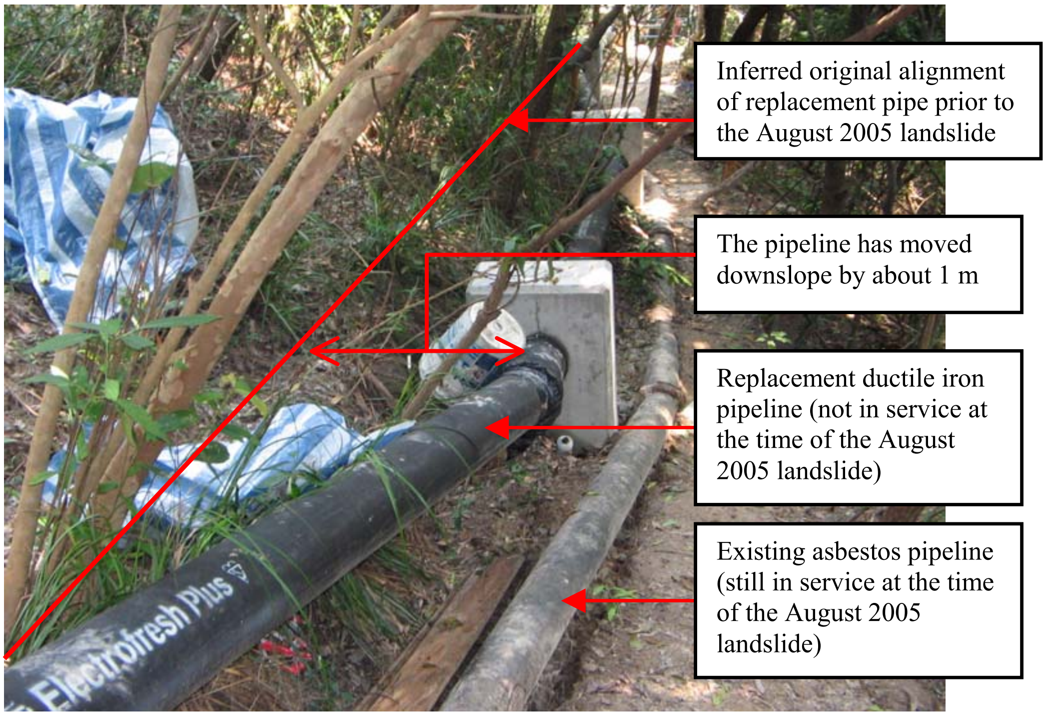

Plate 2 – General View of Displaced Section of New and Existing Pipelines
(Photograph taken by FSW on 24 August 2005)

Plate 3 – Close-up View of the Severed Existing Asbestos Pipeline
(Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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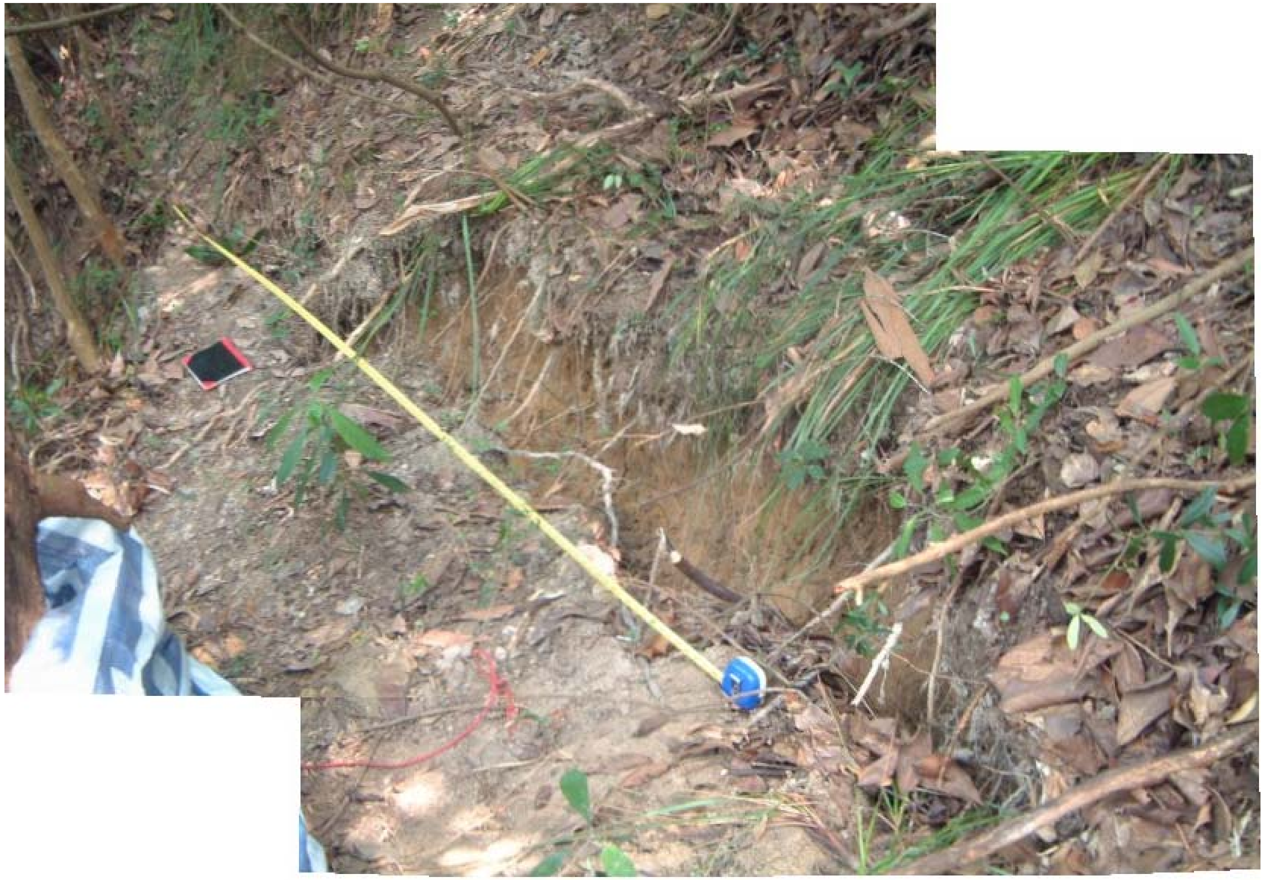

Plate 4 – View of the Northern End of the Main Scarp
(Photograph taken by FSW on 3 October 2005)

Note: See Figure 21 for location and direction of photograph.

Plate 5 – View of Central Portion of the Main Scarp
(Photograph taken by FSW on 3 October 2005)

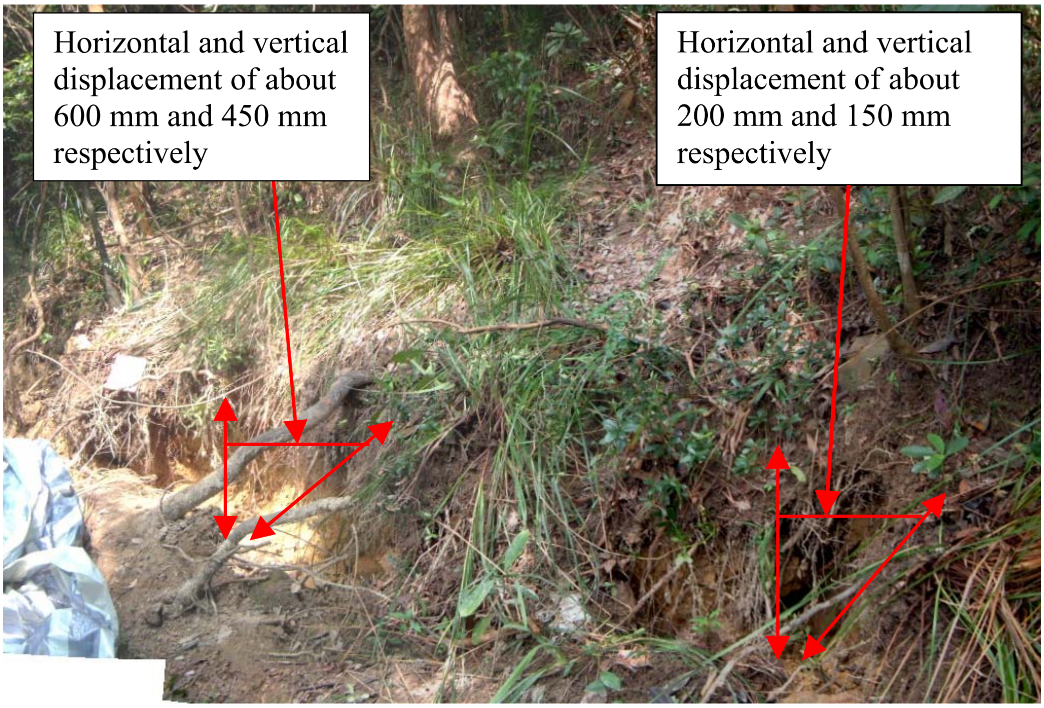

Plate 6 – View of the Southern End of the Main Scarp
(Photograph taken by FSW on 3 October 2005)

Note: See Figure 21 for location and direction of photograph.

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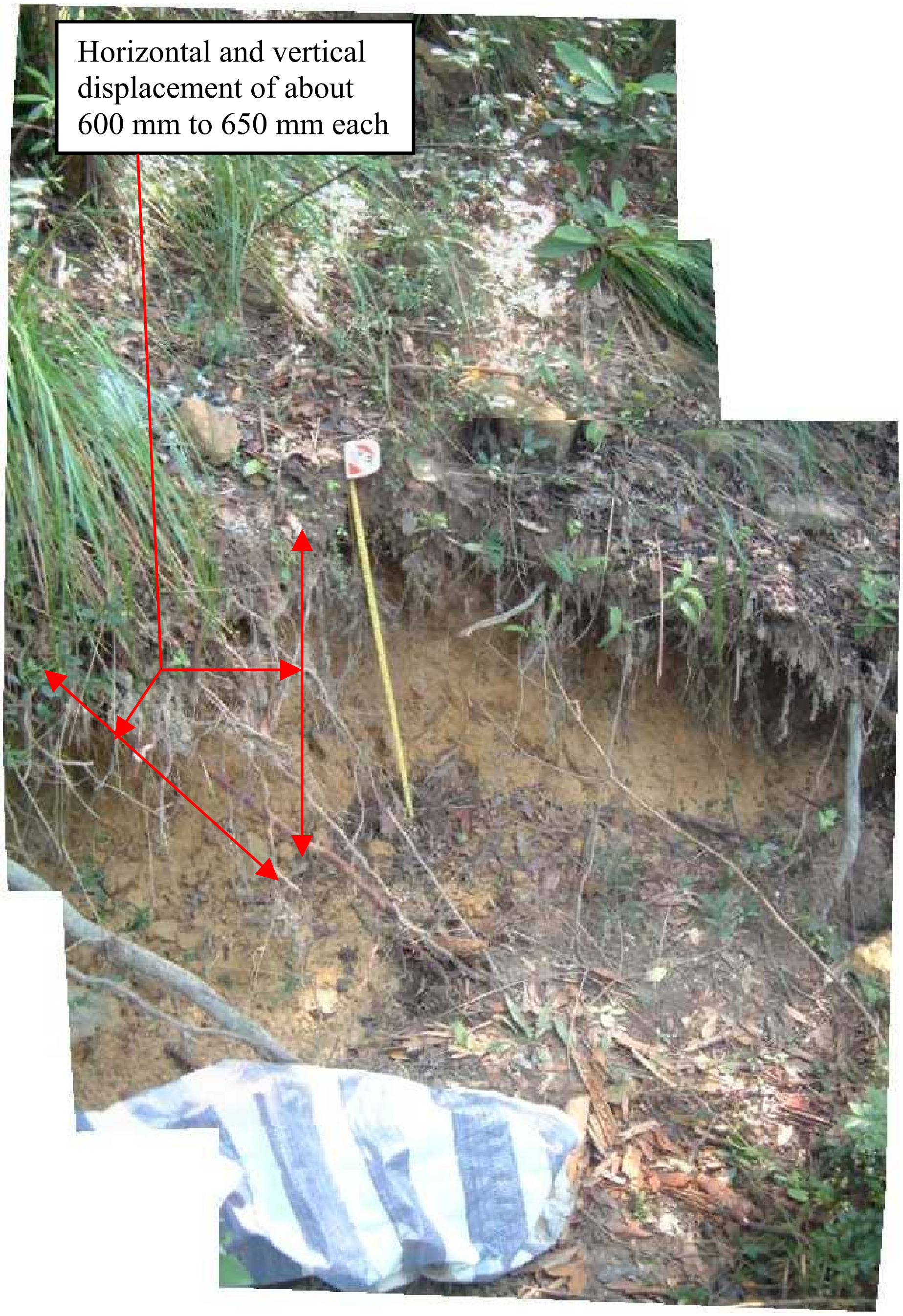

Plate 7 – View of Secondary Scarp in the Upper Southern Flank of the Landslide
(Photograph taken by FSW on 3 October 2005)

Note: See Figure 21 for location and direction of photograph.

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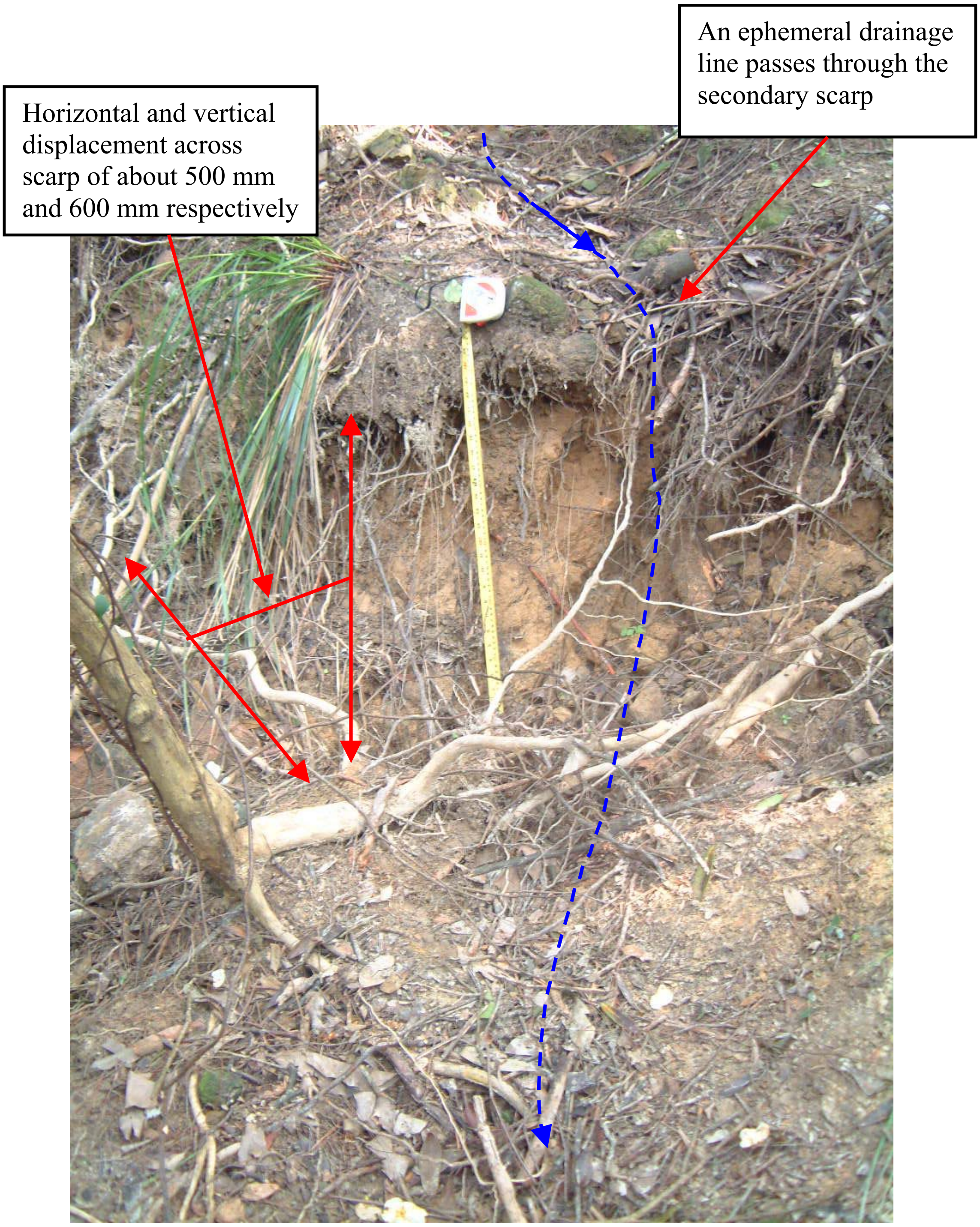

Plate 8 – View of Secondary Scarp along the Lower Northern Flank of the Landslide
(Photograph taken on 3 October 2005)

Note: See Figure 21 for location and direction of photograph.

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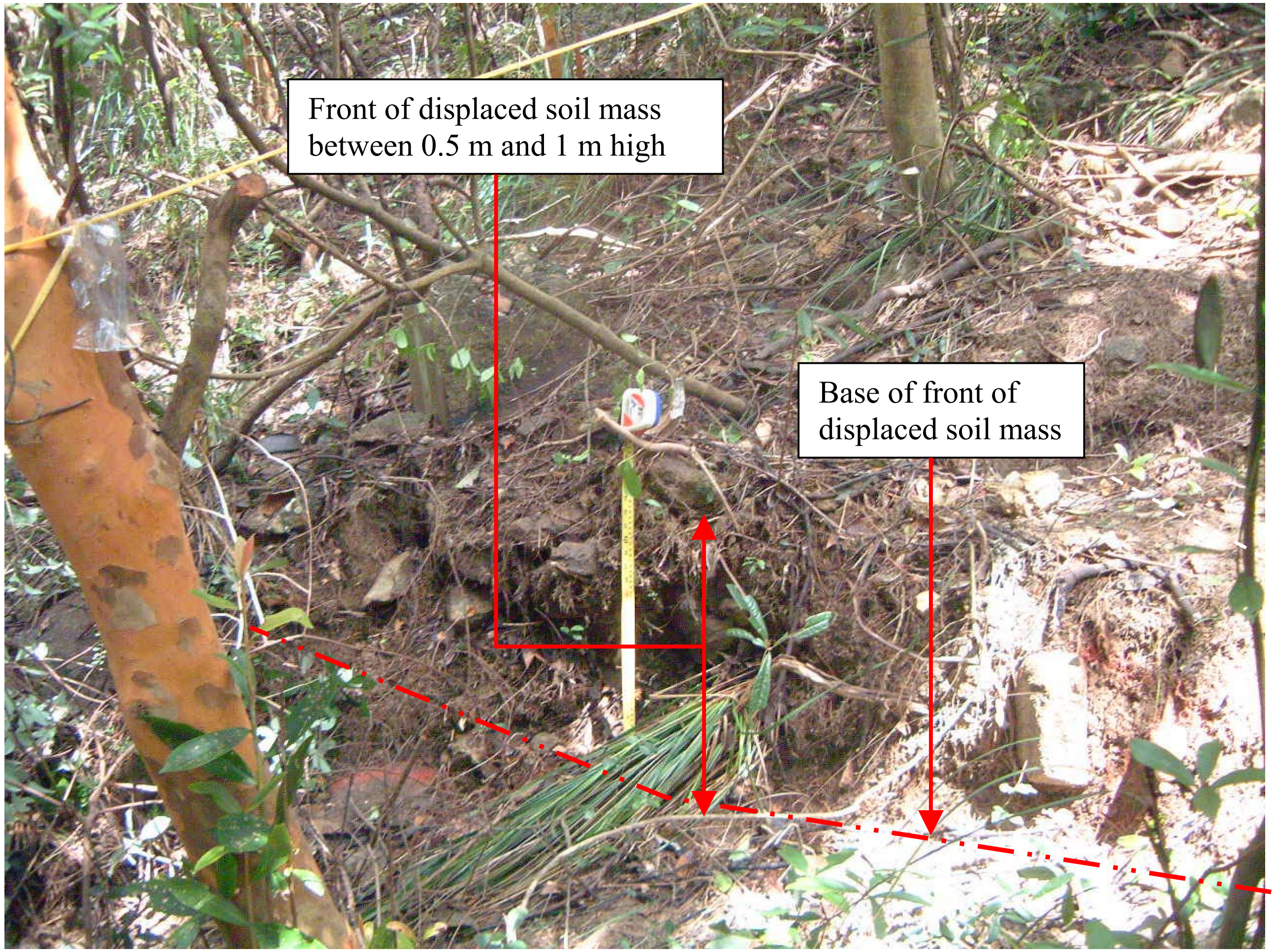

Plate 9 – View of Bulging in the Lower Southern Flank of the Landslide
(Photograph taken by FSW on 28 September 2005)

Note: See Figure 21 for location and direction of photograph.

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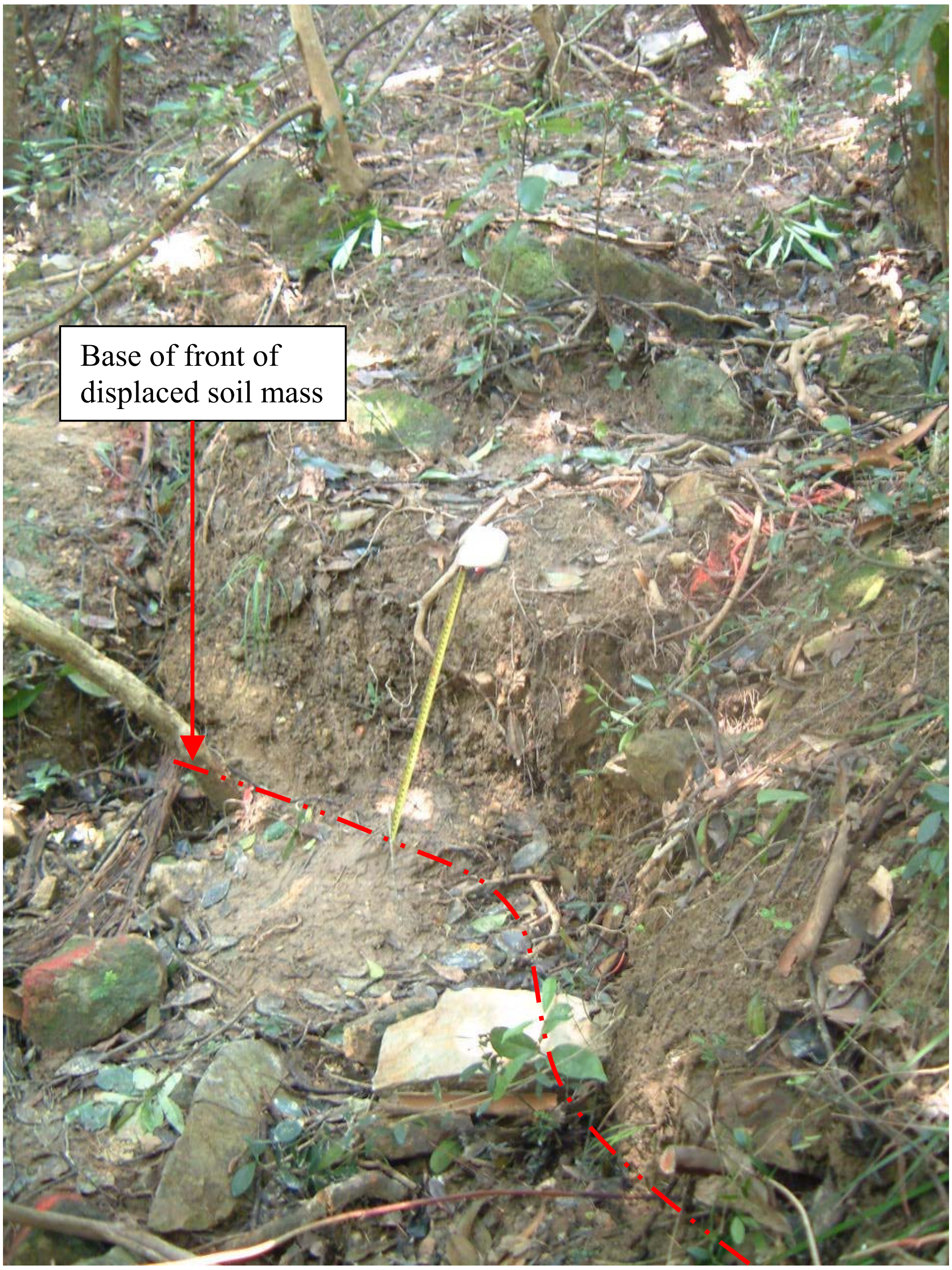

Plate 10 – View of Bulging at the Toe of the Landslide
(Photograph taken by FSW on 28 September 2005)

Note: See Figure 21 for location and direction of photograph.

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Plate 11 – View of Tensile Fracture in Existing Asbestos Pipeline
(Photograph taken by FSW on 12 September 2005)

Plate 12 – View of Hairline Crack at the Base of Concrete Plinth Support to the Replacement Ductile Iron Pipeline
(Photograph taken by FSW on 12 September 2005)

Note: See Figure 21 for location and direction of photograph.

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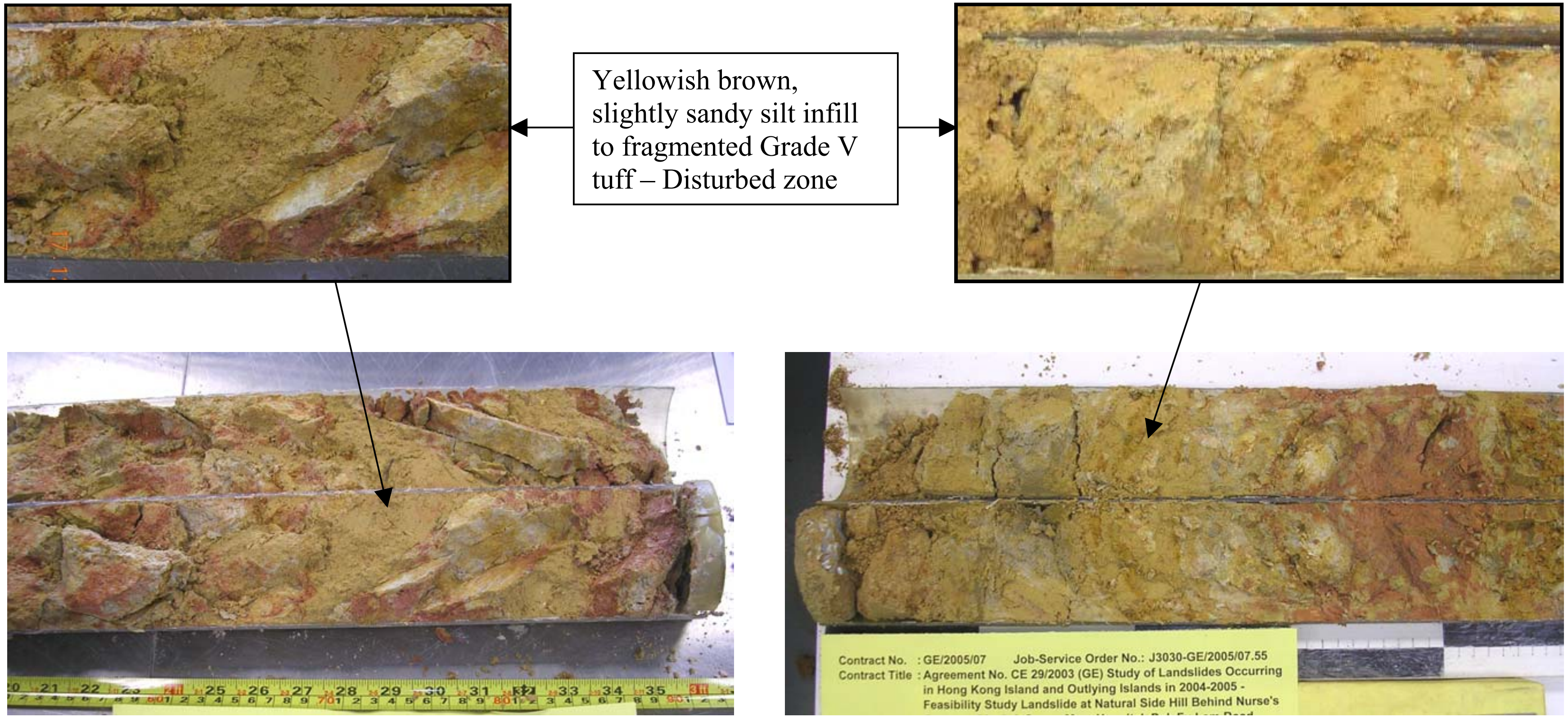

(a) Base of Mazier Sample from Drillhole BH2, Depth 1.5 m to 2.5 m

(b) Top of Mazier Sample from Drillhole BH2, Depth 2.6 m to 3.6 m

Plate 13 – View of Disturbed Zone in Drillhole BH2 at a Depth of 2.3 m to 2.8 m
(Photograph taken by FSW on 17 December 2005)

Note: See Figure 6 for the location of Drillhole BH2.

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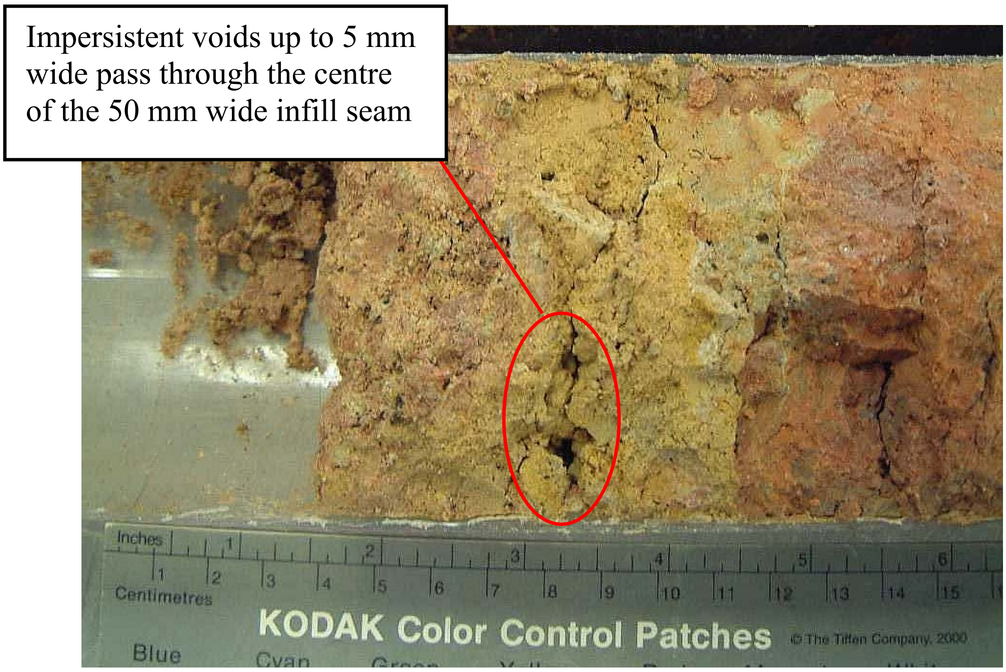

Plate 14 – View of 50 mm Infill Seam in Drillhole BH2 at a Depth of 3.7 m
(Photograph taken by FSW on 30 December 2005)

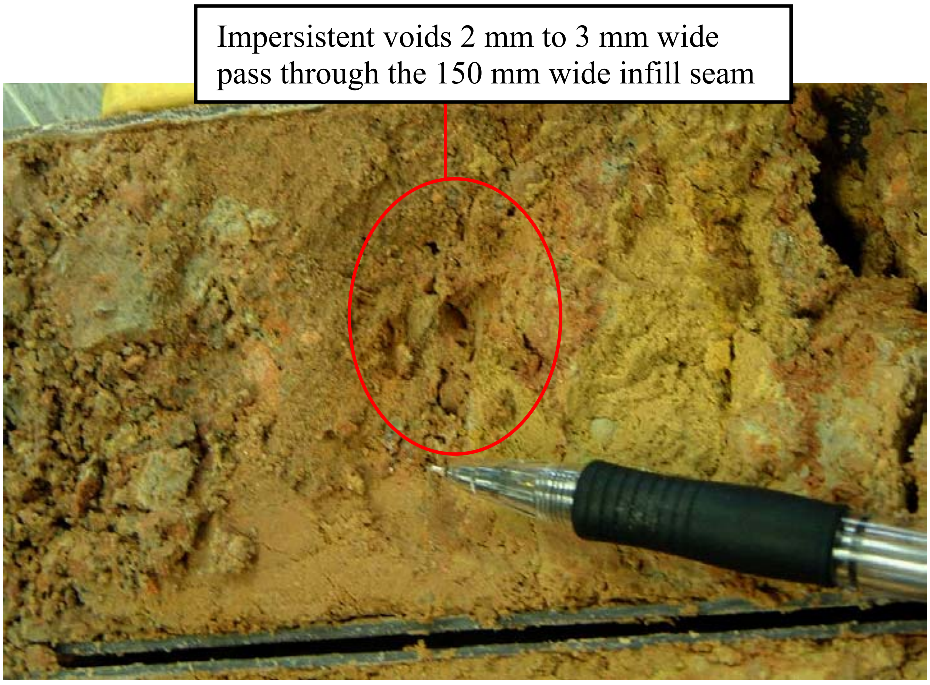

Plate 15 – View of 150 mm Infill Seam in Drillhole BH2 at a Depth of 5.9 m
(Photograph taken by FSW on 30 December 2005)

Note: See Figure 6 for the location of Drillhole BH2.

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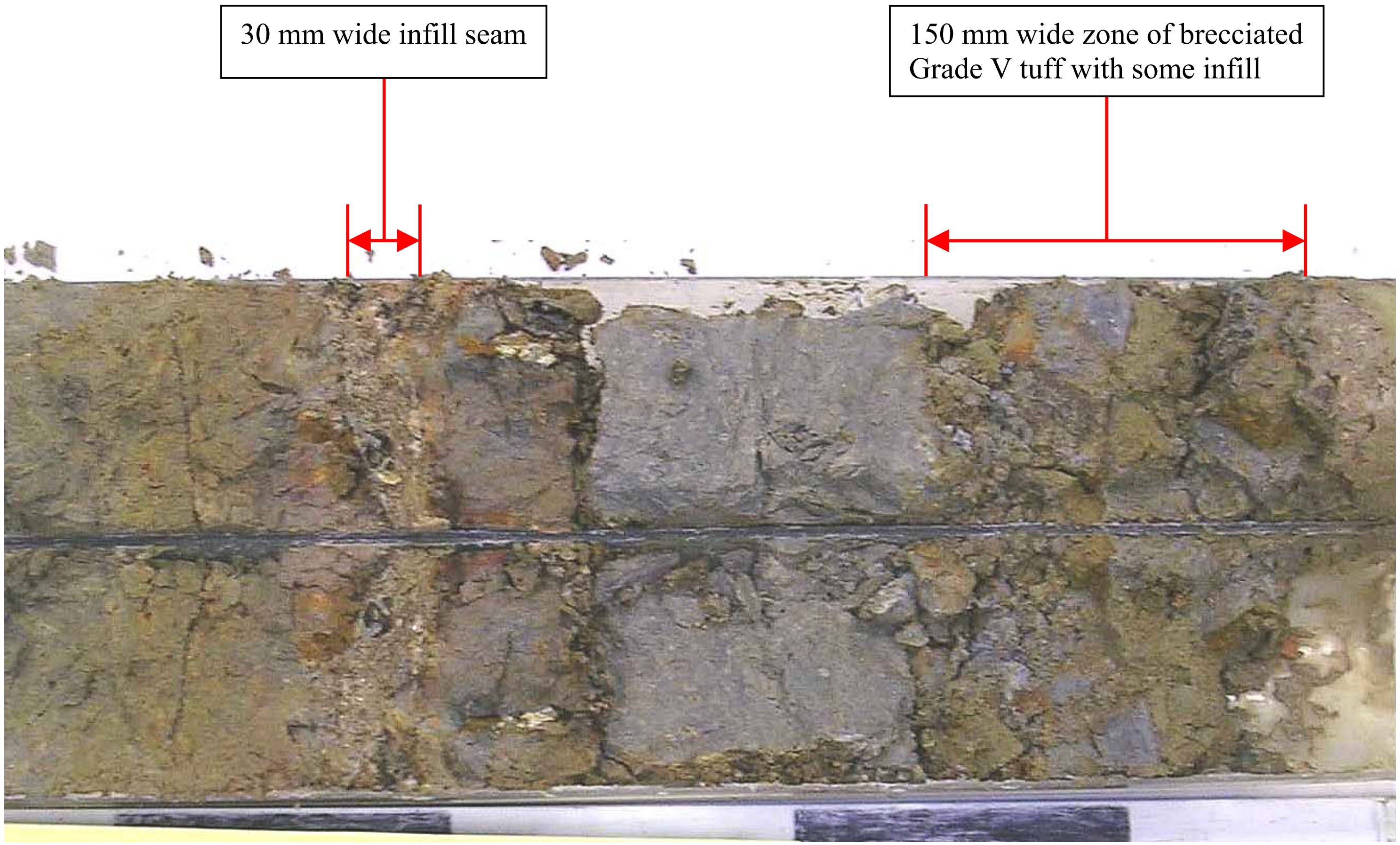

Plate 16 – View of Infill Seams in Drillhole BH2 at Depths of 8.7 m and 8.85 m
(Photograph taken by FSW on 30 December 2005)

Note: See Figure 6 for the location of Drillhole BH2.

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Grey and yellowish brown, slightly sandy silt infill with many small voids was present between a depth of 2.6 m and 3.1 m

Plate 17 – View of Infill Material at Depth of 2.6 m in Drillhole BH1
(Photograph taken by FSW on 14 February 2006)

Note: See Figure 6 for the location of Drillhole BH1.

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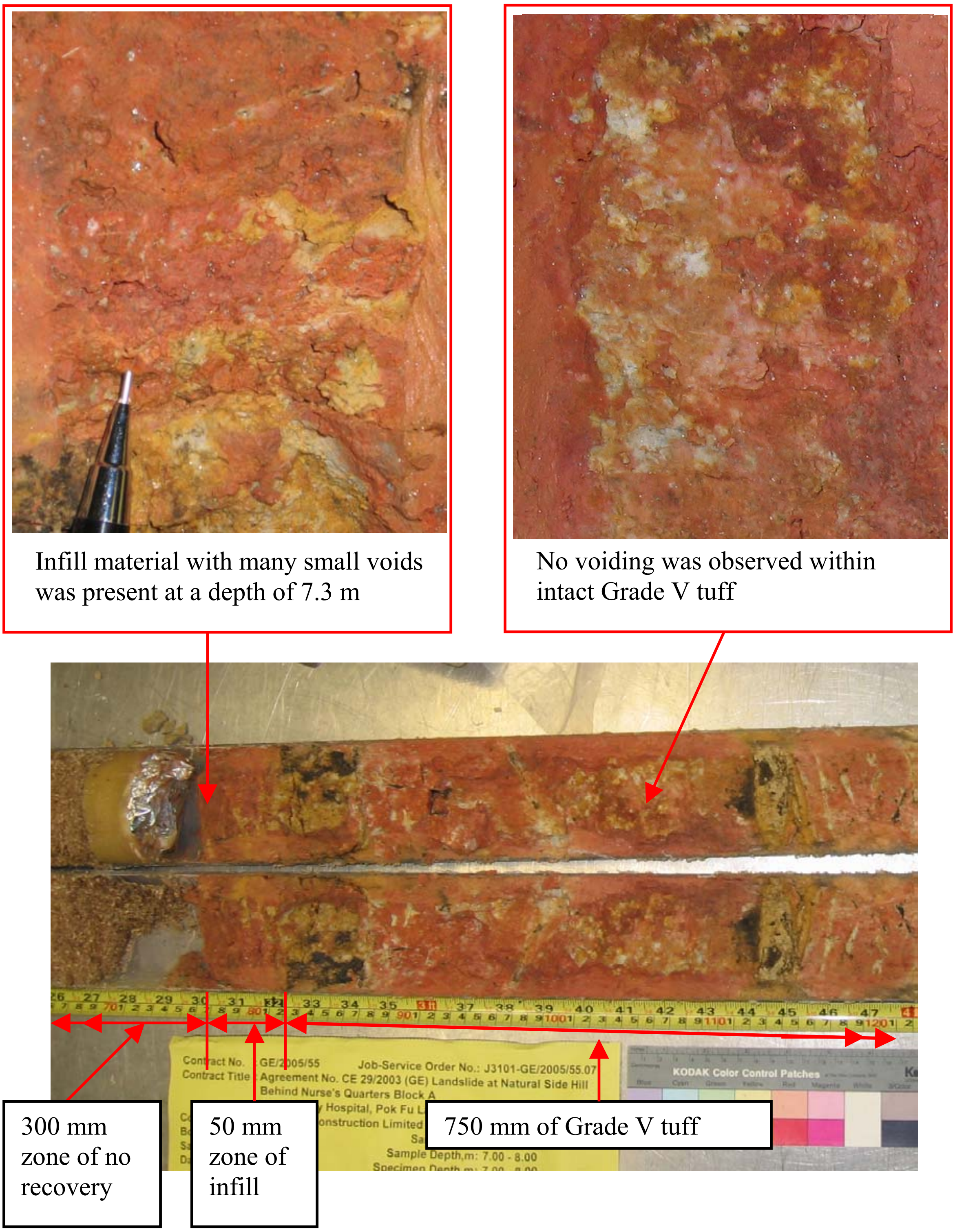

Plate 18 – View of Void and Infill Material at Depths of 7 m to 7.35 m in Drillhole BH1
(Photograph taken by FSW on 14 February 2006)

Note: See Figure 6 for the location of Drillhole BH1.

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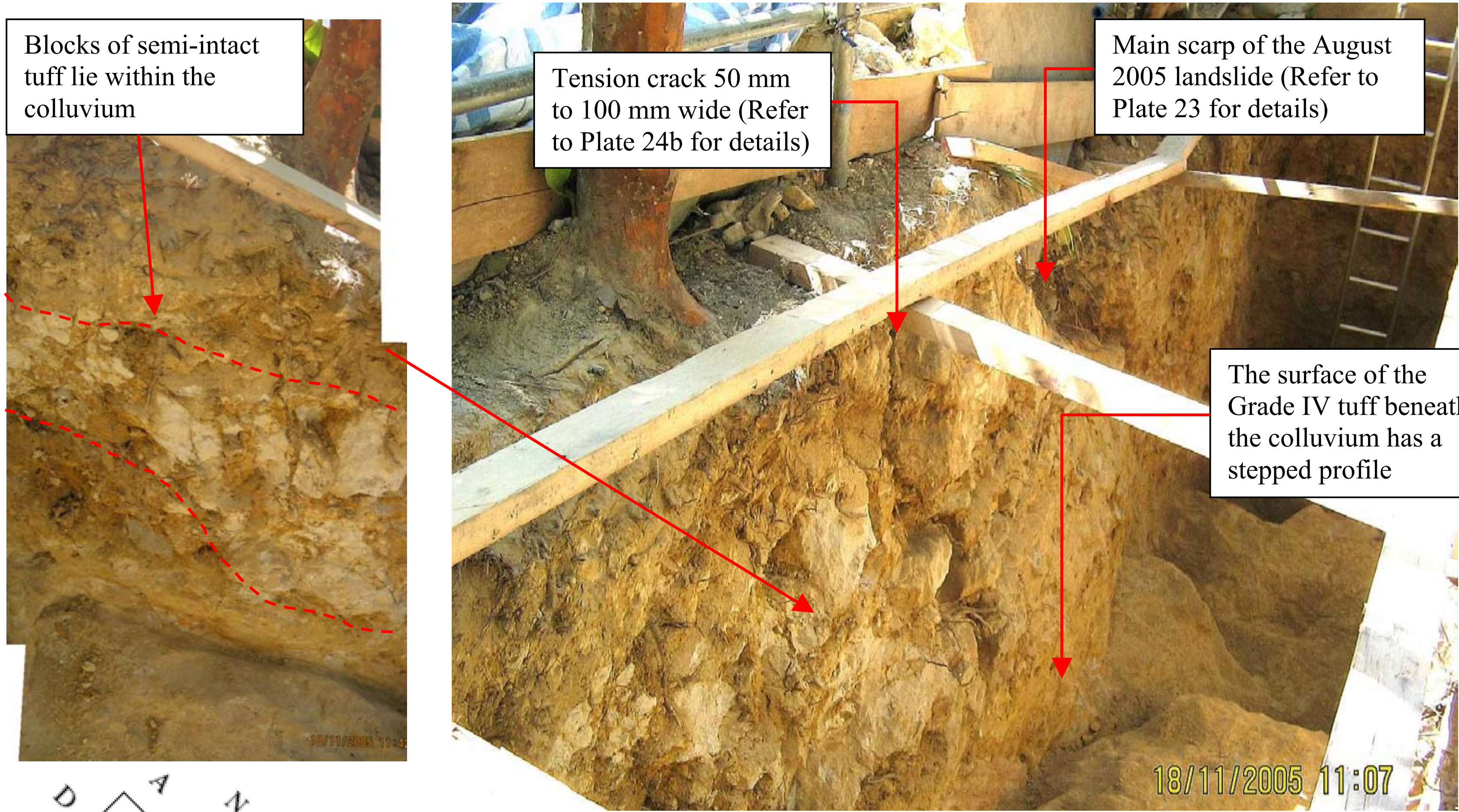

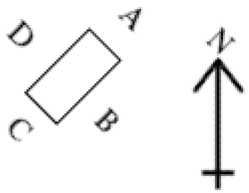

Plate 19 – View of Face B of Trial Trench TT1
(Photograph taken by FSW on 18 November 2005)

Note: See Figure 21 for location and direction of photograph.

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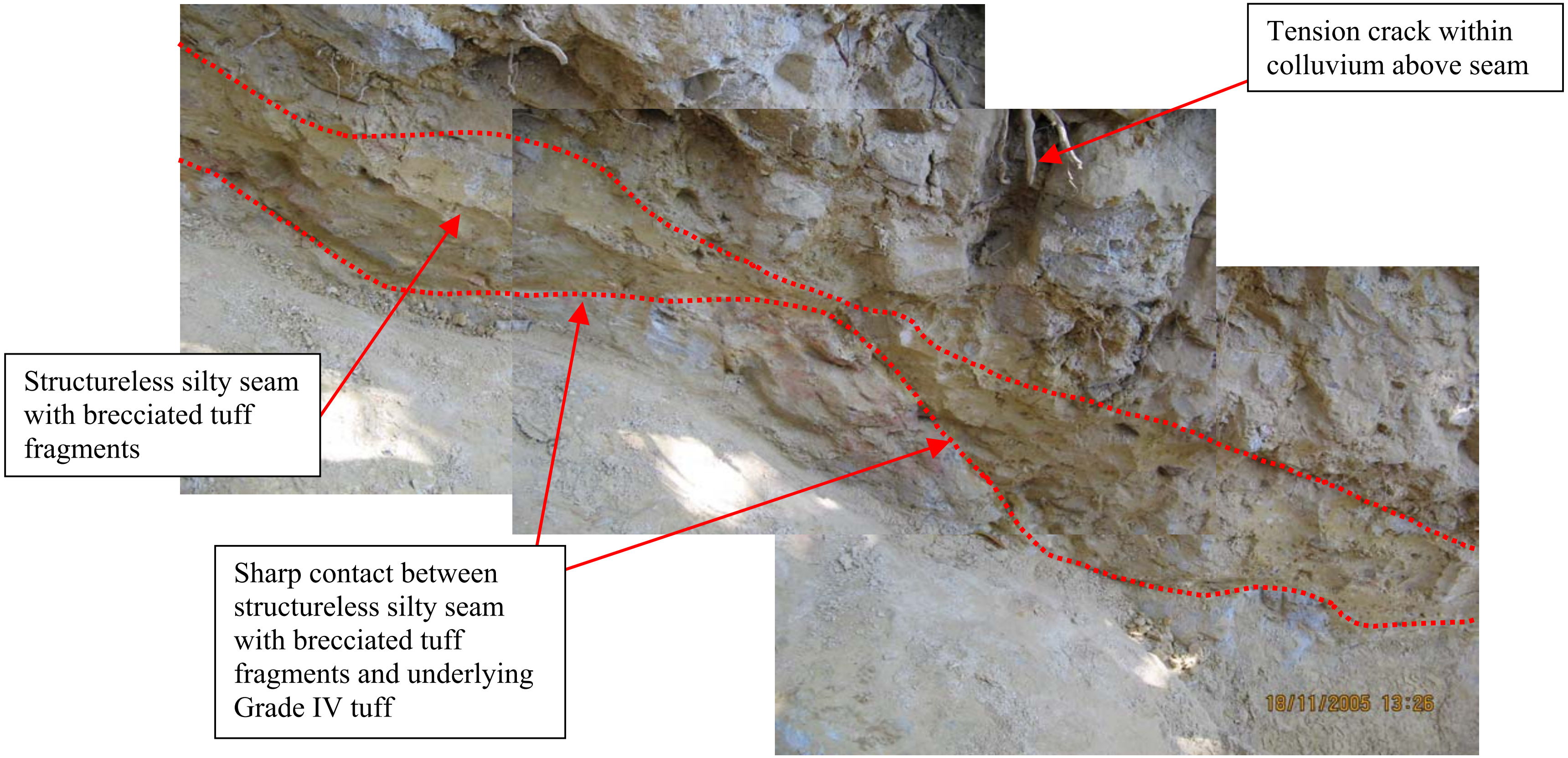

Plate 20 – View of Structureless Seam Observed between the Base of the Colluvium and the Underlying Tuff in Face B of Trial Trench TT1
(Photograph taken by FSW on 18 November 2005)

Note: See Figure 21 for location and direction of photograph.

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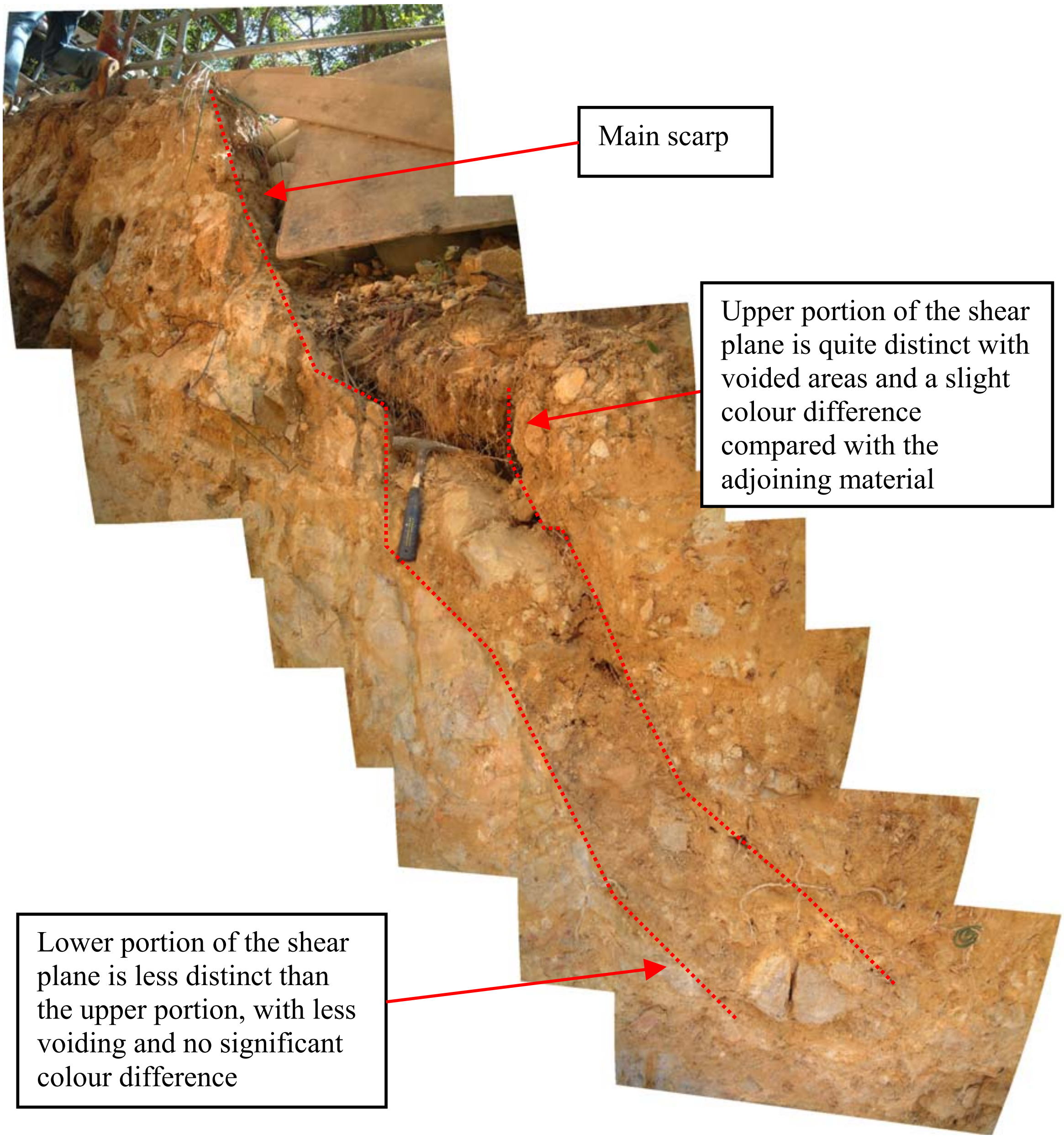

Plate 21 – View of Shear Plane Exposed in Face B of Trial Trench TT1
(Photograph taken by FSW on 18 November 2005)

Note: See Figure 21 for location and direction of photograph.

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a) Tension crack, 50 mm to 100 mm wide at the upslope corner of trial trench TT1 between Face A and Face B

b) Tension crack, 50 mm to 100 mm wide, in Face B of trial trench TT1 about 1 m upslope of the main scarp

Plate 22 – View of Tension Cracks in Trial Trench TT1
(Photograph taken by FSW on 1 November 2005)

Note: See Figure 21 for location and direction of photograph.

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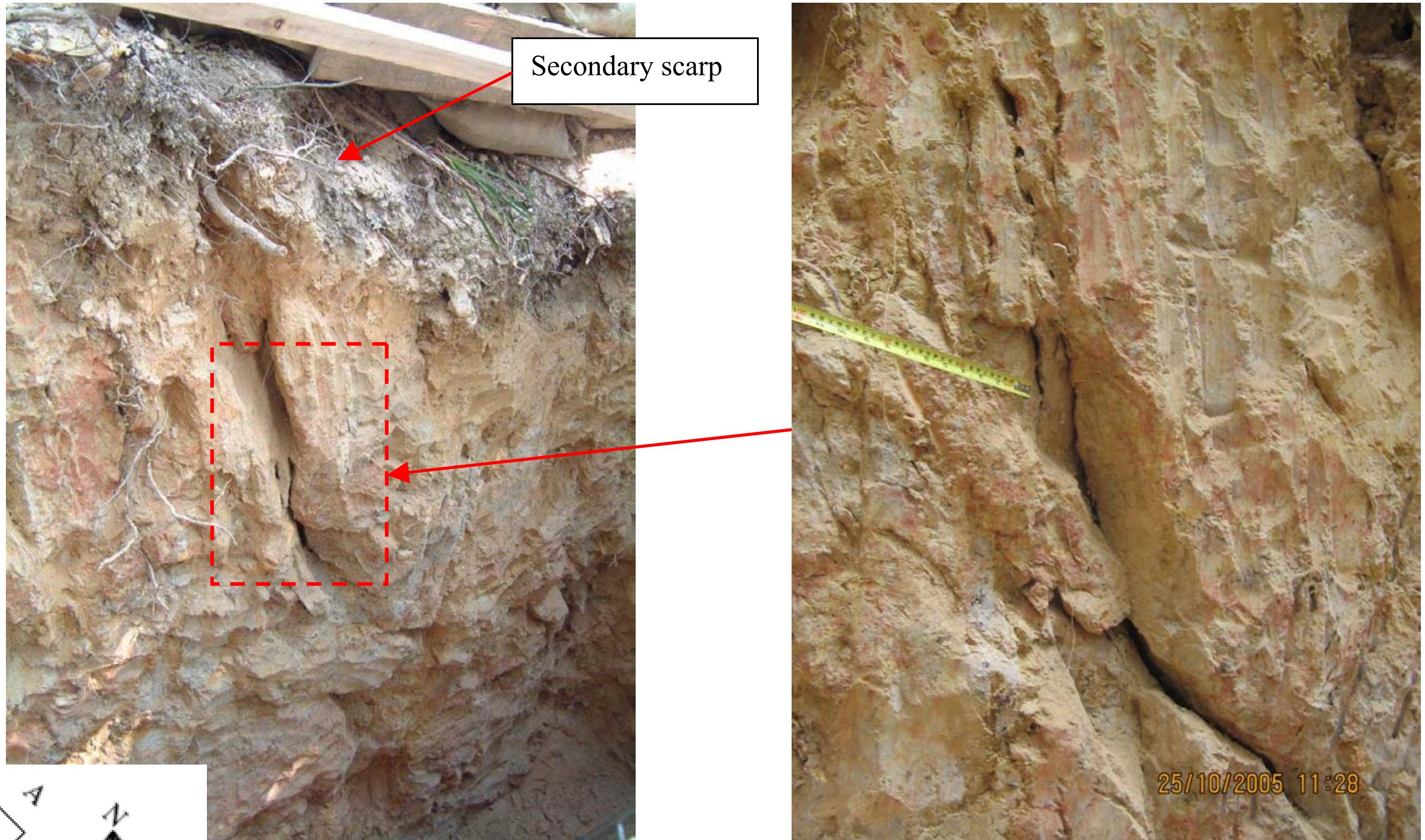

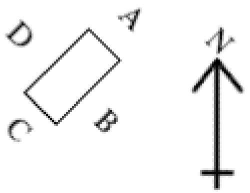

Plate 23 – View of Subsurface Cracking in Face B of Trial Trench TT2
(Photograph taken by FSW on 25 October 2005 and 19 November 2005)

Note: See Figure 21 for location and direction of photograph.

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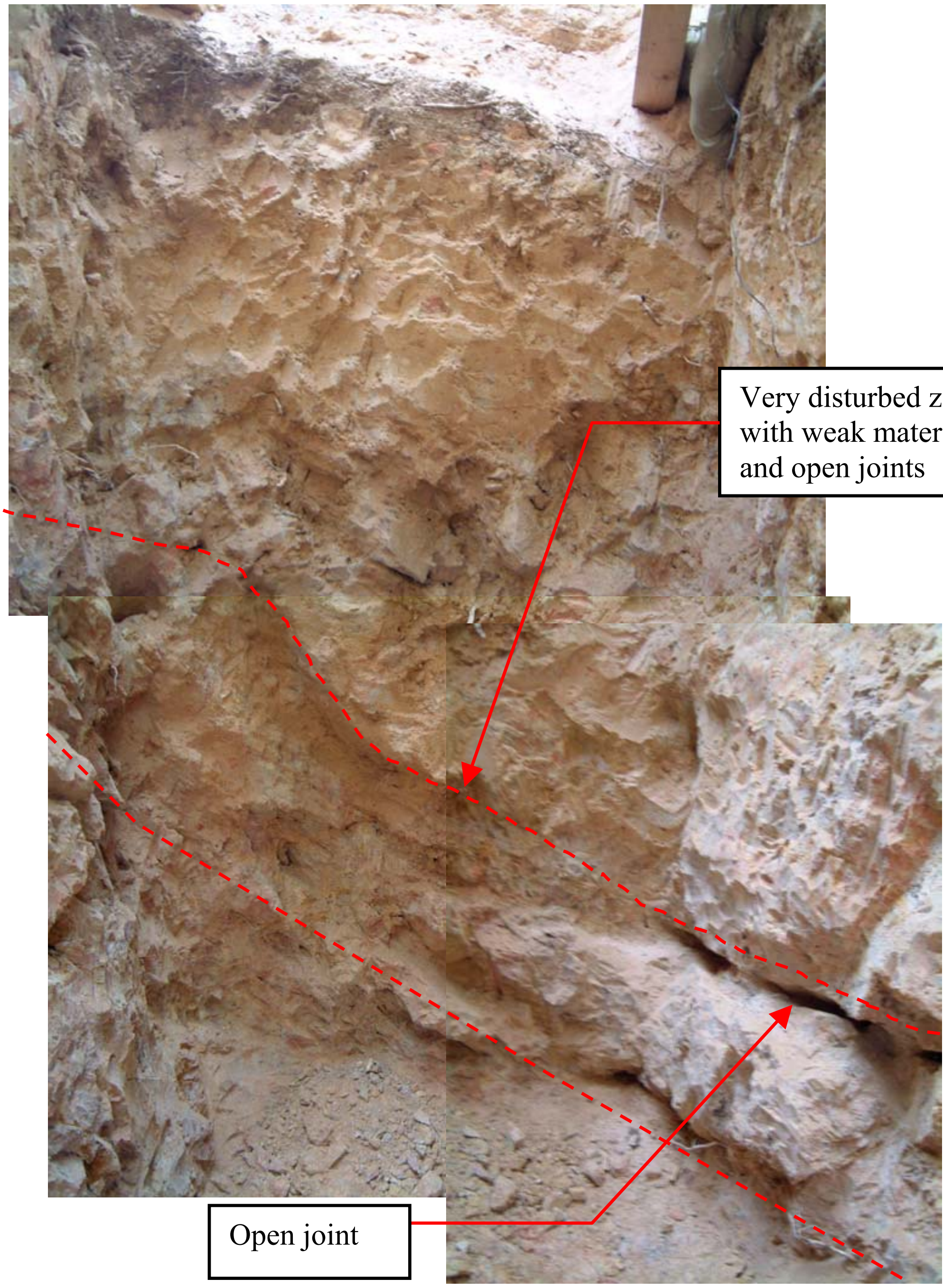

Plate 24 – View of Face C of Trial Trench TT2 Showing Disturbed Zone at a Depth of 2 m to 2.5 m
(Photograph taken by FSW on 19 November 2005)

Note: See Figure 21 for location and direction of photograph.

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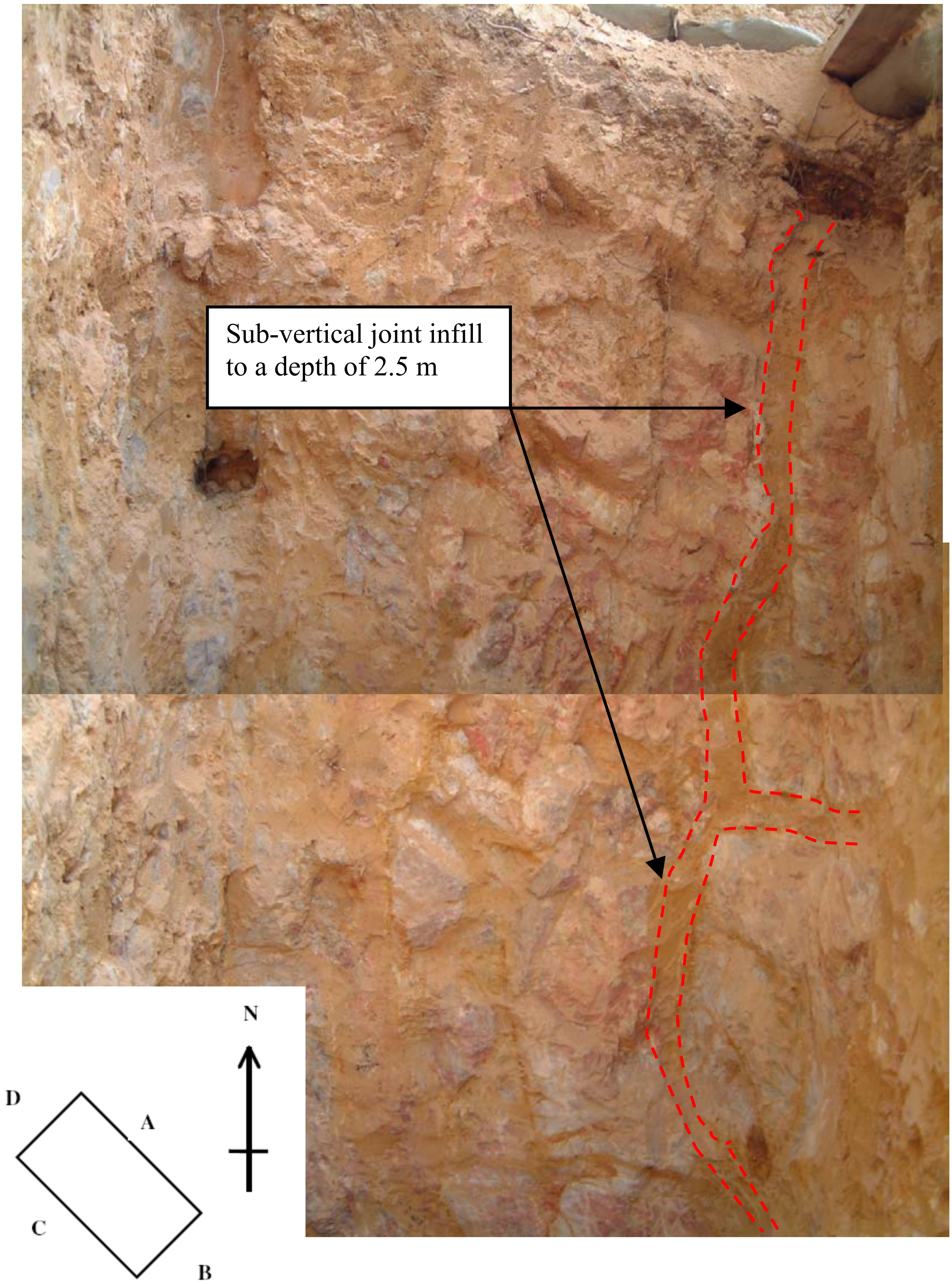

Plate 25 – View of Trial Trench TT6, Face B (Upper)
(Photograph taken by FSW on 19 November 2005)

Note: See Figure 21 for location and direction of photograph.

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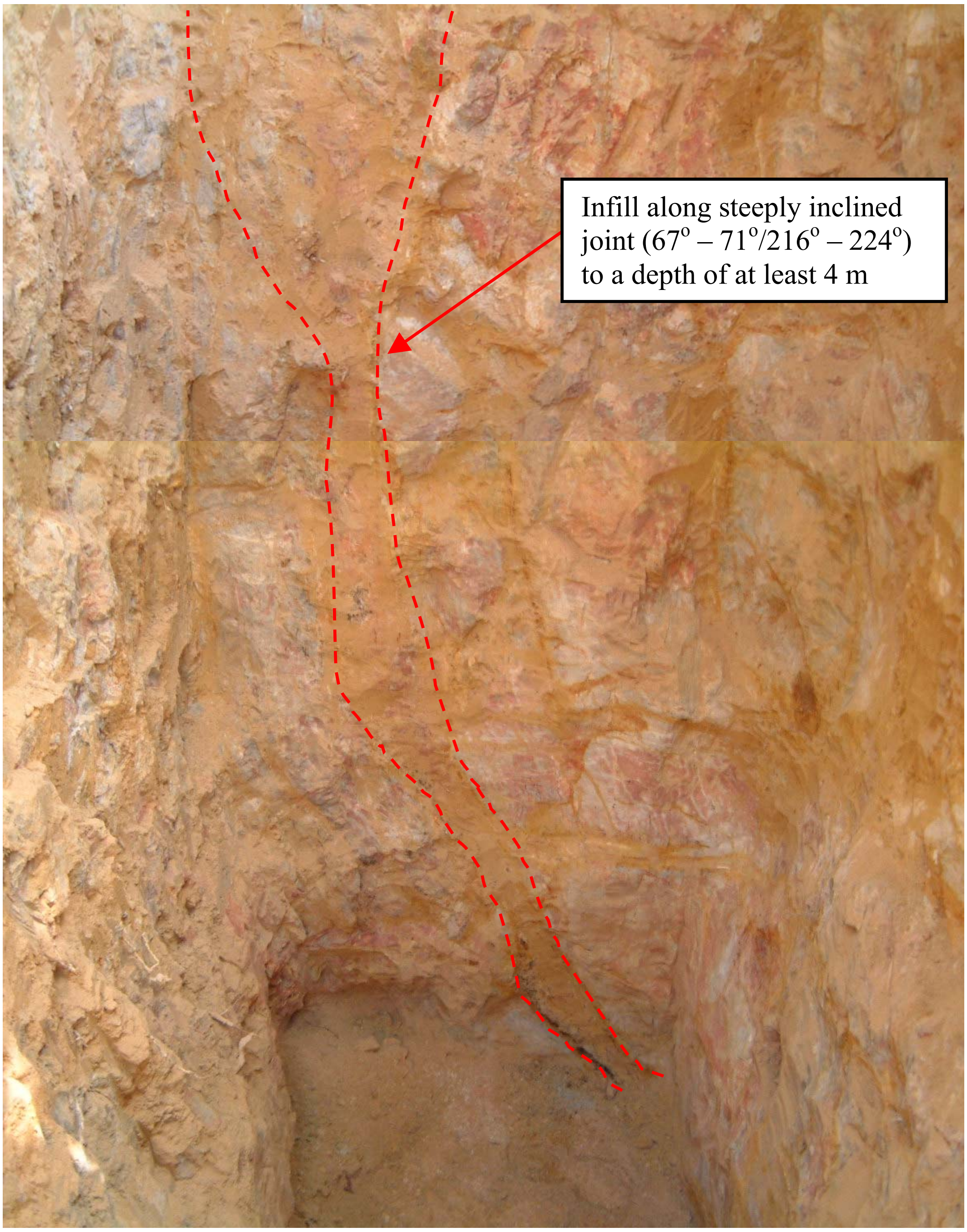

Plate 26 – View of Trial Trench TT6, Face B (Lower)
(Photograph taken by FSW on 19 November 2005)

Note: See Figure 21 for location and direction of photograph.

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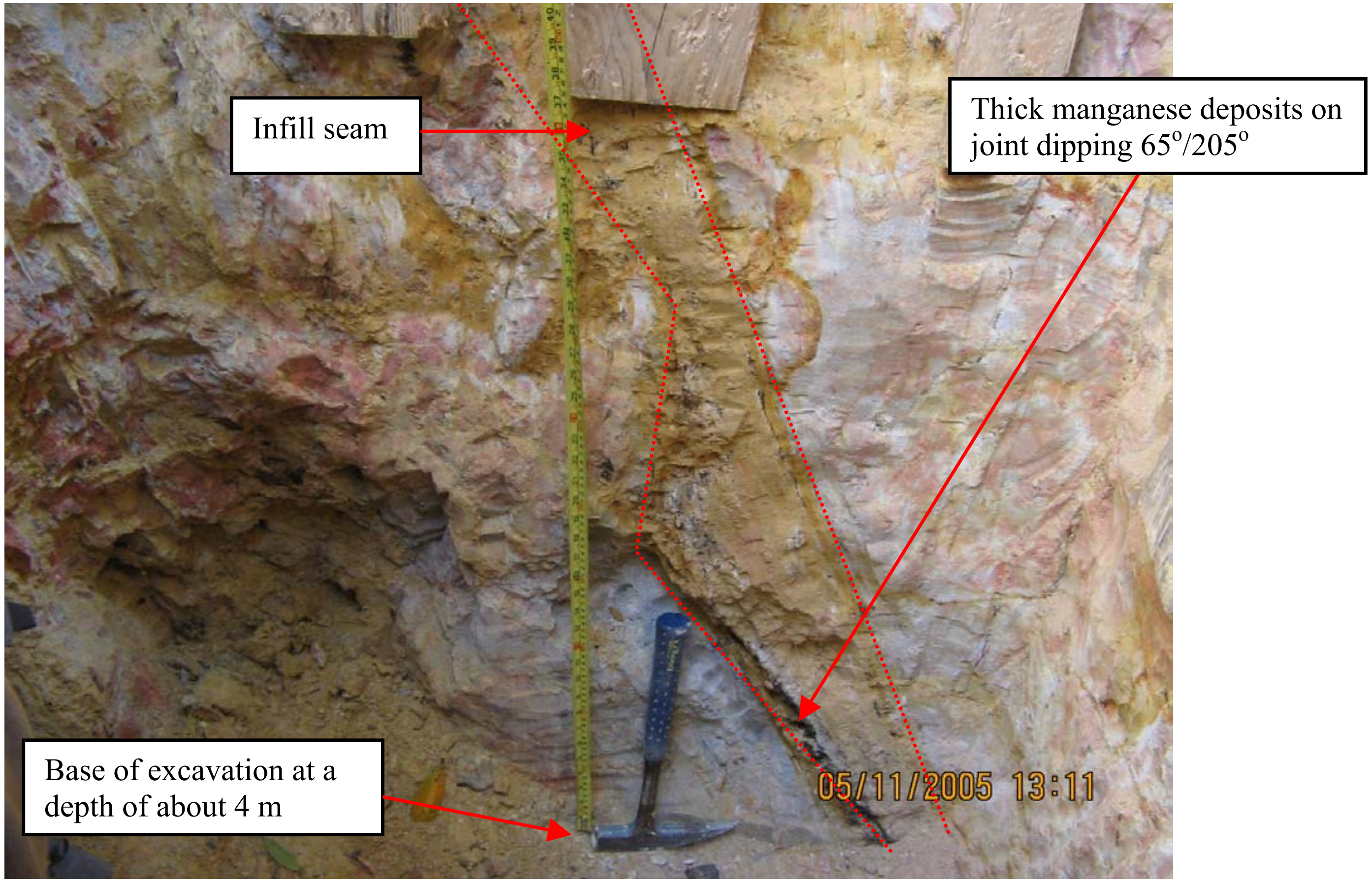

Plate 27 – Close-up of Infill Seam at the Base of Trial Trench TT6, Face B
(Photograph taken by FSW on 5 November 2005)

Note: See Figure 21 for location and direction of photograph.

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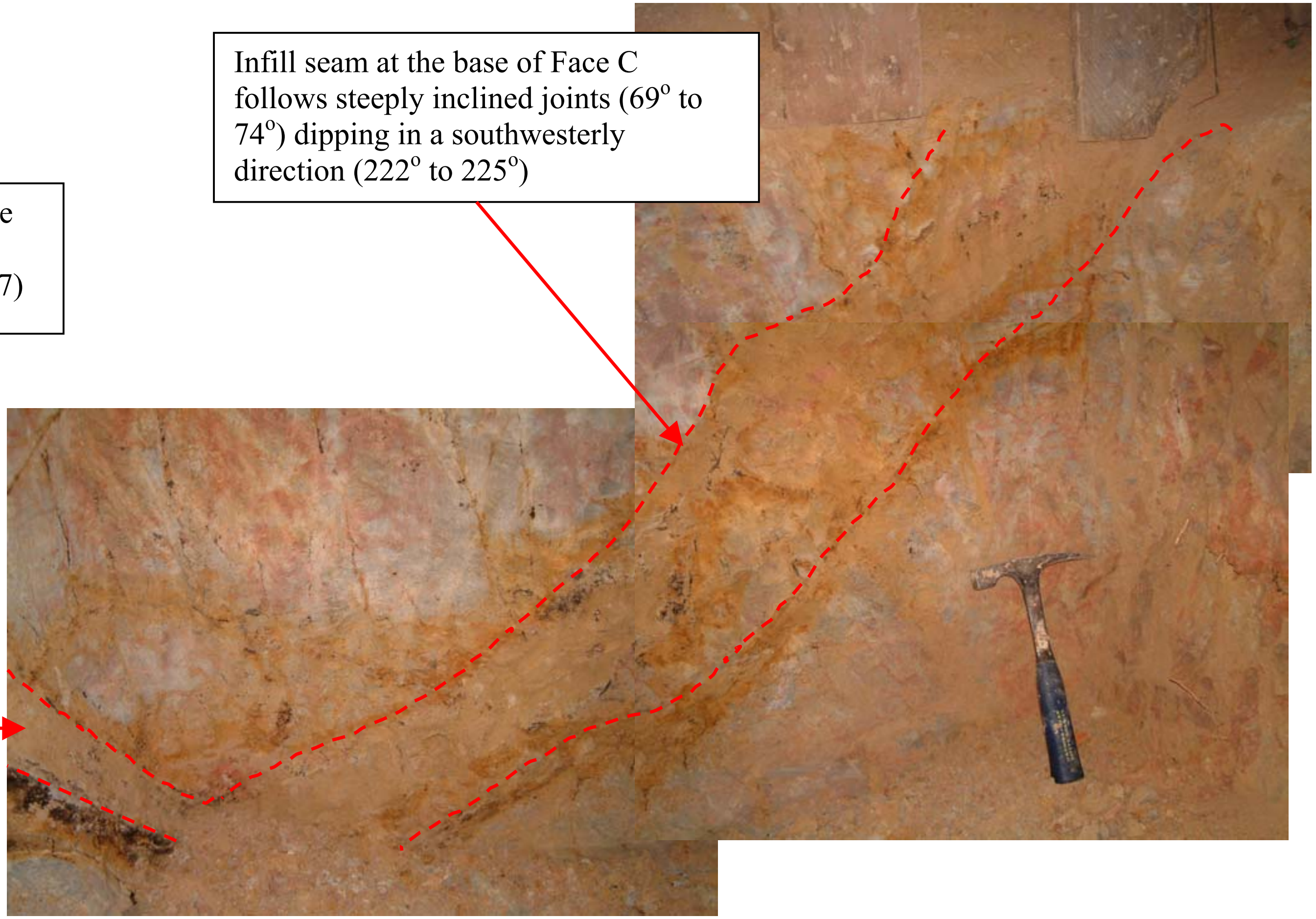

Plate 28 – View of the Infill Seam at the Base of Trial Trench TT6, Face C
(Photograph taken by FSW on 16 November 2005)

Note: See Figure 21 for location and direction of photograph.

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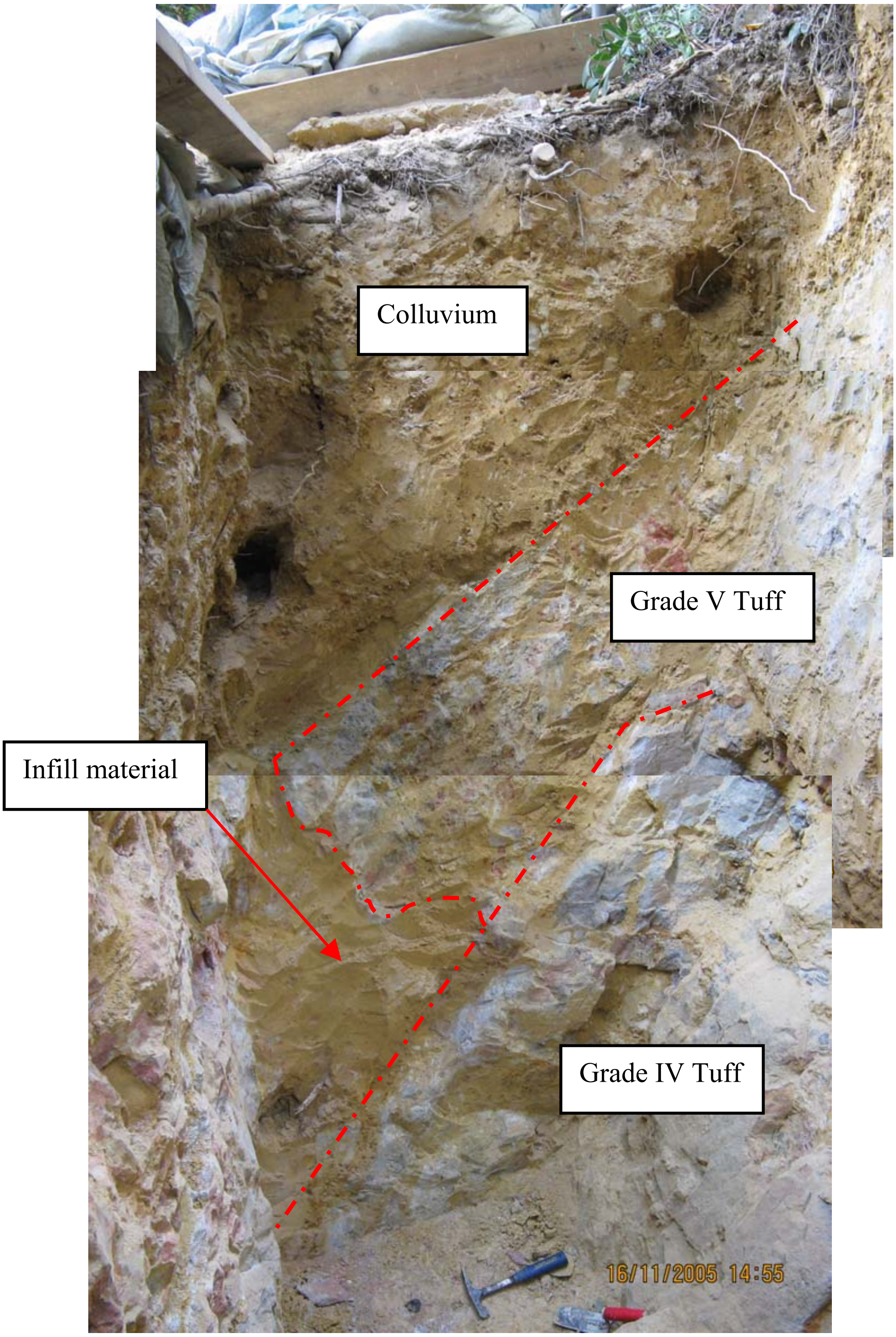

Plate 29 – View of Trial Trench TT6, Face D
(Photograph taken by FSW on 16 November 2005)

Note: See Figure 21 for location and direction of photograph.

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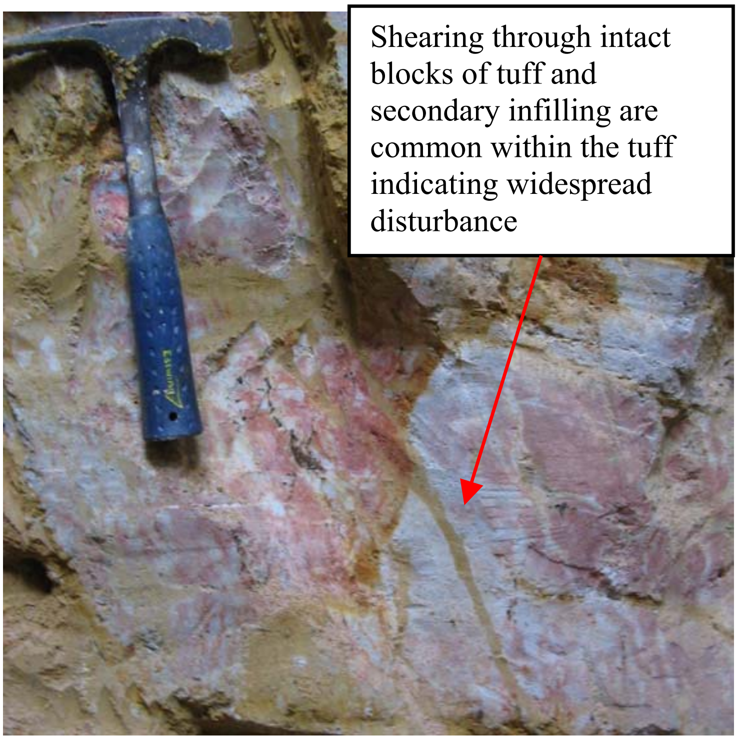

Plate 30 – View of Localised Shearing Through a Block of Tuff
(Photograph taken on 16 November 2005)

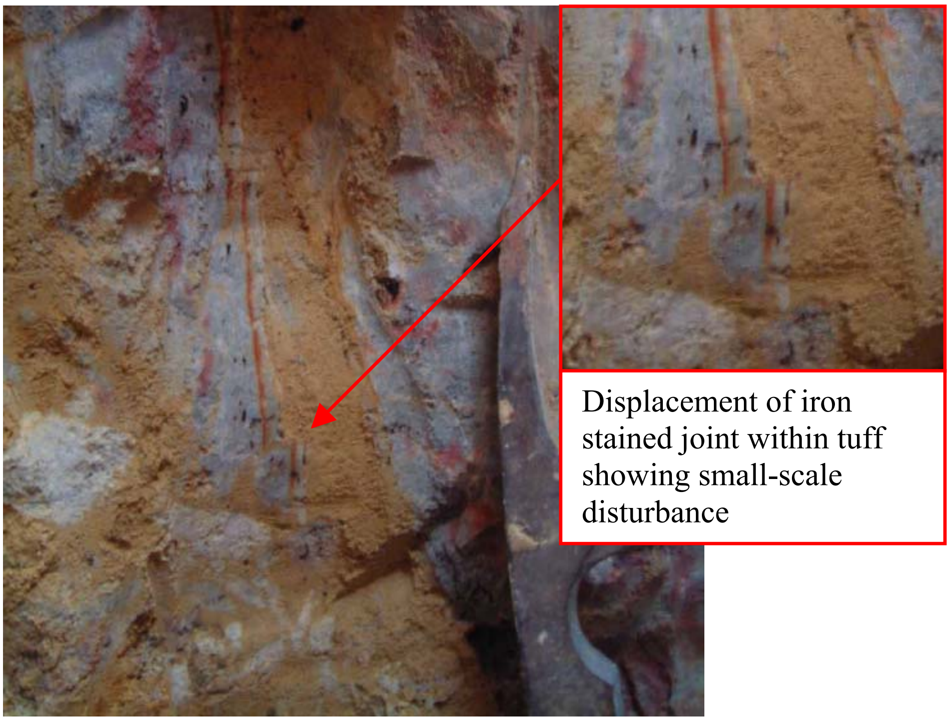

Plate 31 – View of Small-scale Disturbance within the Tuff
(Photograph taken on 16 November 2005)

Note: See Figure 21 for location and direction of photograph.

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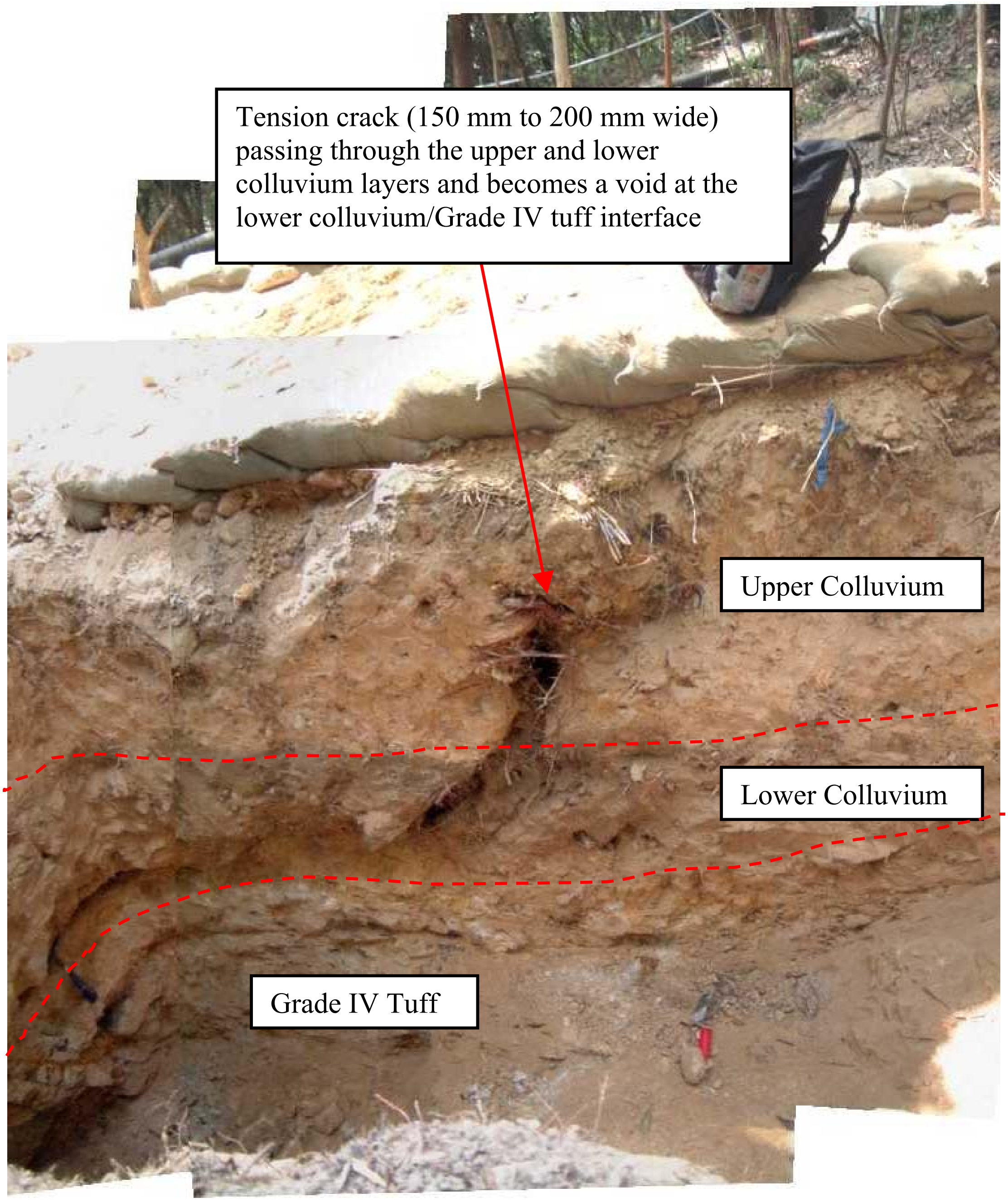

Plate 32 – View of Trial Trench TT7, Face D
(Photograph taken by FSW on 8 November 2005)

Note: See Figure 21 for location and direction of photograph.

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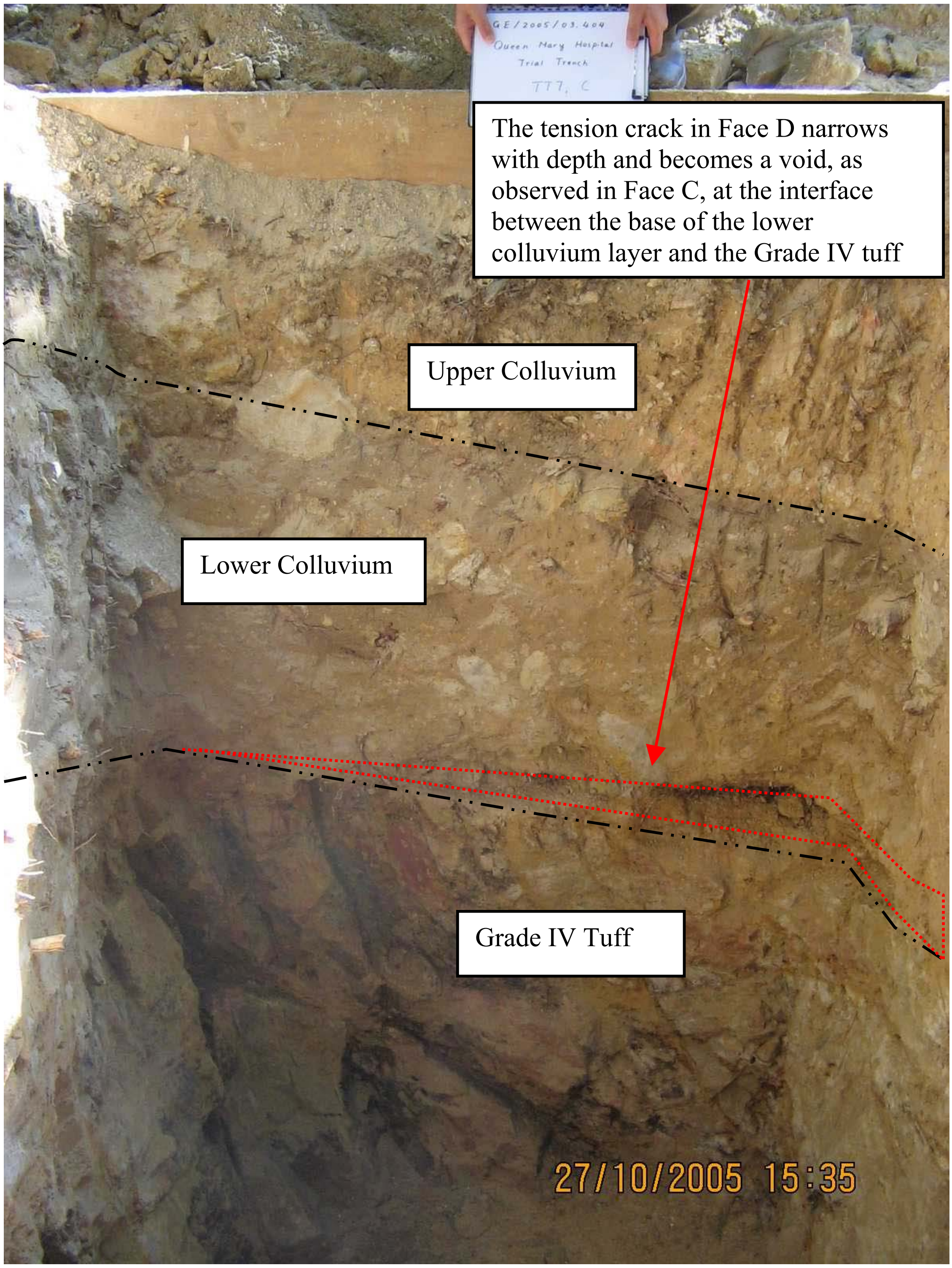

Plate 33 – View of Trial Trench TT7, Face C
(Photograph taken by FSW on 27 October 2005)

Note: See Figure 21 for location and direction of photograph.

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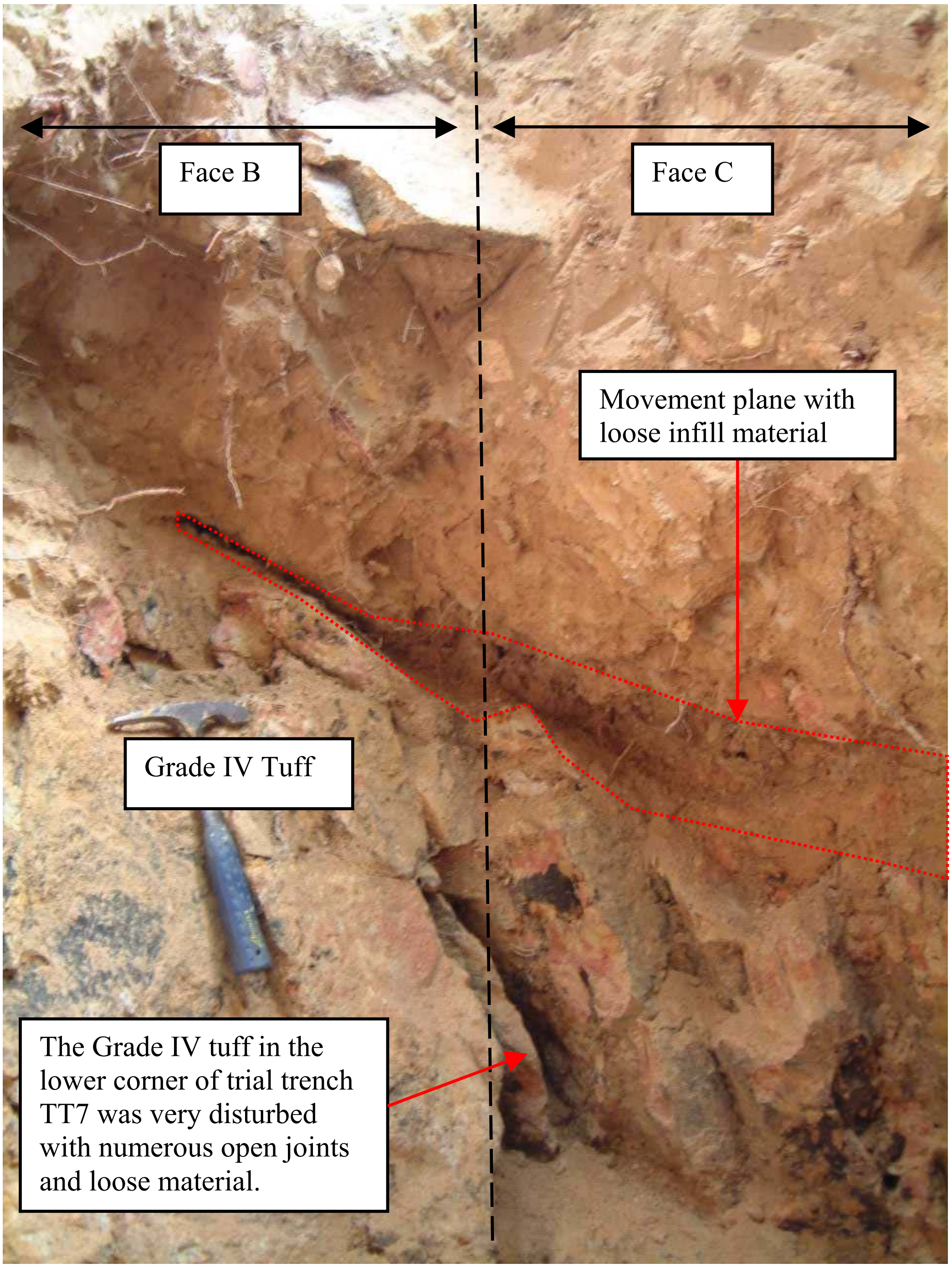

Plate 34 – View of Trial Trench TT7, Face B and Face C
(Photograph taken by FSW on 8 November 2005)

Note: See Figure 21 for location and direction of photograph.

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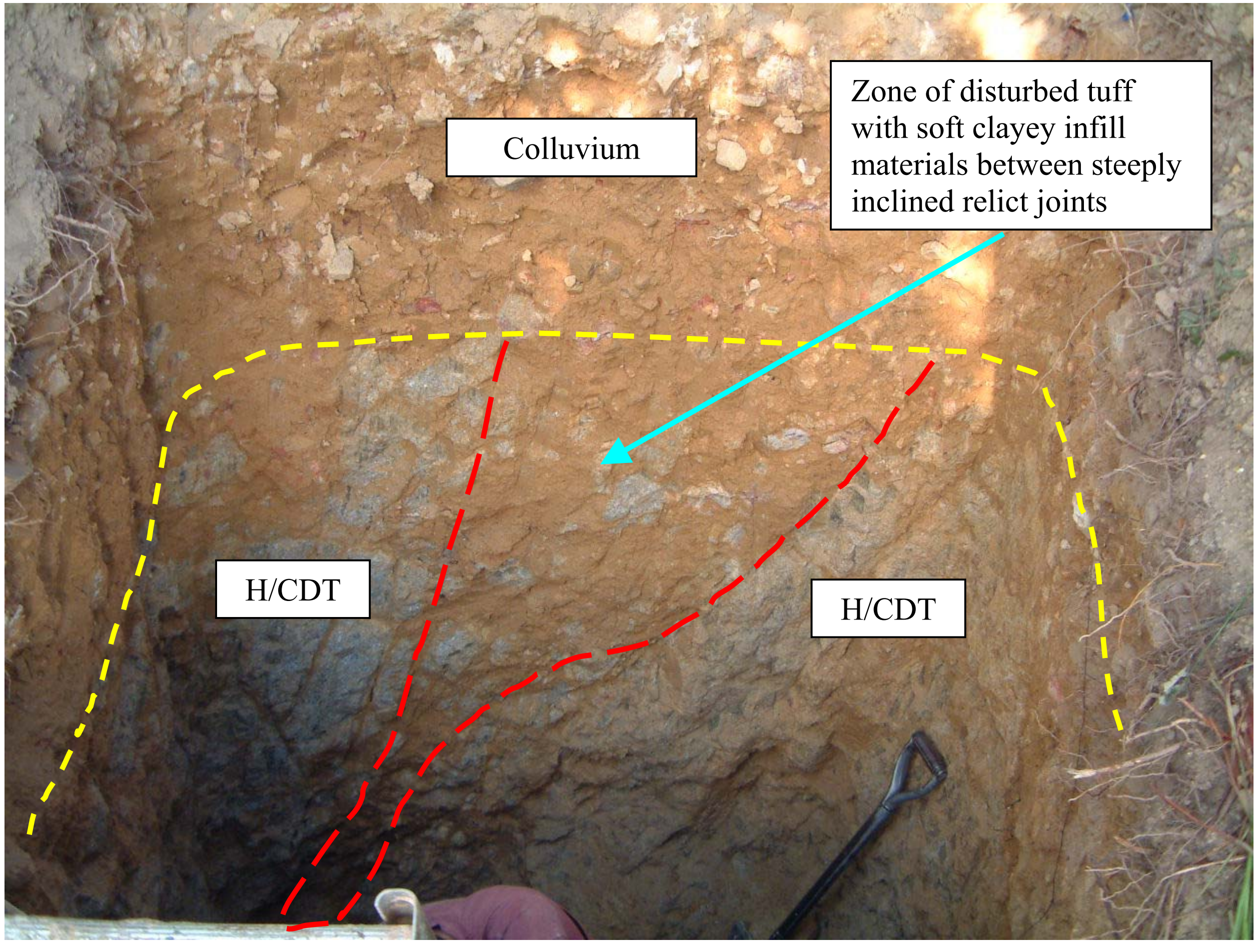

Plate 35 – Zone of Disturbed Tuff with Soft Clayey Infill Materials along Steeply Inclined Relict Joints within H/CDT Exposed in Face A of Trial Pit TP2
(Photograph taken by FSW on 18 November 2005)

Note: See Figure 21 for location and direction of photograph.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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A.1 DETAILED OBSERVATIONS

The site history was interpreted from aerial photographs dating from 1924 to 2004. The development history is illustrated on Figure A1.

Year	Observations
1924	Relatively poor resolution, high flight, stereo pair. Queen Mary Hospital (QMH) has not been formed yet. Clearance works and formation of cut and fill platforms are ongoing across the site. In particular, what appears to be extensive site formation works is apparent as a light toned area in the vicinity of the present-day Nurses' Quarters Block C (M1). The works are bounded to the east by an access road noted as a highly reflective area (M2). A steep cut slope has been formed at the location of the present-day slope No. 11SW-C/C70 (M3) and a tall building lies at the toe of the cut slope. To the north of the cut slope, an access track/footpath has been cleared across the open hillside (M4). The track appears to follow the edge of a minor spur and then crosses a small gully at an approximate elevation of 175 mPD, before descending the hillside again. The uppermost section of the track corresponds to the area above the present-day location of the Nurses' Quarters Block A. The service reservoir and pipeline in the natural hillside above Queen Mary Hospital has not been formed yet. The lower portion of the catchment above the present-day Nurses' Quarters Block A is covered by a dense vegetation, while the upper portion of the catchment is less densely vegetated
1949	Reasonable resolution, high flight, stereo pair. The Nurses' Quarters Block A and main hospital building to the NW have been formed (M5 and M6 respectively) as have the associated cut slopes. The covered service reservoir and pipeline (M7 and M8 respectively) have been formed in the natural hillside above Queen Mary Hospital. The footpath above the service reservoir and towards the crest of the catchment is also present (M9). The catchment surrounding the August 2005 landslide site is covered by moderate vegetation. A large semi-circular depression (M10) is present along the northern spur of the catchment about 30 m to the SE of the covered service reservoir. This depression corresponds to where a cluster of five relict landslides was identified on site during field mapping. Another semi-circular depression (M11) is noted in the upper portion of the catchment about 10 m downslope from the footpath. A large relict landslide was identified on site at this location during field mapping. What appears to be an ephemeral drainage line lies between scars M10 and M11, but no distinct scarp can be seen. The surface of the catchment below these relict landslides has an undulating profile with numerous subtle breaks of slope and has a slightly different vegetation cover to adjoining areas (M12). It is considered that this area corresponds to debris from the relict landslides (i.e. colluvium). These colluvial deposits cover the whole catchment in the mid-slope portion, but then diverge into two sub-parallel drainage lines that are separated by a minor spur. Part of the footpath/track previously identified in the 1924 aerial

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Year	**Observations**
1949 (continued)	photographs can still be seen along this minor spur (M4). The surface of the colluvium converging into the northerly drainage line has a hummocky profile and several arcing lines, denoting subtle breaks of slope, can be seen across the surface (M13 to M15). These lines could represent different phases of landsliding and deposition or could indicate minor slope movements within the colluvium. Indeed, a portion of one of the arcing lines (M13) roughly corresponds to the southern and crest portions of the August 2005 landslide.
1963	Good resolution, low altitude stereo pair. In these very clear aerial photographs, more detail can be seen regarding the relict landslides M10 and M11 observed in the 1945 aerial photographs. The northern flank of landslide M10 is quite sharp, while the southerly flank is more rounded. At least three separate scarps (M16 to M18) can be seen within the overall outline of landslide M10, two of which (M16 and M17) lie directly to the north of the August 2005 landslide and have been identified on site. The crest and upper northern flank of landslide scar M11 are also sharp, while the southern flank is more rounded. A large rock outcrop (M19) adjoins the southern flank of landslide M11. Along the debris trail below landslide M11, a small crescent shaped scarp (M20) and a wider arcing scarp (M21) can be seen at the uppermost portion of the colluvial fan (M12) observed in the 1945 aerial photographs. The vertical displacement across these scarps does not appear large and they may represent ongoing creep movement within the colluvial deposits. Below M21, lies an area of hummocky ground, the lower portion of which covers the area associated with the August 2005 landslide. A broad rounded scarp (M22) that is a possible relict landslide lies above the shallow, poorly defined depression forming the ephemeral drainage line identified between landslide M10 and M11 in the 1949 aerial photographs. The ephemeral drainage line leads into an area of hummocky ground below the western end of feature M21. The tall buildings at the toe of slope No. 11SW-C/C70 (M3) identified in the 1924 aerial photographs have been cleared and to the west a new cut slope and building have been formed at the present-day location of Slope No. 11SW-C/C71 (M23). Above the new cut slope, the pipeline connecting to the service reservoir has been realigned upslope by about 10 m (M24). A highly reflective area is present along the pipeline (M25), which could represent erosion or local cutting for the formation of the new pipeline.
1964	Good resolution high altitude stereo pair. No significant changes are apparent in the natural hillside above QMH. Site formation works are ongoing below and to the south of the Nurses' Quarters Block A. No other changes are observed.
1967	Good resolution, high altitude stereo pair. Construction works in the vicinity of Nurses' Quarters Block A appear to be complete. No significant changes are apparent to the natural hillside above QMH.

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Year	Observations
1968	Good resolution low altitude stereo pair. Clearance works for electricity pylon construction, noted as a large highly reflective bare area, is ongoing along the northern spur about 60 m upslope of the service reservoir. The vegetation cover across the catchment is getting denser.
1972	Good resolution, high altitude, stereo pair. A new electricity pylon has been formed along the northerly spur. A small, narrow light toned area is present in proximity to landslide scars M16 and M17, which may indicate erosion or slight retrogression, but it is not clear. No other significant changes are apparent.
1973 (12 12.73)	Good resolution, low altitude, stereo pair. The light toned area observed in proximity to landslide scars M16 and M17 in the 1972 aerial photographs is still apparent, but is slightly shaded by trees. The northern edge appears quite sharp suggesting localised, renewed instability rather than erosion, but it is not clear because of the tree cover. No other significant changes are apparent.
1973 (20.12.73)	Good resolution, high altitude, stereo pair. The light toned area observed in proximity to landslide scars M16 and M17 in the 1972 aerial photographs appears as a highly reflective, circular area, estimated to be about 5 m in diameter. No other significant changes are apparent.
1974	Good resolution, high altitude, stereo pair. The light toned area observed in proximity to landslide scars M16 and M17 in the 1972 aerial photographs is still present. No other significant changes are apparent.
1975	Good resolution, high altitude, stereo pair. No significant changes are apparent.
1976	Reasonable resolution, low altitude, stereo pair. No significant changes are apparent.
1977	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1978	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1979	Reasonable resolution, high altitude stereo pair. The light toned area observed in proximity to landslide scars M16 and M17 in the 1972 aerial photographs is just barely visible. No other significant changes are apparent.
1980	Good resolution, low altitude, stereo pair. The light toned area observed in proximity to landslide scars M16 and M17 in the 1972 aerial photographs is no longer distinct. No other significant changes are apparent.
1984	Good resolution, low altitude, stereo pair. Slope No. 11SW-C/C73 behind the northern part of Nurses' Quarters Block A, has been cut back and had new

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Year	Observations
	drainage channels constructed across it (M27). Works at the northern end of the slope are still ongoing.
1986	Good resolution, low altitude stereo pair. Works on Slope No. 11SW-C/C73 have been completed.
1988	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1989	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1990	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1991	Good resolution, low altitude stereo pair. The electricity pylon on the northern spur has been removed. No other significant changes to the subject feature are observed.
1994	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1996	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1997	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1998	Good resolution, low altitude, stereo pair. No significant changes are apparent.
1999	Good resolution, low altitude, stereo pair. Slope No. 11SW-C/C72 behind the Nurses' Quarters Block A, has been cleared of vegetation and appears to have been covered by rigid surfacing. No others significant changes are apparent.
2001	Good resolution, low altitude, stereo pair. No significant changes are apparent.
2002	Good resolution, low altitude, stereo pair. No significant changes are apparent.
2003	Good resolution, low altitude, stereo pair. No significant changes are apparent.
2004	Good resolution, low altitude, stereo pair. No significant changes are apparent.

A.2 SUMMARY OF SITE HISTORY

Two prominent areas of relict instability are observed within the catchment in the 1949 aerial photographs. One area comprises a single large relict landslide and the other comprises a cluster of several different landslides, which lies just to the north of the August 2005 landslide. A third, less prominent scar, located between the two relict scars noted in 1949, is evident in the 1963 aerial photographs. These scars were probably in existence in the 1924 aerial photographs, but the poor resolution of these photographs inhibited detailed observations. Possible minor scarps, indicating possible instability, were observed in proximity to the main scarp and toe of the August 2005 landslide in the 1963 aerial

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photographs. In the 1972 aerial photographs, erosion and/or renewed localised instability was observed in the area of relict instability to the north of the August 2005 landslide.

The pipeline that supplies the service reservoir located along the northern spur of the catchment was moved upslope slightly between 1949 and 1963. An electricity pylon was constructed along the northern spur between 1968 and 1972, which was decommissioned between 1990 and 1991. No other works of significance have been undertaken within the catchment.

A.3 PHOTOGRAPHS

Year	Aerial Photograph No.
1949	Y01336, Y01337
1963	Y07285, Y07286
1968	Y14053, Y14054
1969	Y14766, Y14767
1976	14602, 14603
1978	23782, 23783
1979	27957, 27958
1980	33376, 33377
1981	36620, 36621
1982	43031, 43032
1984	53719, 53718
1985	A00814, A00815
1986	A06043, A06044
1987	A10339, A10340
1988	A14453, A14454, A14455, A14456
1990	A23829, A23830
1991	A27909, A27910
1992	A30977, A30978
1993	A37009, A37010
1994	CN8067, CN8068
1996	CN14149, CN14150
1997	CN17595, CN17596
1998	CN21102, CN21103
1999	CN24059, CN24060
2000	CN28306, CN28307
2001	AW52325, AW52326
2002	CW39586, CW39587
2003	CW47569, CW47570
2004	CW57208, CW57209

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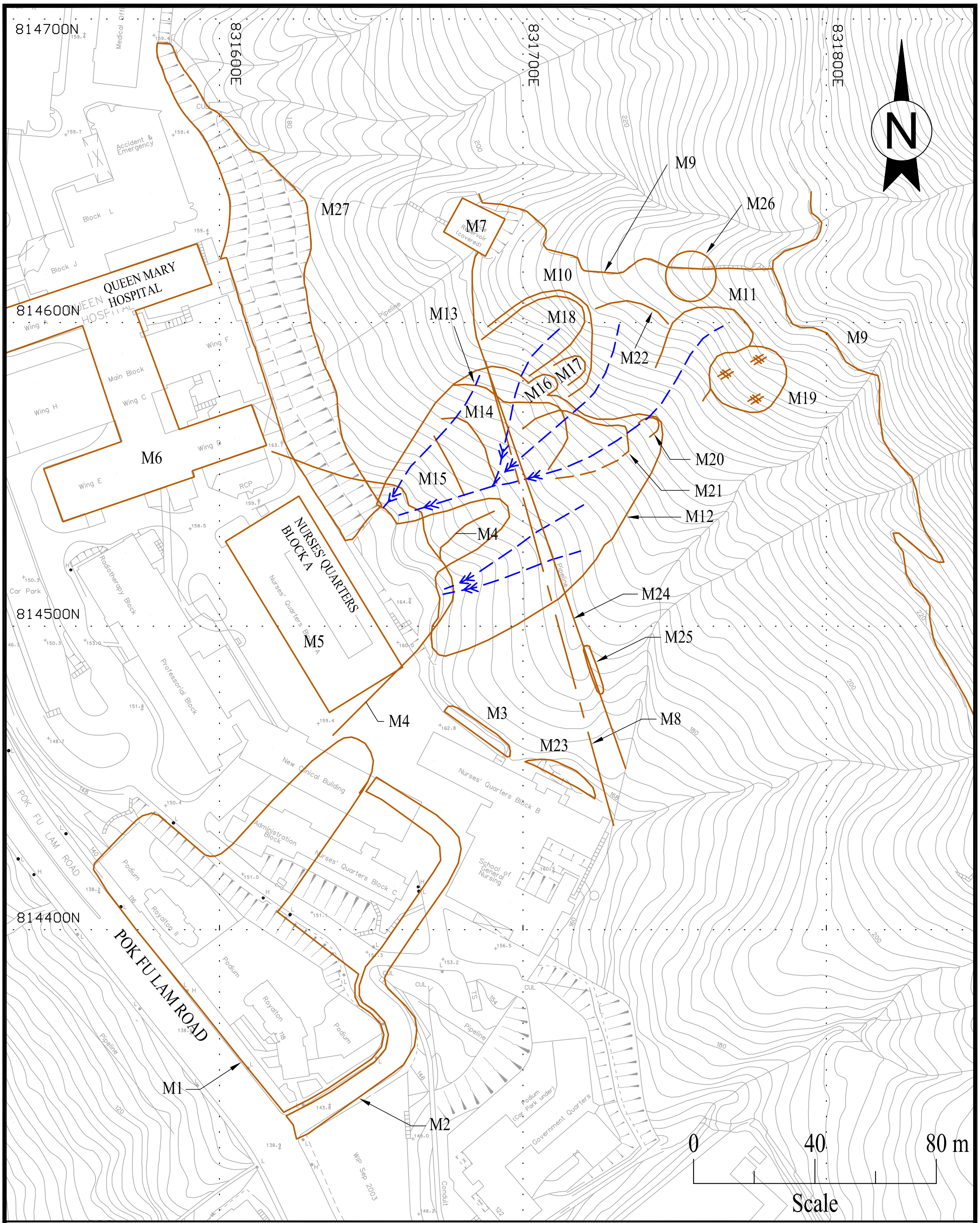

Legend :

Ephemeral drainage line

Note : Base Map is extracted from Survey Sheet No. 11SW-12C & 17A, dated 1999.

Figure A1 - API Plan

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APPENDIX B

RECORDS OF AUTOMATIC GROUNDWATER MONITORING

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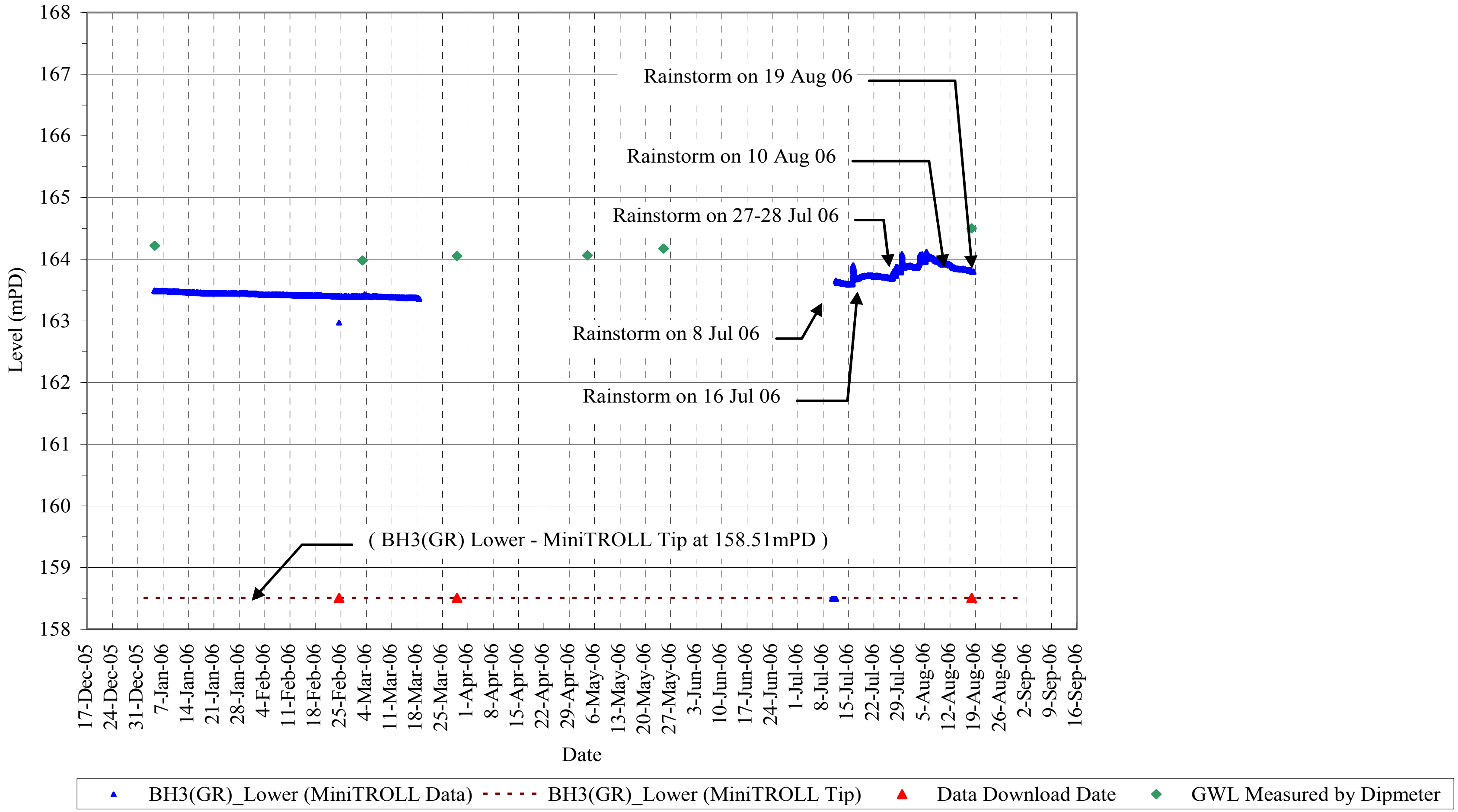

Note: (1) MiniTROLL removed during site works from 19 March to 11 July 2006

Figure B1 - Groundwater Monitoring for Drillhole BH3 (GR) Lower

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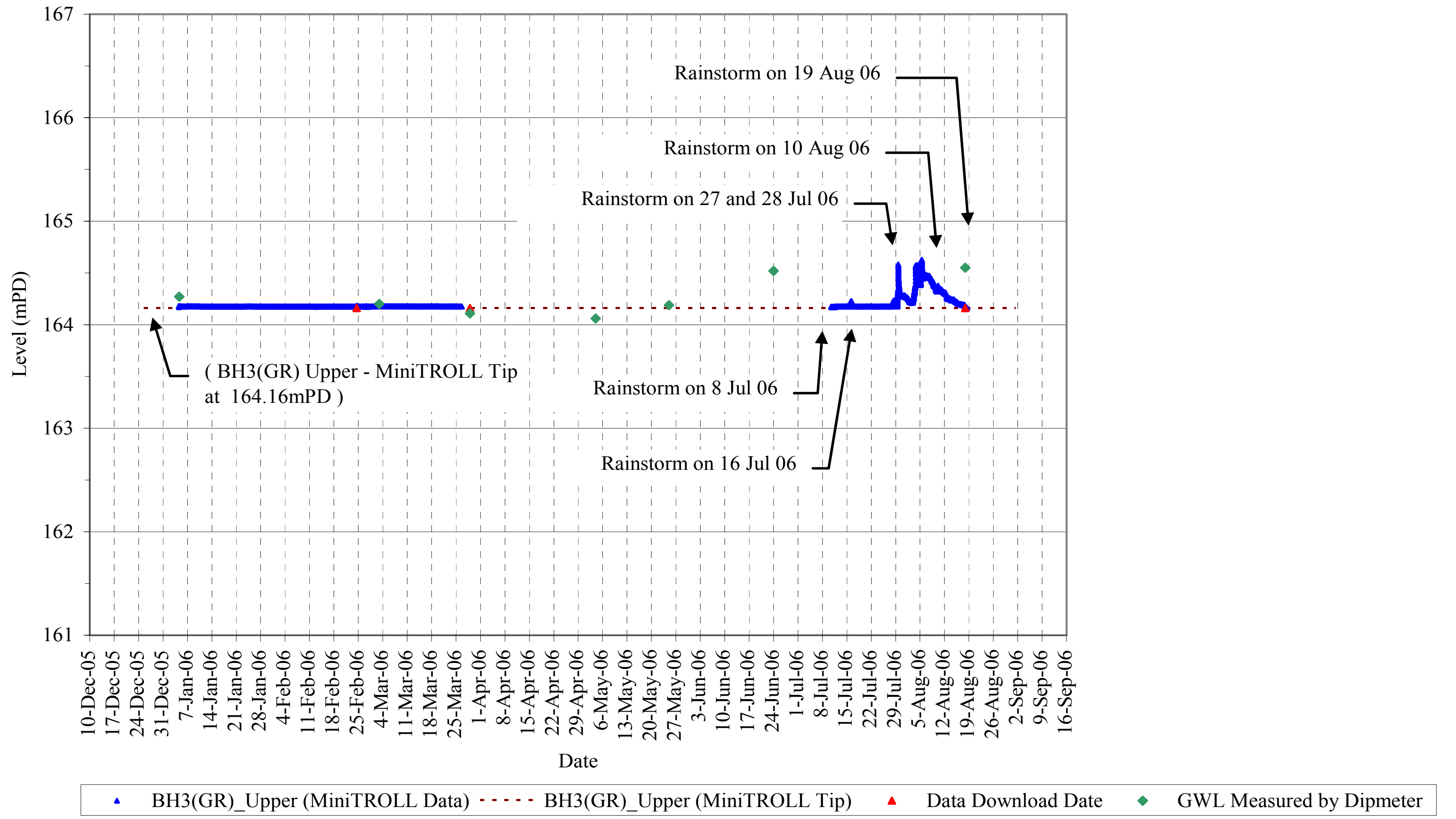

Note: (1) MiniTROLL removed during site works from 29 March to 11 July 2006

Figure B2 - Groundwater Monitoring for Drillhole BH3 (GR) Upper

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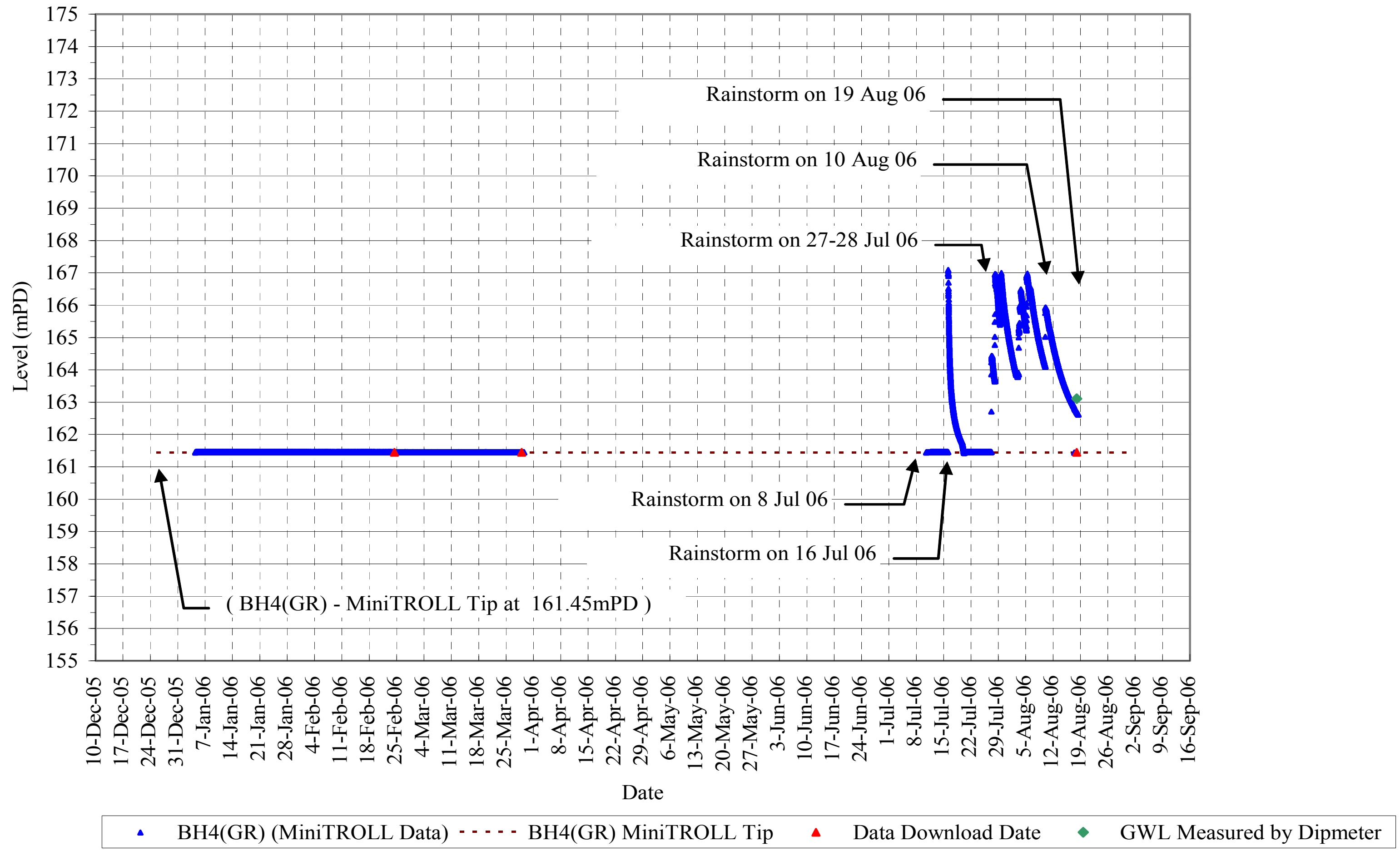

Note: (1) MiniTROLL removed during site works from 29 March to 11 July 2006

Figure B3 - Groundwater Monitoring for Drillhole BH4(GR)

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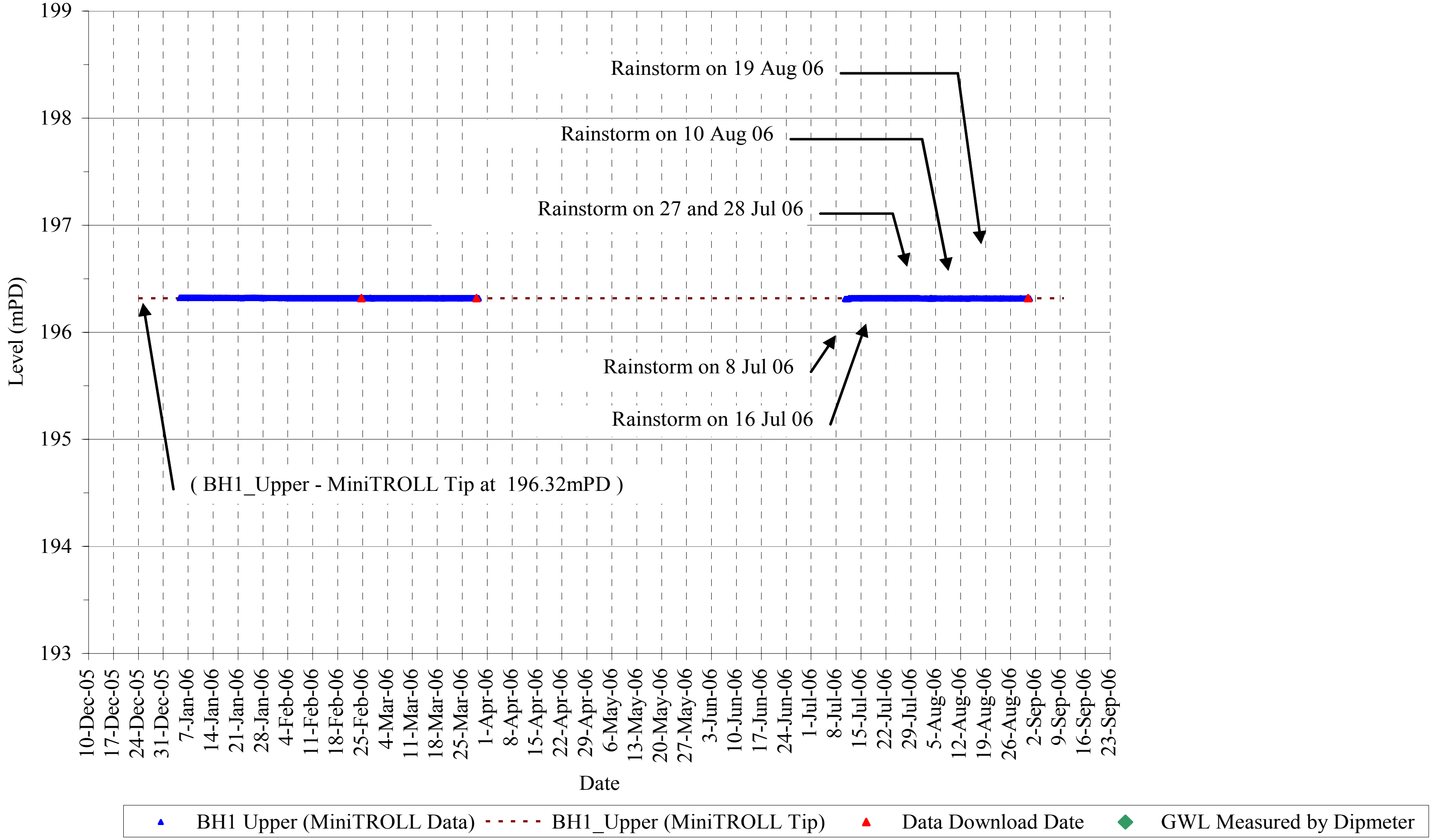

Note: (1) MiniTROLL removed during site works from 29 March to 11 July 2006

Figure B4 - Groundwater Monitoring for Drillhole BH1 Upper

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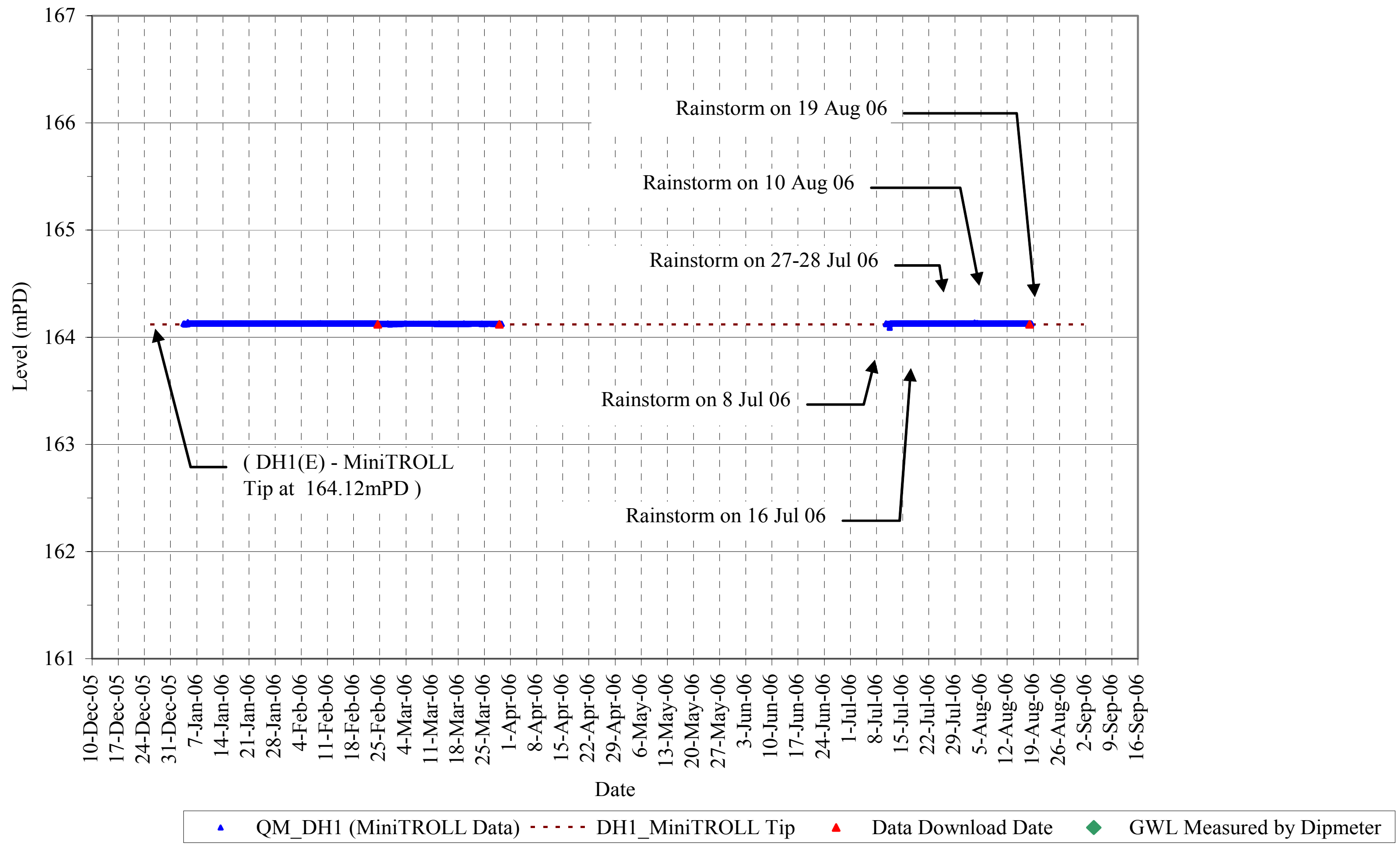

Note: (1) MiniTROLL removed during site works from 29 March to 11 July 2006

Figure B5 - Groundwater Monitoring for Drillhole DH1 (E)

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土力工程處之主要刊物

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

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

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.

GEOLOGICAL PUBLICATIONS

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

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

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