THE 5 MAY 2003 DEBRIS FLOW AT KAU LUNG HANG SHAN TAI PO

GEO REPORT No. 196

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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Table of Contents

Table of Contents

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Table of Contents

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Table of Contents

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Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

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
December 2006

Table of Contents
Table of Contents
Table of Contents

FOREWORD

This report presents the findings of an investigation into Incident No. 2003/05/0031, which involved a landslide on the natural hillside north of Kau Lung Hang Village, Tai Po. The landslide occurred during severe rainfall at about 4 a.m., approximately 1 hour prior to the hoisting of a Red Rainstorm Warning Signal.

The landslide involved a failure volume of about 200 m^3. Some 180 m^3 of the failed material detached from the source area and travelled down an ephemeral drainage line as a debris flow. The debris resulted in complete blockage of the sole access road to Cloudy Hill Transmitter Station for four days and severed a wire boundary fence of an orchard within private Lot No. 155 in D.D. 9 at the toe of the hillside below the access road. The runout distance of the main debris flow was about 165 m (disregarding the fluvial outwash). The deposition of fine-grained fluvial outwash material continued for a further 20 m, reaching the boundary of two village houses (within the private Lot No. 155 in D.D. 9). No damage to these village houses was observed and no casualties were reported.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study comprised site reconnaissance, desk study and detailed engineering geological and geomorphological mapping. Recommendations for follow-up actions are presented separately.

The report was prepared as part of the 2003/2004 Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2003 and 2004, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 94/2002 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

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Project Director
Maunsell Geotechnical Services Limited

Agreement No. CE 94/2002 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2003 and 2004 – Feasibility Study

Table of Contents
Table of Contents
Table of Contents
Table of Contents

CONTENTS

		Page No.

Table of Contents
Table of Contents
Table of Contents

1. INTRODUCTION

At about 4 a.m. on 5 May 2003, a landslide (Incident No. 2003/05/0031) occurred during intense rainfall on the hillside north of Kau Lung Hang Village, Tai Po (Figure 1 and Plate 1).

The landslide involved an estimated failure volume of about 200 m^3 from the source area (crown at about 87 mPD). Approximately 180 m^3 of the failed material detached from the source area and travelled down an ephemeral drainage line as a debris flow (20 m^3 of debris was deposited within the source area). The debris resulted in complete blockage of the sole access road to Cloudy Hill Transmitter Station for four days and severed a wire boundary fence of an orchard at the toe of the hillside below the access road, which is located within private Lot No. 155 in D.D. 9. Below this location, some cultivated terraces at the foot of the hillside were also covered with outwash material up to 0.5 m thick. The runout distance of the main debris flow was about 165 m (disregarding the fluvial outwash). The deposition of fine grained fluvial outwash material continued for a further 20 m, reaching the boundary of two village houses (within private Lot No. 155 in D.D. 9) (Plate 2). No damage to these village houses was observed and no casualties were reported.

Following the incident, Maunsell Geotechnical Services Limited (MGSL), the 2003/2004 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a review of the landslide incident for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 94/2002 (GE).

The key objectives of the study were to document the facts about the landslide, present the results of engineering geological and geomorphological mapping of the landslide source area, and establish the probable causes of the failure. The scope of the review does not include any ground investigation. Recommendations for follow-up actions are reported separately.

2. THE SITE

2.1 Site Description

The study area is bounded to the northwest by a northeast-southwest trending spur that extends down from the northern part of Lung Shan peak, and to the southwest by Kau Lung Hang Village, which is situated in a valley. Tai Po Road forms the south-western limit of the study area (Figure 1). The landslide site is located on the lower portion of the southeast-facing hillside, which is lightly vegetated with low shrubs and grass and is inclined at an angle of approximately 25° to 35° (Plates 1 and 3).

The source area of the 5 May 2003 landslide is located at an elevation of about 103 mPD, some 70 m above the toe of the hillside where an orchard and two village houses are located at the edge of Kau Lung Hang Village.

An access road leading to Cloudy Hill Transmitter Station traverses the hillside approximately 60 m downslope of the 5 May 2003 landslide source area.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

2.2 Regional Geology

The Hong Kong Geological Survey (HKGS) 1:20 000 Solid and Superficial Geology Map Sheet No. 3 - Sheung Shui (GCO, 1991) indicates that volcanic rocks of the Tai Mo Shan Formation underlie the landslide site (Figure 2). These rocks, as described on the map sheet, comprise undifferentiated coarse ash crystal tuff. Pleistocene debris flow deposits and terraced Holocene alluvium are also indicated across the lower portion of the hillside and the foothill respectively.

The Tai Mo Shan formation also contains slightly metamorphosed zones and occasional siltstone bands, generally striking between NE-SW and ENE-WSW. Foliation fabric in the metamorphosed zones generally dip to the northwest but in places the foliation is shown to dip to the northeast at about 35° and to the northwest at about 68°. Northeast trending faults and northwest trending cross-faults are shown to the east and southeast of the landslide site although no faults or photogeological lineaments are shown to intersect the site. The valley, in which Kau Lung Hang is situated, is coincident with the major northeast-southwest trending Shau Tau Kok fault (Figure 2).

The HKGS 1:100 000-scale Pre-Quaternary Geology Map of Hong Kong (Sewell et al, 2000) also indicates that volcanic rocks of the Tai Mo Shan Formation underlie the study area. These are described on the map as lapilli lithic-bearing coarse ash crystal tuff.

2.3 Geotechnical Area Studies Programme (GASP)

Geotechnical data relating to the study Area were compiled as part of the Geotechnical Control Office's (GCO, renamed GEO in 1991) Geotechnical Area Studies Programme (GASP) Report No. V, North New Territories (GCO, 1998). The data are shown on a 1:20 000 scale map, which is used for regional appraisal and strategic planning purposes. The Engineering Geology Map indicates that the open hillside on which the 5 May 2003 landslide occurred comprises predominantly pyroclastic rocks with some lava. The Geotechnical Land Use Map (GLUM) designated the terrain within the open hillside of the study area as generally GLUM Class II (moderate geotechnical limitation), whereas GLUM Class IV (extreme geotechnical limitation) is indicated along the large drainage lines adjacent to the landslide site. The Physical Constraint Map shows no classification for the open hillside terrain of the study area although it classifies the terrain within the large drainage lines adjacent to the landslide site as "zones of general instability associated with predominantly colluvial terrain".

3. PAST INSTABILITY

3.1 General

The history of instability within the study area has been determined from aerial photograph interpretation (API) and a review of relevant documentary information (Figure 3). Detailed API observations are presented in Appendix A, and key observations are presented below.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

3.2 Natural Terrain Landslide Inventory and Large Landslides Database

In 1995, GEO compiled the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high-level aerial photographs dating from 1945 to 1994 (Evans et al, 1997; King, 1997). According to the NTLI database, there are two records (Tag Nos. 3SWD0143 and 3SWD0144) of landslides approximately 100 m northeast of the 5 May 2003 landslide site, although a further nine NTLI landslides were recorded in the steep upper hillside areas below Lung Shan in the north of the study area catchment (Figure 4). The two nearest NTLI landslides have a relatively small runout distance of less than 20 m. However, one NTLI landslide (Tag No. 3SWD0001) in the north of the study area catchment (about 175 m from the May 2003 landslide source) has a runout of approximately 70 m.

The GEO's Large Landslides Database contains no records of large landslides within the study area.

3.3 Aerial Photograph Interpretation

The earliest aerial photographs of the study area were taken in 1924. At that time, the natural hillside in the vicinity of the May 2003 landslide site was sparsely vegetated. The area below the hillside, which is occupied by the present-day Kau Lung Hang Village, comprised extensive cultivation terraces and isolated village houses located on the low-lying and gently inclined colluvial and alluvial terrain.

On the 1949 aerial photographs, the source areas of eight relict landslides can be identified on the adjacent hillside by distinctive concave depressions. No debris trail remnants can be seen and hence estimation of runout distance of these relict landslides was not possible. Five of the relict landslides which predate the 1949 aerial photographs (designated pre-1949/R2 to R6 in Figure 3) are located near the centre of the study catchment. They can be seen as shallow depressions and are covered with thin vegetation. One of these relict landslides (designated pre-1949/R4) appears to be in approximately the same location as the 5 May 2003 landslide.

The other relict landslides that predate the 1949 aerial photographs (designated pre-1949-R1, R7 and R8) are located in the northern portion of the study area. Of these other relict landslides, two (designated pre-1949/R7 and R8) appear to have developed as a result of several individual landslides coalescing into a relatively large area of instability. Based on the API, re-activation of landslides pre-1949/R4 and 1949/1 appeared to have occurred in May 2003 (covered by this report) and 1975 respectively, although in the case of the latter landslide, no evidence of relict instability can be seen (Figure 3). It is also noted from the 1975 aerial photographs that retrogressive failure had occurred upslope of landslide 1949/1. Areas of surface erosion are visible in the northern portion of the study area near the ridgeline.

Photogeological lineaments trending northeast-southwest and northwest southeast directions are visible on the natural hillside above the May 2003 landslide. The hillside is generally planar in profile although some geomorphological features are observed as shallow concave depressions (possible relict instabilities) in the upslope area of the May 2003 landslide site.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The 1963 aerial photographs were taken at low altitude and are of high resolution. Rock outcrops are clearly visible near the ridgeline and on the mid-slopes. Depressions, being signs of relict landslides, are observed near the head of some of the drainage lines. Colluvial fans, also indications of past instability, are observed at the base of these drainage lines. On these photographs, there are numerous signs of instability, particularly to the north of the landslide site, and most of the apparent landslide scars seem to be quite recent (Figure 3).

Anthropogenic features visible on the 1963 aerial photographs of the study area include minor footpaths and occasional graves. In addition, there are shallow excavations and trenches along the ridgelines and around the summit of Lung Shan, which were probably a result of military construction. The access road to Cloudy Hill Transmitter Station, which is approximately 60 m downslope of the 5 May 2003 landslide site, was constructed some time between 1949 and 1963.

By 1975, most of the previous landslides were re-vegetated and there was an increase in the number of village houses near the foothills. Two recent landslides (designated 1982/1 and 1982/2 in Figure 3) can be seen on the 1982 aerial photographs in the upper hillside areas to the north of the May 2003 landslide site and debris of these landslides appears to have become channelised along drainage lines.

In 1989, construction of transmission line towers was in progress on the hillside approximately 100 m to the north and east of the May 2003 landslide source area. The construction works were completed by 1990.

3.4 GEO Incident Reports

According to GEO's Landslide Database, no landslides have been reported to the GEO within the immediate vicinity of landslide study site (Figure 4). Within the study area catchment, seven incidents were reported. Among them, three incidents are within 200 m of the landslide site. The closest landslide to the source area of the May 2003 landslide is Incident No. ME2001/06/0013, which was located at about 130 m to the northeast and had a volume of about 15 m^3. The other two incidents, Incident No. 2003/05/0090 (which occurred at the same time as the May 2003 landslide) and 2003/07/0151 were relatively small, each with a volume of about 5 m^3 (Figure 4). According to the landslide incident reports, all three incidents occurred on soil cut slopes above the access road leading to Cloudy Hill Transmitter Station.

The other 4 incidents within the study catchment were all small-scale failures on cut slopes adjacent to the access road or village houses.

4. DESCRIPTION OF THE LANDSLIDE AND SITE OBSERVATIONS

4.1 General

According to the GEO Incident Report, the landslide occurred at about 4 a.m. on 5 May 2003 during heavy rainfall. This is corroborated by discussions with the owner of the orchard at the toe of the landslide trail during site visits, who stated that he heard "a noise"

Table of Contents Table of Contents Table of Contents Table of Contents

sometime between 3 a.m. and 4 a.m. The landslide resulted in complete blockage of the only access road to the Cloudy Hill Transmitter Station for four days and severed a wire boundary fence adjacent to an orchard at the toe of the hillside.

The first inspection of the 5 May 2003 landslide site by MGSL was carried out on 9 May 2003, with several subsequent visits made for detailed landslide, geological and geomorphological mapping. A plan of the landslide scar is shown in Drawing No. 1. To provide a reference for field mapping and fixing the positions of features within the debris trail, a chainage was established along the centreline of the landslide scar starting at 0 m (chainage CH 0) at the upslope extremity of the crown of the landslide source and extending as far as the toe of the outwash material at 176 m (chainage CH 176). This terminology is adopted in the following text to locate features along the debris trail with reference to Drawing No. 1.

A longitudinal section and a cross-section through the landslide source area are given in Figure 5, and longitudinal and cross-sections through the debris trail are shown in Figure 6 and Appendix B. These sections show the observed surface and interpreted sub-surface geology. Materials encountered within the landslide scar have been classified as one of nine material types (MT) and are described in Appendix B. To avoid repetition, materials designations (viz. MT1 to MT9) have been used where appropriate in this report. The estimated volumes of material entrained and deposited along the path of the landslide are shown in Table 1 and Appendix B, and detailed descriptions of the landslide source and debris trail are presented in the following Sections. General views of the landslide source and trail are shown in Plates 3 and 4.

4.2 Geometry

The main body of the landslide scar is approximately 165 m long (about 180 m including outwash material), with an elevation difference of approximately 70 m extending from the source area at an elevation of about 102 mPD, to the orchard at the toe of the hillside at approximately 33 mPD. The landslide scar has an average aspect of about 140° and the landslide debris has a travel angle of some 23°. The width of the main scarp is approximately 20 m and the average width of the trail is approximately 7 m except at location where the debris spread out across the access road. The thickness of debris reached a maximum of about 0.5 m in the lobe that formed at the toe of the debris trail. The debris trail profile generally had no major breaks in slope except at the intercept with the access road with slope gradients generally decreasing gently from about 26° to 10°. Most of the debris trail is confined within the pre-existing drainage line descending the hillside from the source area.

4.3 Source Area (CH 0 to CH 12)

The crown of the source area is at an elevation of approximately 102 mPD and is located at the head of an ephemeral drainage line on a natural hillside inclined at about 40° with low shrub and grass cover. The landslide source area has a maximum depth of about 1.2 m and is ‘Y’-shaped in plan, with distinct western and eastern branches (Drawing No. 1 and Plates 1 to 4). The source area is about 15 m in length and varies in width from about

Table of Contents
Table of Contents
Table of Contents
Table of Contents

21 m across the top of the 'Y' to about 10 m at the base of the 'Y'. The western branch of the source area is slightly larger than the eastern branch, with respective volumes of approximately 115 m³ and 85 m³. Longitudinal and cross-sections through the source area are shown in Figure 5.

The materials exposed within the source area of the May 2003 landslide consist mainly of colluvium in the main scarp area, and completely to highly weathered tuff within the source floor. Plate 5 shows a general view of these materials in the west and east portions of the main scarp, and Plate 6 shows a general view of the upper source floor area. The detached material consists primarily of colluvium, which comprises firm to stiff, greyish brown, sandy with many angular cobble-sized rock (tuff) fragments (material MT3a). Soil pipes within the main scarp area are rare and no signs of seepage or wet/damp material were observed during the site visits.

General views of the eastern and western flanks of the main scarp of the May 2003 landslide are shown in Plates 7 and 8 respectively. These Plates also show that the thickness of colluvium is up to about 1 m and that it occupies the flanks and overlies the completely to highly decomposed tuff on the floor of the source area. An area of colluvium in the western flank has had the surface vegetation stripped off only, without complete detachment. This colluvial mass is considered potentially unstable as it is vulnerable to direct rainfall infiltration and overlies the undulating joint-controlled surface of rupture (Plate 9). The steep upper source floor area consists of moderately and highly strong, light grey mottled orange brown tuff, with clasts of light purplish grey mudstone/siltstone (material MT6). The central source floor area comprises moderately weak to moderately strong, light pinkish grey, completely to highly decomposed coarse ash tuff (material MT5). Below this material, there was a second narrow (about 0.5 m) band of material type MT5 where a small break in slope had formed (Plate 10). Extensive quartz veins are exposed within the tuff of the upper source floor, possibly alluding to evidence of hydrothermal alteration and therefore consequent resistance to weathering. The material in the centre of the main scarp that did not detach (thus leading to the 'Y' shape source area) and comprised moderately decomposed tuff with locally wide joint spacing, which may explain its increased resistance to weathering.

About 20 m³ of the displaced material remained within the source area. This included a remoulded debris levee consisting of soft dark greyish brown sandy silt (material MT1), clastic debris that comprises boulder-sized and cobble-sized angular rock fragments (material MT8), and a vegetated intact debris raft (Plate 11) comprising material MT2.

About 50% of the surface of rupture is formed by a set of discontinuous joints (materials MT5 and MT6) that are inferred to be stress relief joints, due to their limited persistence (generally less than 2 m) and similar orientation to the slope of the hillside (average dip of 40º, and dip direction of 180º). Considerable dilation and infilling (generally consisting of a sandy clay material) of stress relief joints was observed within the source area. Tectonic joints were especially pronounced within the less weathered material of the upper source area (moderately and highly decomposed material MT6), and are limonite/manganese stained and kaolin coated (<1 mm thick). The lower part of the surface of rupture appears to have been formed partly by shearing through the completely decomposed soil (material MT5), and partly along the pre-existing stepped interface between the highly decomposed rocks and the overlying colluvium, which also appeared to be weakly foliated. The overall surface of

Table of Contents
Table of Contents
Table of Contents
Table of Contents

rupture can be described as stepped and undulating (see also Section 6 for quantification of the roughness).

A number of tension cracks, primarily within the colluvium, could be seen in the flanks of the source area (between 20 mm and 300 m wide, 3 m to 5 m long, see Drawing No. 1 and Plates 12 to 14). These were probably associated with the recent instability since the cracks were free of vegetation and could not be traced more than a few metres from the flanks of the source area.

The rock exposed in the upper source area corresponds to a break in slope in the pre-failure source area and the adjacent hillside. API suggests that the source area prior to failure was a degraded concave depression and therefore possibly the site of past failures. Other linear rock outcrops are visible above and below the May 2003 landslide, striking across the hillside with a northeast-southwest trend, which is similar to that of the regional structure including the Shau Tau Kok fault and metamorphosed bands within the tuff.

There is no clear evidence on site to indicate whether one branch of the source failed before the other. On the contrary, the large extent of the uniformly flattened vegetation (see Section 4.6) on either side of the trail below the source (Plates 15 and 16) would suggest that both branches probably failed at about the same time and that the bulk of the detached material contributed to the debris flow as a single pulse.

4.4 Upper Debris Trail (CH 12 to CH 56)

The upper debris trail consists of the portion between the source area and the access road (Plate 16). Detailed sections of the upper debris trail are shown in Drawing No. 1 (Sections 1 to 6), and Figures B1 and B2. The gradient of the ephemeral drainage line below the source area is about 26°, and the width of the upper debris trail ranges from about 7 m to 9.2 m. Channelisation ratio (CR) of the upper debris trail varied between 7 and 15, with an average of about 10.

About 15 m^3 of debris was deposited within the upper debris trail with an intact debris raft coming to rest just below the lip of the landslide source area, with some remoulded debris levees developing along the flanks of the debris trail.

There appears to have been negligible entrainment of material during the main debris flow event. However, subsequent minor surface water ditch erosion of the upper debris trail was noted, amounting to about 2 m^3 of material. About 15 m^3 of material, which comprised mainly remoulded debris levees (material MT1) and alluvial (i.e. water transported) material consisting of loose greyish brown silty sand (material MT7), were deposited.

4.5 Access Road (CH 56 to CH 61)

About 60 m^3 of landslide debris was deposited on the 2.5 m wide access road to the Cloudy Hill Transmitter Station with a maximum depth of about 0.3 m (Plates 17 to 19). The western-most 15 m consisted primarily of remoulded debris (material MT1) that had been

Table of Contents
Table of Contents
Table of Contents
Table of Contents

reworked and transported from the original deposit by subsequent overland flow from the ephemeral drainage line (Plate 17).

The head of an incised erosion gully is located just below the access road on the northeast side of the lower debris trail and the entrance point coincides with the uphill extent of the debris blocking the road. As there is no provision of roadside drainage along the access road, the deposition of landslide debris on the road probably caused diversion of surface runoff into the drainage line below, thus leading to the formation of erosion gully.

4.6 Lower Debris Trail (CH 61 to CH 135)

The lower debris trail comprised the portion below the access road. A general view of the lower debris trail is shown in Plate 1 and a view of the lower debris trail below the access road is shown in Plate 20. Detailed sections of the lower debris trail are shown on Drawing No. 1 (Sections 7 to 15), and in Figures B2 to B4.

The gradient of the drainage line immediately below the access road is about 35° but this gradually decreases to about 14° at chainage CH 125. The lower debris trail was about 19.5 m wide below the access road where the slope is relatively open and the trail narrows to between 4 m and 6 m along the channelised section between chainage CH 90 and CH 135. About 35 m^3 of remoulded debris (material MT1) was deposited within the lower debris trail.

The incised gully resulted in the erosion of about 36 m^3 of material although this was probably the result of subsequent water erosion (see Section 4.5) rather than during the main landslide event (Plates 21 & 22). The erosion gully extended from chainage CH 75 to CH 132 and generally exposed moderately decomposed (material MT6) tuff (Plate 23) and completely to highly decomposed (material MT5) tuff in the substrate (see cross sections 9 to 14 in Figures B3 & B4), and has a maximum width and depth of about 2.8 m and 3.2 m respectively. Several minor post-event stream flank failures were observed due to probable undercutting by surface water in the lower drainage line (Plate 24). At about chainage CH 88, a failure occurred in the eastern flank of the drainage line (Plate 25) exposing colluvium (material MT3) overlying completely decomposed coarse ash tuff (material MT4).

On the western flank of the debris trail at chainage CH 88, colluvial layers were observed within the incised erosion gully with a distinct contrast in the clast and matrix properties, possibly indicating different ages of deposition (Plate 26). Further down the debris trail, between chainages CH 120 and CH 125, other well-defined vertical profiles were observed within the erosion gully flanks (Plates 27 to 30) generally exposing variable colluvium and occasionally exposing the underlying metamorphosed siltstone (Plate 27).

From approximately chainage CH 110 to CH 135, the lower debris trail slope angle decreases rapidly from about 24° to 10° where the trail widens out to form the debris fan and outwash deposits (Plate 32). Near chainage CH 130, alluvial deposits were found in the substrate of the debris trail (Plates 33 and 34). Evidence of debris height was provided by the accumulation of vegetation debris around trees along the flank of the trail.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

4.7 Debris Fan and Outwash (CH135 to CH185)

The debris fan is lobe-shaped, which comprised mainly clastic debris (material MT8), and had a maximum length of about 30 m and a maximum width of 16 m (see Figure B5, cross-section 17). The debris came to rest at a gradient of about 10° in the flat-lying orchard located at the toe of the hillside. About 70 m³ of debris was deposited in the orchard and the maximum thickness was about 0.5 m with an average of 0.2 m.

Isolated pockets of remoulded debris existed within the debris fan, suggesting that much of the initial fan material may have been remoulded debris. However, as a result of subsequent overland flow which washed out most of the fines, the bulk of the remaining material comprised clastic debris (material MT8) that consisted of gravel-, cobble- and small boulder-sized fragments less than 400 mm across.

Outwash debris consisting of primarily sand with about 10% gravel (material MT9) was deposited in a sheet with an average thickness of about 20 mm between the debris fan and village houses, as shown in Drawing No. 1. From Table 1, it can be seen that about 36 m³ of primarily fine material was eroded by subsequent overland flow along the lower debris trail.

Table of Contents

5. GEOLOGICAL SETTING OF THE LANDSLIDE SITE

5.1 General

The surface and subsurface conditions at the landslide site were inferred from a review of existing information, API and field mapping.

5.2 Geology and Geomorphology

Table of Contents

The solid geology of the source area comprises completely to moderately decomposed coarse ash crystal tuff with subordinate clasts of sedimentary rock. The decomposed rocks are overlain by up to 0.7 m thickness of colluvium. A geological longitudinal section and cross-section through the source area are shown in Figure 5, and views of the source area are shown in Plates 5 to 14. The coarse ash crystal tuff is light purple with abundant flecks of white clay material, which was inferred to be kaolin. A rock outcrop of coarse ash tuff is located approximately 30 m southeast of the source area (Drawing No. 1 and Plates 37 and 38). The stress relief joints are kaolin infilled (up to 5 mm thick) and show signs of relative movement with polished and undulating surfaces.

The geological structure inferred from API and the field mapping is shown on the enlargement of the 1963 aerial photograph in Figure 7. The pattern of the major photogeological lineaments corresponds well to the regional trend of the metamorphic fabric and faults, as indicated in the published geology. A series of faint lineaments observed from API near the crown of the landslide and striking east-southeast, generally corresponds to the strike of the resistant strata of tuff with siltstone clasts at the upper source area.

Table of Contents

The main aspects of the geological structure of the landslide scar, in relation to the regional structure, dip and aspect of the natural hillside, are summarised below (some of these aspects of the structure are illustrated on the stereographic projection in Figure 8):

(a) the stress relief joints dip between 30° and 60°, and overall are unfavourably orientated for stability as they are undulating, with an average dip of 40°, similar to that of the adjacent hillside,

(b) some tectonic joint sets are unfavourable for stability as they strike sub-parallel to the hillside and may form back-release surfaces in which transient cleft water pressures could develop during rainfall, and

(c) the strike of some of the major local joint sets seen in the scar (northeast) is generally consistent with the orientation of adjacent linear rock outcrops (seen on site and in the aerial photographs) and the regional structure (Shau Tau Kok fault).

API indicated that few landslides occurred on the hillside in the immediate vicinity of the May 2003 landslide between 1949 and 2002. However, the western and eastern branches of the source area of the landslide are within an area of well-vegetated shallow depression, which is probably in connection with relict instabilities that can be clearly seen on the 1963 aerial photographs. The main inferred geomorphological features in the vicinity of the landslide are shown on an enlargement of the 1963 aerial photograph in Figure 9 and key observations are summarised as follows:

(a) the source area is located below a convex break in slope on the hillside, near the head of an ephemeral drainage line,

(b) the upper part of the drainage line above the access road is generally broad and rounded and has a relatively low overall channelisation ratio,

(c) the lower part of the drainage line below the access road is locally narrow and has a relatively high channelisation ratio in these areas,

(d) API suggests that the source area prior to failure was a degraded concave depression and therefore possibly the site of relict instabilities, and

(e) a debris fan is inferred to be present at the base of the drainage line. This debris fan is possibly a very ancient feature following the outline marked in Figure 9.

Detailed regolith mapping was not undertaken within the study area as it is considered to be of limited value due to insufficient contrast in the regolith materials observable by API.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

5.3 Hydrogeology

The May 2003 landslide site lies immediately below a rounded, gently inclined spur located within a steep natural terrain. Although the direct catchment for surface water flow above the landslide area is small, the presence of a concave depression above the landslide site would have enabled concentrated surface water being directed into the source area during heavy rainstorms.

No seepage was observed within the source area at the time of the field inspection made four days after the event. However, the presence of clay infilling of stress relief joints and manganese oxide staining of the joint surfaces on the source area floor suggests the regular occurrence of transient groundwater levels. The observed dilation of steep tectonic joints striking across the upper source area suggest possible high cleft water pressures may have developed in these discontinuities and the clay-infilled stress relief joints suggest that these could act as relatively impermeable layers and cause perching during heavy rainfall. Thus, the combination of the steep, dilated, tectonic joints and the clay-infilled stress relief joints would likely enhance vertical water infiltration in discrete areas and inhibit horizontal groundwater flow.

5.4 Landslide Susceptibility

Within the close vicinity of the 5 May 2003 landslide site, previous natural terrain landslides as well as signs of past instability in the form of depressions and colluvial fans are observed from the detailed API (using both high and low altitude photographs) carried out by MGSL under this study. The number of natural terrain landslides identified within the study catchment was significantly larger than that recorded in the NTLI database (derived from high altitude photographs only), which illustrates the limitations of the NTLI database for site-specific analysis (see Figures 3 and 4).

In these circumstances and given the paucity of relevant local data, it is difficult to deduce with any degree of confidence the potential for the landslide incident in question prior to the failure. Figures 2, 10 and 11 show respectively the geology, slope angle and slope aspect across the study area catchment. These indicate that the geology, slope aspect and slope angle of the May 2003 landslide site may not have a significant contrast to the nearby hillside.

Notwithstanding this, in an area to the north of the study area, where more landslides have occurred, the slope angle of the hillside is greater, rock outcrops are more common and there are significant breaks in slope within the hillside. It is possible that the prevalence of metamorphosed bands within the tuff in these areas (as shown on the published geological maps) and the mineralogical composition of the tuff have rendered it less resistant to weathering, with the result that steeper ground and occasional linear rock outcrops have developed. Although more prominent in the north of the study area, the resultant landforms comprise a convex break in slope below which debris accumulates to form (in the case of the May 2003 landslide) up to 1 m thick of colluvium.

Colluvial fans observed at the base of some of the drainage lines which indicated the occurrence of past instabilities on the upslope. This is consistent with the observation from

Table of Contents
Table of Contents
Table of Contents
Table of Contents

API using low-level aerial photographs and relict landslides are observed at the head of those drainage lines. Therefore, the presence of colluvial fans is an indication of past failures.

Thus, as many of the previous landslides occur below steep rock outcrops or a break in slope, the underlying geology and structure probably play a significant role in controlling susceptibility of the hillside to landslide initiation. Where these features coincide with the heads of drainage lines the potential for channelised debris flows exists.

6. FAILURE INITIATION AND THEORETICAL STABILITY ANALYSES

An assessment of the roughness of the surface of rupture has been carried out to estimate landslide initiation conditions in terms of the likely operational shear strength (expresses in terms of angle of friction) along the surface of rupture. The roughness angle (i) is an additional component of friction to the basic friction angle, as measured in the laboratory using a planar specimen, and is a measure of the work required to override or shear through asperities before failure.

The roughness characteristics of the surface of rupture were assessed by carrying out a compass line survey at approximately 300 mm intervals down the scarp in both the western and eastern parts of the source area. The results of the surveys, which have been plotted on stereonets to interpret the data graphically and determine a value for the roughness angle (i), are shown on Drawing No. 1.

The results for the western source area indicate a slightly greater variation of roughness than the eastern source area, with an average roughness angle (i) of about 15°. The results of the eastern source area indicate a slightly smaller variation of roughness than the western source area, with an average roughness angle (i) of about 10°. Assuming a range of basic friction angles of between 30° and 40° (average 35º), operational angles of friction of about 50° and 45° have been calculated for the western and eastern source areas respectively, assuming no build-up of water pressure at failure.

Although some material in the lower source floor area is highly decomposed, most of the material above the surface of rupture is colluvium, which is relatively permeable compared to the underlying insitu weathered tuff. It is considered that some perching of groundwater on this interface leading to a build-up of transient groundwater pressure, may have occurred prior to the landslide. Steeply inclined tectonic joints and dilated sheeting joints (partly clay-infilled) may also have contributed to landslide initiation by forming transient cleft groundwater pressures and inhibiting horizontal groundwater flow.

Theoretical stability analyses were carried out to assist in determining the probable range of operational mass shear strength parameters along the failure surface, corresponding to various possible groundwater levels at the time of failure.

The cross-section of the source area for the back analysis as established from engineering geological mapping is shown in Figure 12. The surface of rupture lies partly within colluvium and partly within completely decomposed tuff (CDT). A range of groundwater levels was assumed to simulate the possible range of groundwater conditions prevailing at the time of failure. To simplify the situation, the influence of possible cleft

Table of Contents
Table of Contents
Table of Contents
Table of Contents

groundwater pressure within steeply inclined tectonic joints immediately behind the scarp of the failure was ignored in these analyses.

The results of the analyses are presented in Figure 12 for a range of shear strength parameters, c' and ϕ'. If the mass shear strength parameters of the colluvium/CDT are taken to be c' = 2 kPa and ϕ' = 34°, which are typical parameters for the exposed material as mapped, the calculated FOS would fall below unity for a groundwater table about 0.7 m above the surface of rupture.

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. N05 which is the nearest raingauge to the landslide and located at Cheung Chi House, Cheung Wah Estate in Fanling, about 2.2 km to the northwest of the landslide (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals via telephone line to the Hong Kong Observatory and GEO.

According to the owner of the orchard, the landslide occurred between 3 a.m. and 4 a.m. on 5 May 2003. For the purpose of rainfall analysis, the time of the landslide was assumed to be at 4:00 a.m., when the peak hourly rainfall was recorded. The Amber and Red Rainstorm Warnings were hoisted at 1:45 a.m. and 4:45 a.m. respectively on 5 May 2003.

The daily rainfall recorded by raingauge No. N05 over the month preceding the incident, together with the hourly rainfall data for the period between 3 and 5 May 2003, are presented in Figure 13. The rain was heavy on the morning of 5 May 2003 between 2:10 a.m. and 10:00 a.m. The 24 hour and 12 hour rainfall before the landslide was 217 mm and 180 mm respectively. The maximum 1-hour rolling rainfall was recorded as 98 mm between 2:30 a.m. and 3:30 a.m. on 5 May 2003.

Table 3 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. N05 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 15-minute rolling rainfall of 41 mm before the landslide was the most severe, with a corresponding return period of about 18 years, whilst for other rainfall durations less than 48 hours, the corresponding return periods range from 2 years to 7 years. Return period for rainfall durations over 48 hours was less than 2 years.

The return periods were also assessed based on the statistical parameters derived by derived by Evans & Yu (2001) for rainfall data recorded by local raingauge No. N05 between 1984 and 1997. The return periods of the 1-hour and 2-hour rainfall were about 42 years and 46 years respectively. It is noted that the estimated return periods of the May 2003 rainstorm based on rainfall data at local raingauge are significantly greater than those estimated by the historical rainfall data at the Hong Kong Observatory, Tsim Sha Tsui.

The maximum rolling rainfall for the rainstorm on 5 May 2003 has been compared with the past major rainstorms between 1983 and 2002 recorded by raingauge No. N05, which came into operation in March 1983 (Figure 14). The maximum rolling rainfall for the

Table of Contents
Table of Contents
Table of Contents
Table of Contents

rainstorm on 5 May 2003 is comparable to the most severe rainstorm recorded between 1983 and 2003 for duration up to 2 hours.

8. DISCUSSION

The 5 May 2003 landslide was probably triggered by an intense short-duration rainfall. The rainfall preceding the 5 May 2003 landslide was severe with a calculated return period of up to about 50 years. The shallow failure was probably caused by the build-up of transient groundwater pressure at the source area, which was located at the head of a natural drainage line.

The exposed materials in the landslide source area generally comprised colluvium in the main scarp and flanks, overlying variably weathered tuff and siltstone that formed much of the surface of rupture. Approximately 50% of the surface of rupture was formed at the interface of the colluvium and moderately to highly decomposed tuff where discontinuous sheeting (stress relief) joints were exposed and found to be sub-parallel to the existing ground surface. The sheeting joints are stepped (on a micro-scale) and gently undulating (on a macro-scale). The average dip angle was about 40º, which is similar to the inclination of the existing ground surface.

The steeply-dipping tectonic joints striking across the hillside are generally adverse near the crown of the landslide source area. The adverse conditions include the presence of back-release surfaces and the potential ingress of surface water leading to build-up of cleft water pressure, and the dilation and partial clay infilling of low-angle stress relief joints, possibly inhibiting horizontal water flow and forming relatively impermeable barriers to vertical groundwater flow. The remaining (lower) surface of rupture extended through a thin mantle of insitu completely decomposed tuff during failure.

The aerial photographic records indicate that the site of the 5 May 2003 landslide occurred within a relict landslide scar and therefore probably involved, at least in part, re-activation and retrogressive failure. It is noteworthy that the probable location of the surface of rupture partly passed through insitu weathered tuff and hence the landslide was not solely the re-activation of old colluvium accumulated in a relict depression. Although the hillside has suffered previous instabilities, especially in the northern part of the study area, the frequency of their occurrence in the vicinity of the 5 May 2003 landslide over the period of the photographic records has generally been low. Given the adverse tectonic and sheeting joint orientations, together with possibly high transient sub-surface groundwater levels and the occurrence of previous failures, possible scenarios that may explain the failure of the 5 May 2003 landslide and the low frequency of failure in the surrounding hillside are outlined below.

Few landslides were recorded in the NTLI database near the 5 May 2003 landslide site. However, several relict landslides (with the presence of concave depressions) were identified by the detailed low-level API carried out for this study (Figure 3). These generally have a similar setting to the subject landslide, i.e. below a break in slope and at the head of, or adjacent to, a drainage line. Therefore, any attempt at prediction of magnitude-frequency relationship of such landslides, or the susceptibility of the hillside, would require detailed low-level API to establish a more accurate landslide inventory. The presence of colluvial

Table of Contents
Table of Contents
Table of Contents
Table of Contents

fans at the base of the drainage lines may also be an indication of the occurrence of past instabilities along the drainage lines or the area in vicinity. However, this is subject to the limitation that the geomorphological process may be associated with ancient landsliding activities occurring under very different environmental conditions to that of recent times, and hence may not necessarily be relevant. Age dating of the colluvial lobe would be of use to provide an approximate time 'stamping' of the hillside processes.

The orientations of the linear breaks in slope and rock outcrop above the source area follow the regional structural northeast/east-northeast trend as well as that of metamorphosed bands within the tuff. The metamorphic effects on the parent tuff can include alignment of mineral grains and alteration of the mineralogy. It is noteworthy that these effects can result in increased resistance to weathering compared with the surrounding rock mass that has not been affected by metamorphism. The metamorphic effects may vary locally and the metamorphosed bands also vary in thickness. Therefore, these effects can result in discontinuous linear bands of more resistant rock, manifesting itself at the surface by forming breaks in slope or small scarps at the boundary of these features. Where these form, scarps may have rock or intermittent rock outcrop and the material downslope will probably weather preferentially, gradually becoming over-steepened and subject to progressive deterioration until failure. Rock blocks or fragments from outcrop will also tend to detach over time and add to accumulated debris downslope.

Thus the presence of a break in slope above the May 2003 landslide site also suggests the potential for accumulation of colluvium below the break. Where these areas coincide with the head of a drainage line, and where localized surface water may be directed into the source area which is the head of a drainage line, then initiation of a debris avalanche is possible and there is also higher potential for development of channelised debris flows along the drainage line.

The likelihood of failures through intact material would have been controlled by the rate at which the material weakens through progressive deterioration under repeated significant rainstorms. The metastable condition prevails until the strength of the toe, the natural bridges and asperities along the sheeting joints can no longer resist the disturbing forces caused by the build-up of groundwater pressures in the sheeting joints and the potential formation of tension cracks during past intense rainstorms due to slope displacement or dilation of joints. The subsequent infilling of dilated sheeting joints at the source area indicates an ongoing process of gradual weakening of the near-surface weathered rock mass through the process of successive rain-induced ground displacement and groundwater movement. No evidence of hillfire or anthropogenic influences on landslide initiation was found at the landslide site.

The relatively long runout of the 5 May 2003 landslide can be attributed to channelisation effects along the drainage line. The debris probably mixed with the surface water flow down the drainage line and the runoff along the access road, which may have contributed to the large travel distance.

Based on the field inspections, there are no obvious signs of potential incipient large-scale instability of the hillside.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

9. CONCLUSIONS

The 5 May 2003 landslide was probably the result of progressive deterioration of an adverse geomorphological and hydrogeological setting, which was probably of marginal stability. The failure was triggered by an intense short-duration rainstorm. The landslide mass travelled along a drainage line and became a channelised debris flow, with mobile debris.

10. REFERENCES

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table 1 - Estimated Mass Balance Along Landslide Scar

Horizontal chainage (m)		Section	Slope angle (deg.)	Erosion by debris flow (m^3)	Erosion by subsequent water flow (m^3)	Deposition (m^3)	Maximum clast dia. (m)	Debris flow active volume at end of section (m^3)	Overall volume balance at end of section (m^3)
From	To								
0	12	Source area	40	200	0	20	0.4	180	180
12	56	Upper Debris Trail	25	0	2	17	0.4	163	165
56	61	Access Road	0	0	0	62	0.2	101	103
61	135	Lower Debris Trail	35 to 14	0	36	35	0.2	66	68
135	165	Debris Fan (toe of remoulded debris at CH 165)	<10	0	0	68	0.4	-2	0
165	185	Outwash	<5	0	0	5	0.01	-7	31

Table of Contents
Table of Contents
Table of Contents

Table 2 - Estimation of Velocity Based on Superelevation Observations

CH 48 (Section 5)	h_1	1	m	Debris height on inside of bend
	h_2	1.8	m	Debris height on outside of bend
	b	7.47	m	Top Surface Width
	r	61	m	Bend radius
	k	1		Correction coefficient
	Δh	0.8	m	Superelevation
	V	8.01	m/s	Flow velocity [#] = $((\Delta h*r*9.81)/(k*b))^{0.5}$
CH 53 (Section 6)	h_1	1	m	Debris height on inside of bend
	h_2	2.5	m	Debris height on outside of bend
	b	9.2	m	Top Surface Width
	r	61	m	Bend radius
	k	1		Correction coefficient
	Δh	1.5	m	Superelevation
	V	9.88	m/s	Flow velocity = $((\Delta h*r*9.81)/(k*b))^{0.5}$
CH 66 (Section 7)	h_1	1	m	Debris height on inside of bend
	h_2	3	m	Debris height on outside of bend
	b	14.5	m	Top Surface Width
	r	61	m	Bend radius
	k	1		Correction coefficient
	Δh	2	m	Superelevation
	V	9.09	m/s	Flow velocity = $((\Delta h*r*9.81)/(k*b))^{0.5}$
CH 73 (Section 8)	h_1	1	m	Debris height on inside of bend
	h_2	2.8	m	Debris height on outside of bend
	b	9.15	m	Top Surface Width
	r	61	m	Bend radius
	k	1		Correction coefficient
	Δh	1.8	m	Superelevation
	V	10.85	m/s	Flow velocity = $((\Delta h*r*9.81)/(k*b))^{0.5}$
CH 100 (Section 11)	h_1	1	m	Debris height on inside of bend
	h_2	1.65	m	Debris height on outside of bend
	b	6	m	Top Surface Width
	r	41	m	Bend radius
	k	1		Correction coefficient
	Δh	0.65	m	Superelevation
	V	6.60	m/s	Flow velocity = $((\Delta h*r*9.81)/(k*b))^{0.5}$
CH 109 (Section 12)	h_1	1	m	Debris height on inside of bend
	h_2	2	m	Debris height on outside of bend
	b	5.24	m	Top Surface Width
	r	41	m	Bend radius
	k	1		Correction coefficient
	Δh	1	m	Superelevation
	V	8.76	m/s	Flow velocity = $((\Delta h*r*9.81)/(k*b))^{0.5}$
Note: [#] equation based on Hungr, Morgan and Kellerhals (1984)				

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. N05 for Selected Durations Preceding the Landslide on 5 May 2003 and Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (See Note 4)	Estimated Return Period (Years)	
			By Lam & Leung (1994)	By Data of N05 from Evans & Yu (2000)
5 Minutes	14.0	2:55 a.m. on 5 May 2003	3	5
15 Minutes	41.0	3:05 a.m. on 5 May 2003	18	15
1 Hour	98.0	3:30 a.m. on 5 May 2003	8	42
2 Hours	134.5	4:00 a.m. on 5 May 2003	7	46
4 Hours	148.0	4:00 a.m. on 5 May 2003	4	7
12 Hours	180.0	4:00 a.m. on 5 May 2003	2	3
24 Hours	217.0	4:00 a.m. on 5 May 2003	2	2
48 Hours	277.5	4:00 a.m. on 5 May 2003	3	3
4 Days	277.5	4:00 a.m. on 5 May 2003	< 2	< 2
7 Days	282.5	4:00 a.m. on 5 May 2003	< 2	< 2
15 Days	282.5	4:00 a.m. on 5 May 2003	< 2	< 2
31 Days	315.5	4:00 a.m. on 5 May 2003	< 2	< 2

Notes : (1) Maximum rolling rainfall was calculated from 5-minute rainfall data.

(2) Return periods were derived from the rainfall data recorded at Hong Kong Observatory between 1884 and 1939 and between 1947 and 1990 (Lam & Leung, 1994) as well as the data recorded at local Raingauge No. N05 between 1984 and 1997 (Evans & Yu, 2001). The return periods obtained from the local raingauge by Evans & Yu in one and two-hour rainstorm durations are significantly greater than those estimated by Lam & Leung.

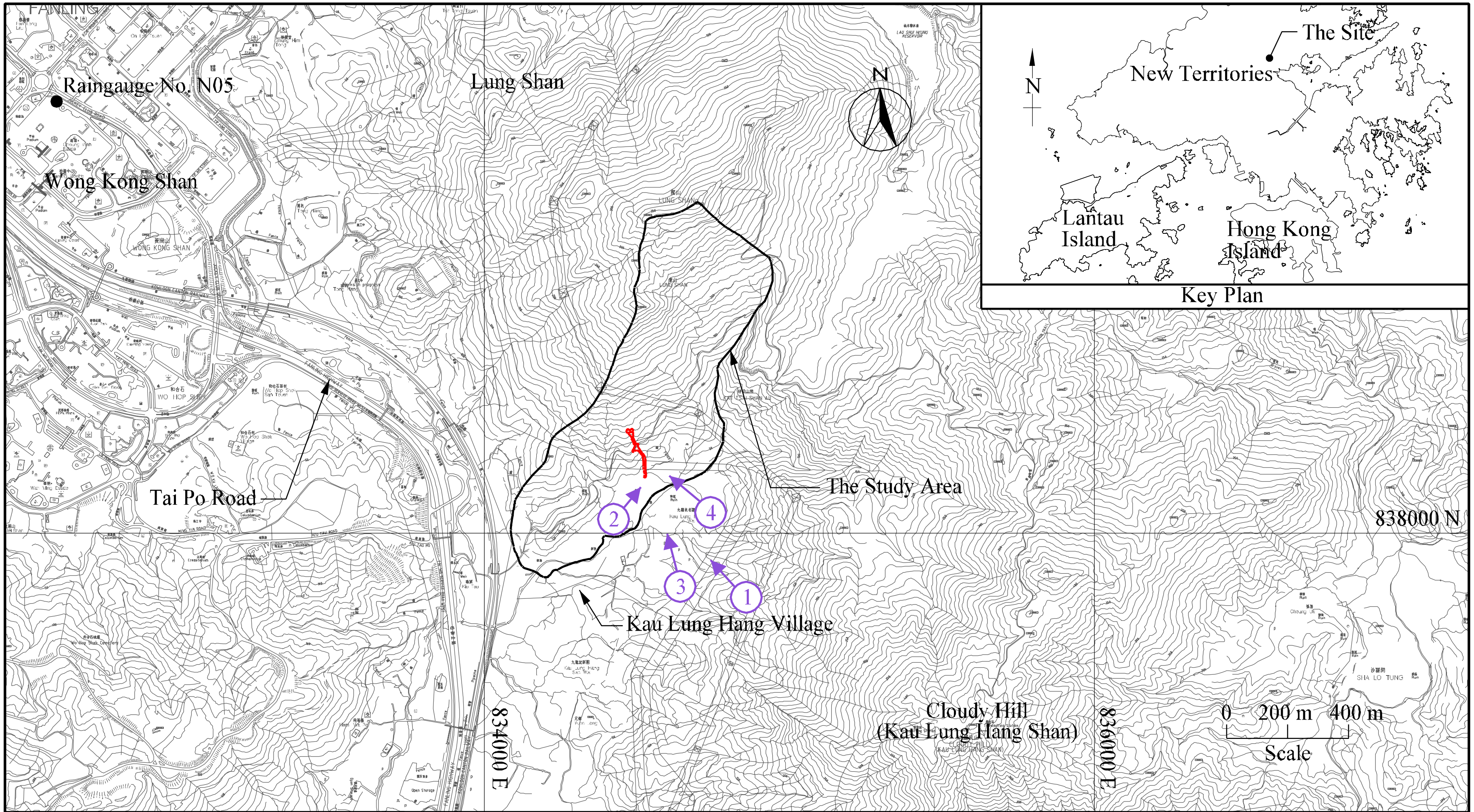
(3) According to the available information, the landslide occurred at about 4:00 a.m. on 5 May 2003.

(4) GEO raingauge No. N05 which is situated at about 2.2 km to the northwest of the landslide site and became operational since March 1983.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF FIGURES

Table of Contents
Table of Contents
Table of Contents

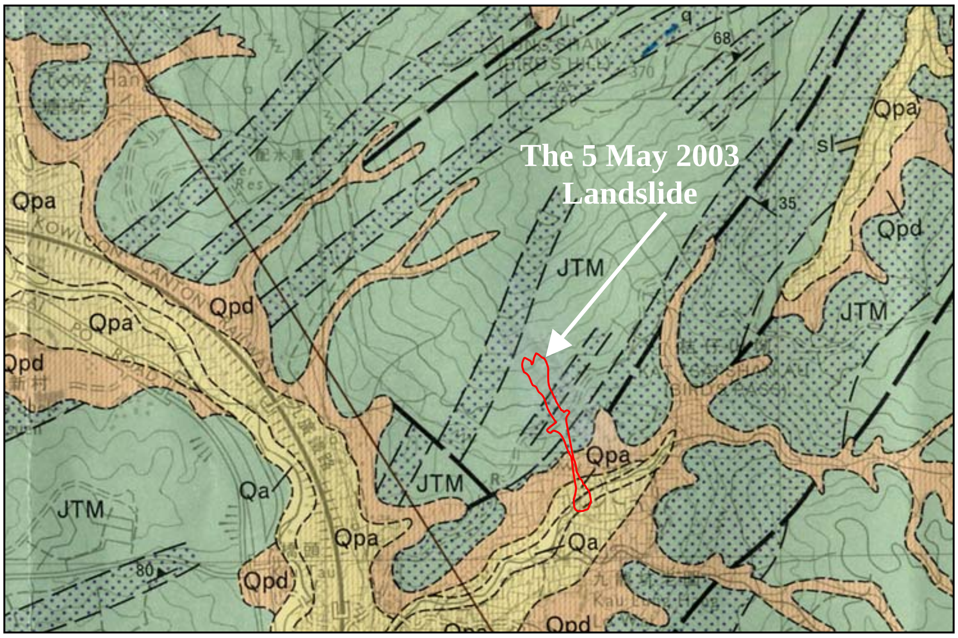


Legend : The 5 May 2003 Landslide (1)→ Location and direction of photograph

Note : Base plan is extracted from 1 : 5000 survey sheets Nos. 3SW-A, 3SW-B, 3SW-C and 3SW-D dated June 2002.

Figure 1 - Location Plan

Table of Contents
Table of Contents
Table of Contents



0m 1000 m

LEGEND:

SUPERFICIAL DEPOSITS

Qa	Clay/silt, sand and gravel; Well-sorted to semi-sorted (Alluvium	Qpa	Clay/silt, gravelly sandy, Well-sorted to semi-sorted (Terraced alluvium)
Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (Debris flow deposits)	Qpd	Silt/sand, gravelly, clayed with cobbles and boulders; unsorted (Debris flow deposits)

SOLID GEOLOGY

JTM	Coarse ash crystal tuff (Tai Mo Shan Formation, undivided)	gdf	Fine-grained granodiorite, <2 mm (Jurassic-cretaceous)
JSM	Fine ash to coarse ash tuffs, tuff-breccia and tuffite (Shing Mun Formation, undivided)		Metamorphosed (Jurassic-cretaceous)
sl	Siltstone and mudstone (Tuen Mun Formation, undivided)		

GELOGICAL LINES

- Geological boundary, superficial deposits
- Fill boundary, with limit of reclamation at date shown
- Geological boundary, solid rock (* Broken lines denote uncertainty)
- Fault (crossmark indicates downthrow side)
- Mineral
- Photogeological lineament

STRUCTURAL SYMBOLS

- 72 Jointing for inclined
- Jointing for vertical
- 20 Foliation

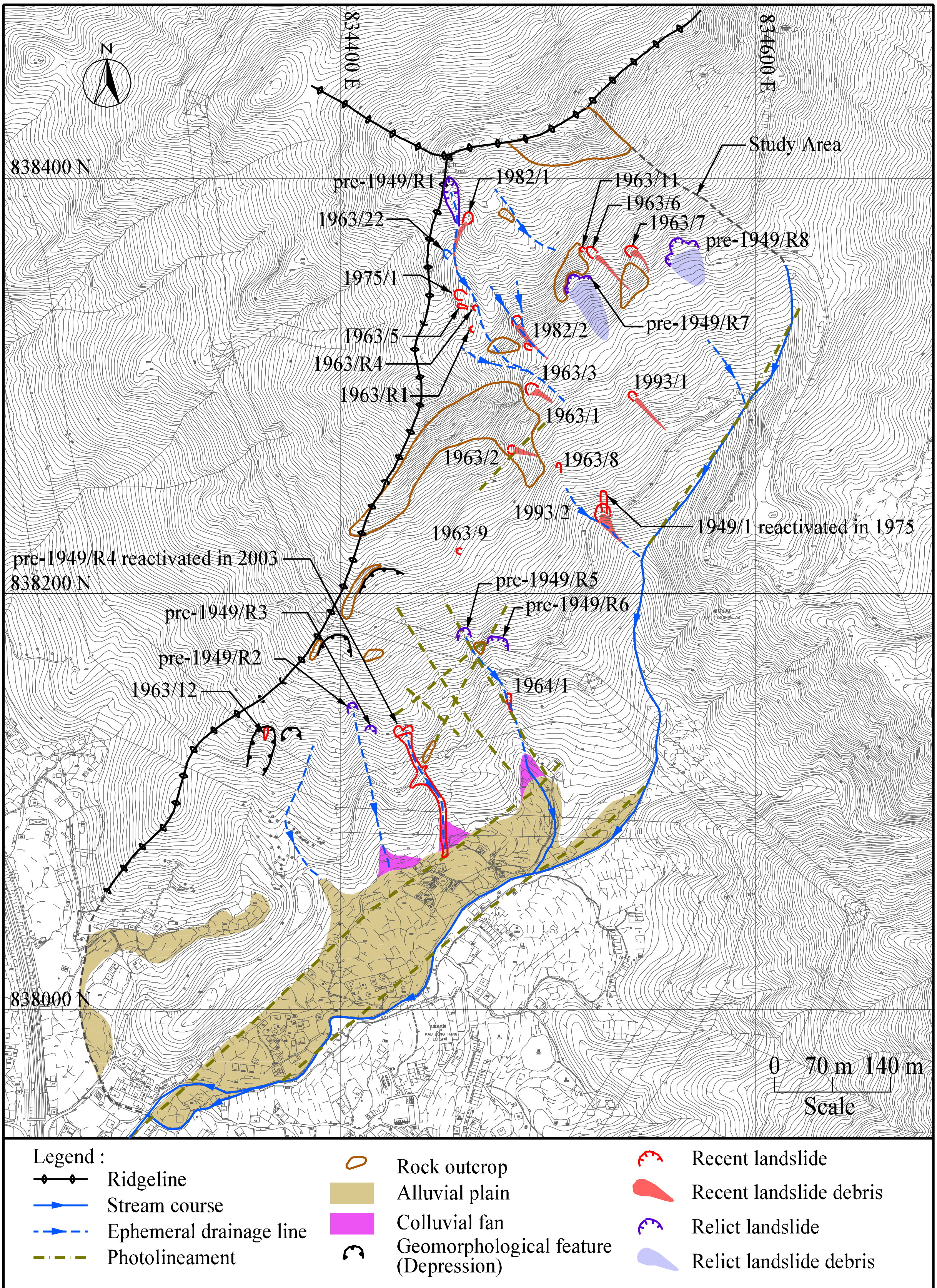
MINERAL SYMBOLS

- ●q Mineral occurrence (Quartz)

Note: Extracted from Hong Kong geological Survey, Map Series HGM20, Sheet No. 6, 1:20 000 Scale (GCO, 1988)

Figure 2 - Regional Geology

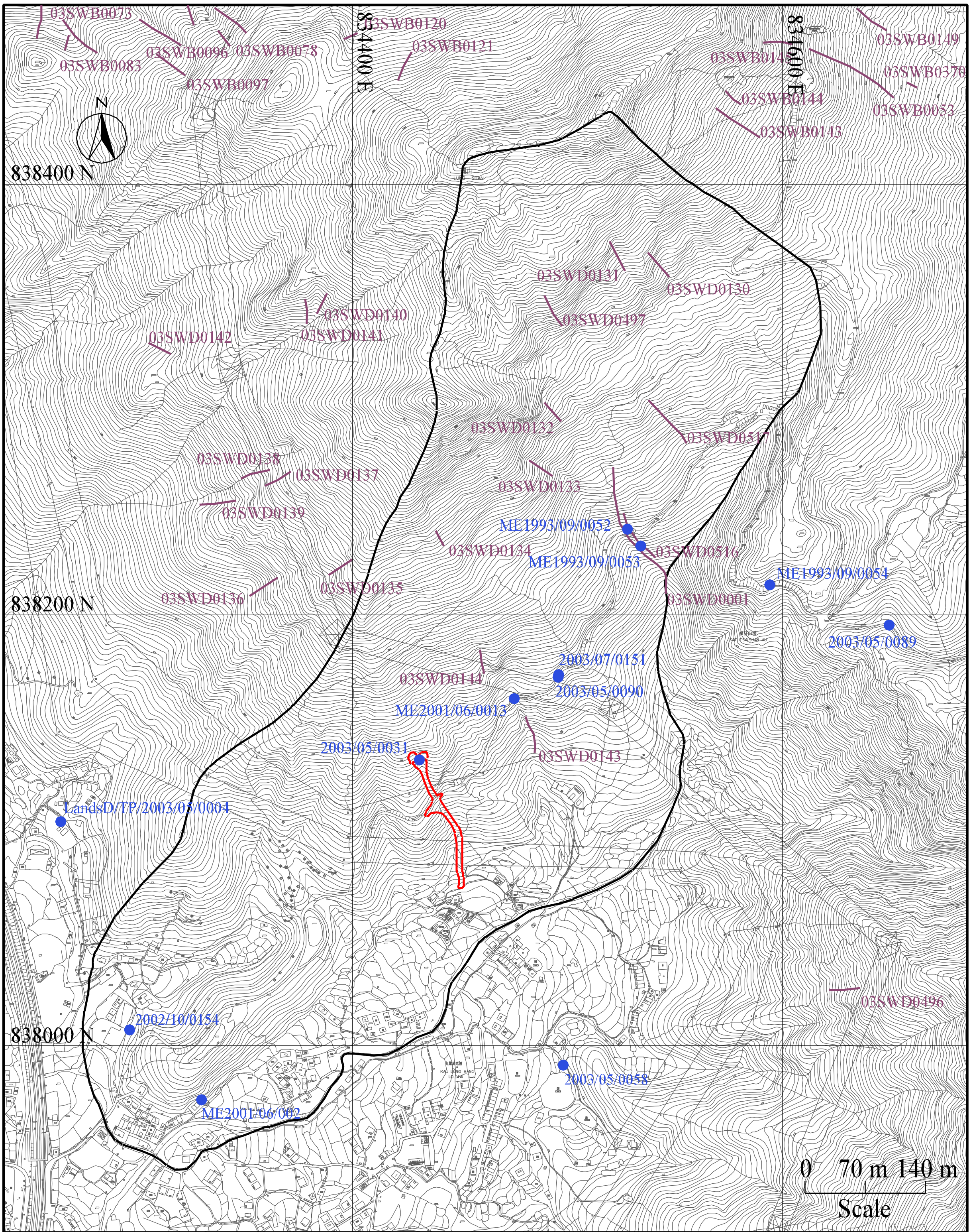
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes : (1) Base plan is extracted from 1 : 1000 survey sheets Nos. 3SW-13B, 3SW-13D, 3SW-14A, 3SW-14C, 3SW18B and 3SW19A dated June 2002.

Figure 3 - Aerial Photograph Interpretation

Table of Contents
Table of Contents
Table of Contents
Table of Contents

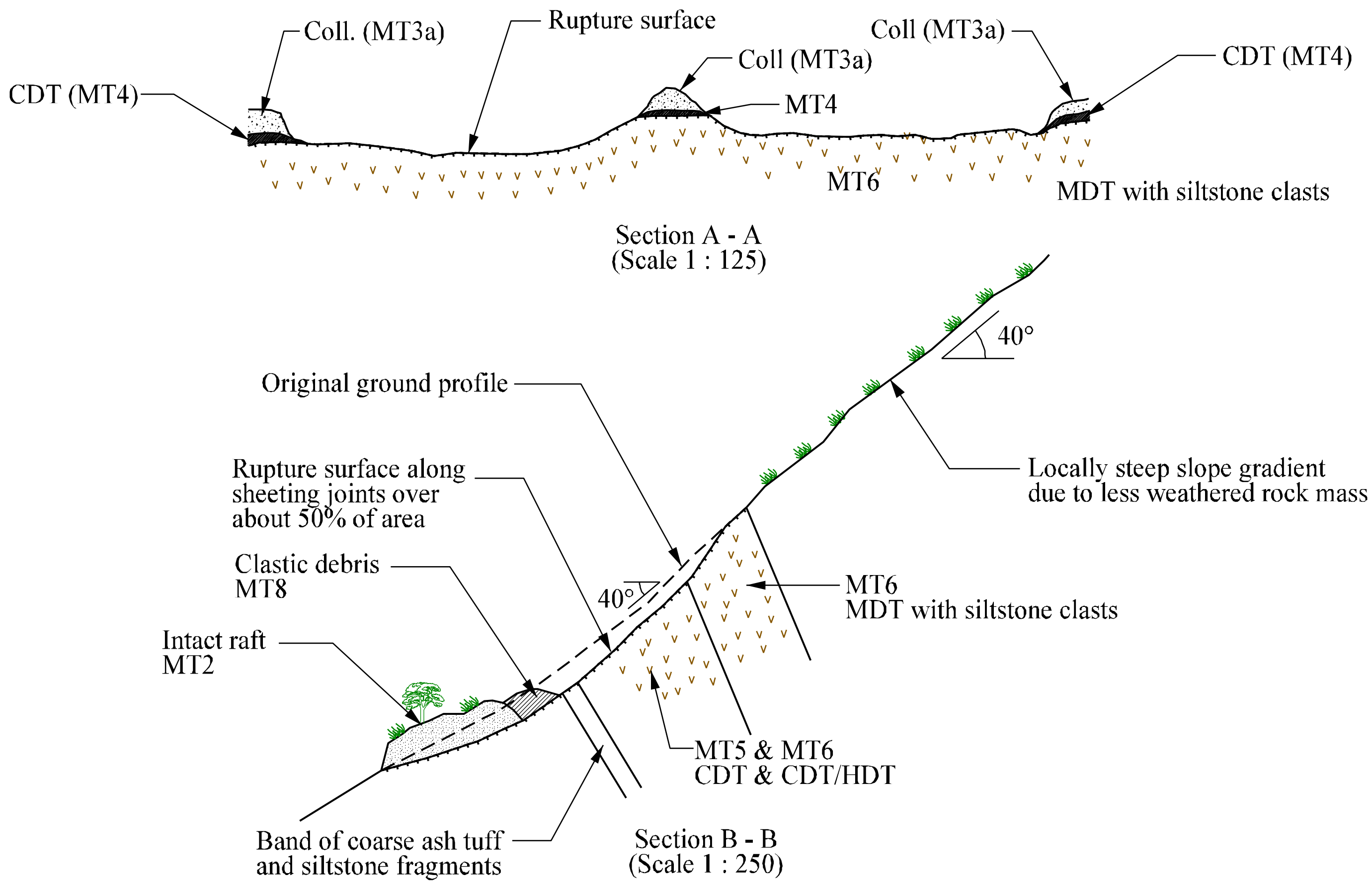


Legend : The May 2003 landslide — Study Area Catchment — 03SWD0496 NTLI Landslide with Reference No. — 2002/10/0154 GEO Incident No. 2002/10/0154

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 3SW-13B, 3SW-13D, 3SW-14A, 3SW-14C, 3SW18B and 3SW19A dated June 2002.

Figure 4 - Documented Past Instabilities

Table of Contents
Table of Contents
Table of Contents
Table of Contents

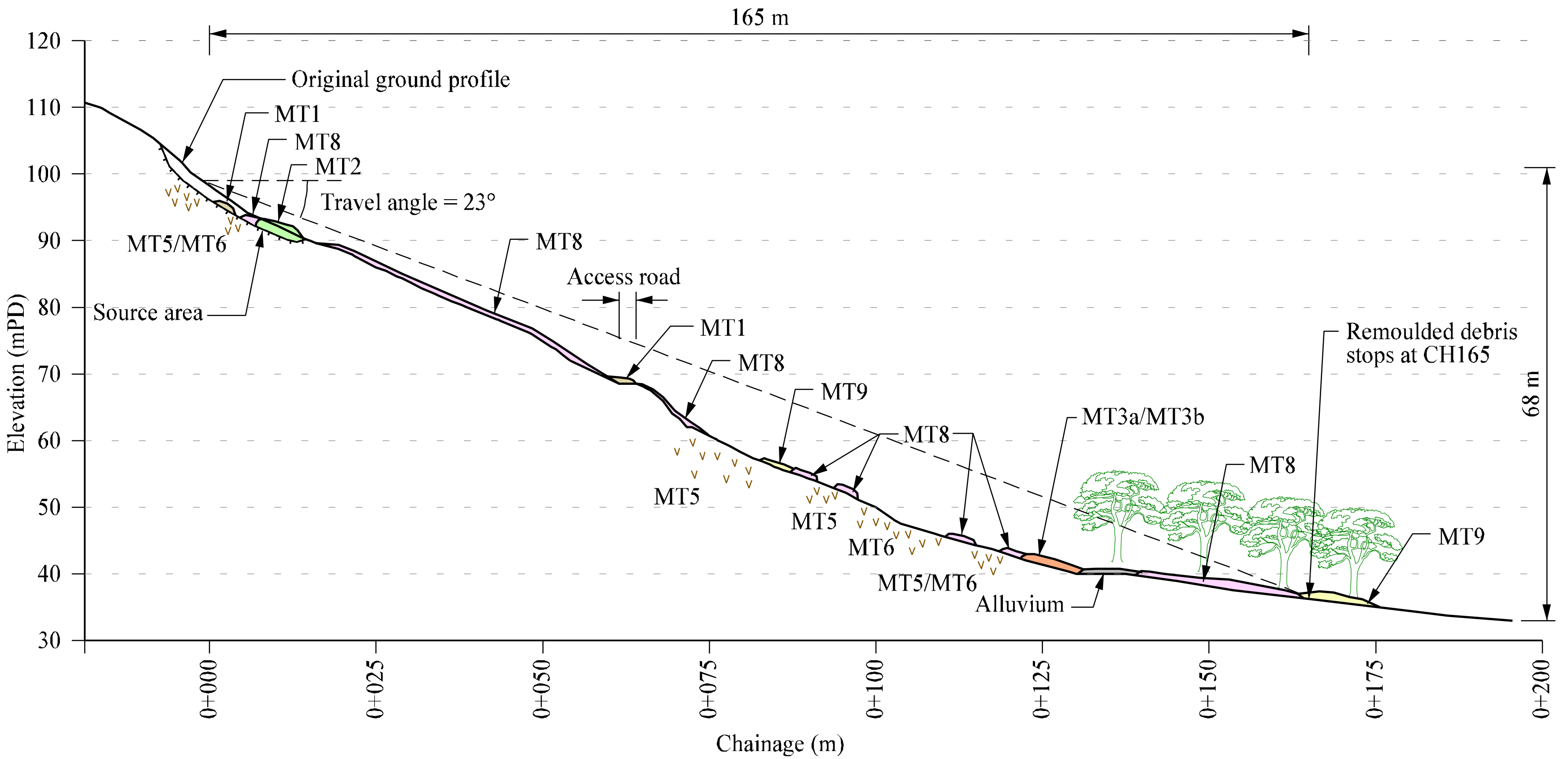


Legend :	Coll	Colluvium	MT1	Remoulded debris	MT4	CDT	MT8	Clastic Debris
	CDT	Completely decomposed tuff	MT2	Intact raft	MT5	CDT/HDT	MT9	Outwash
	HDT	Highly decomposed tuff	MT3a	Topsoil/Colluvium	MT6	MDT/MDS		
	MDT	Moderately decomposed tuff	MT3b	Colluvium	MT7	Slopewash		

Note : See Drawing No. 1 for plan location of sections

Figure 5 - Longitudinal and Cross-Section Through Source Area

Table of Contents
Table of Contents
Table of Contents



Legend :	MT1	Remoulded debris	MT4	CDT	MT8	Clastic Debris
	MT2	Intact raft	MT5	CDT/HDT	MT9	Outwash
	MT3a	Topsoil/Colluvium	MT6	MDT/MDS		
	MT3b	Colluvium	MT7	Slopewash		

Note : See Drawing No. 1 for plan view of debris trail.

Figure 6 - Longitudinal Section Along Debris Trail

Table of Contents
Table of Contents
Table of Contents

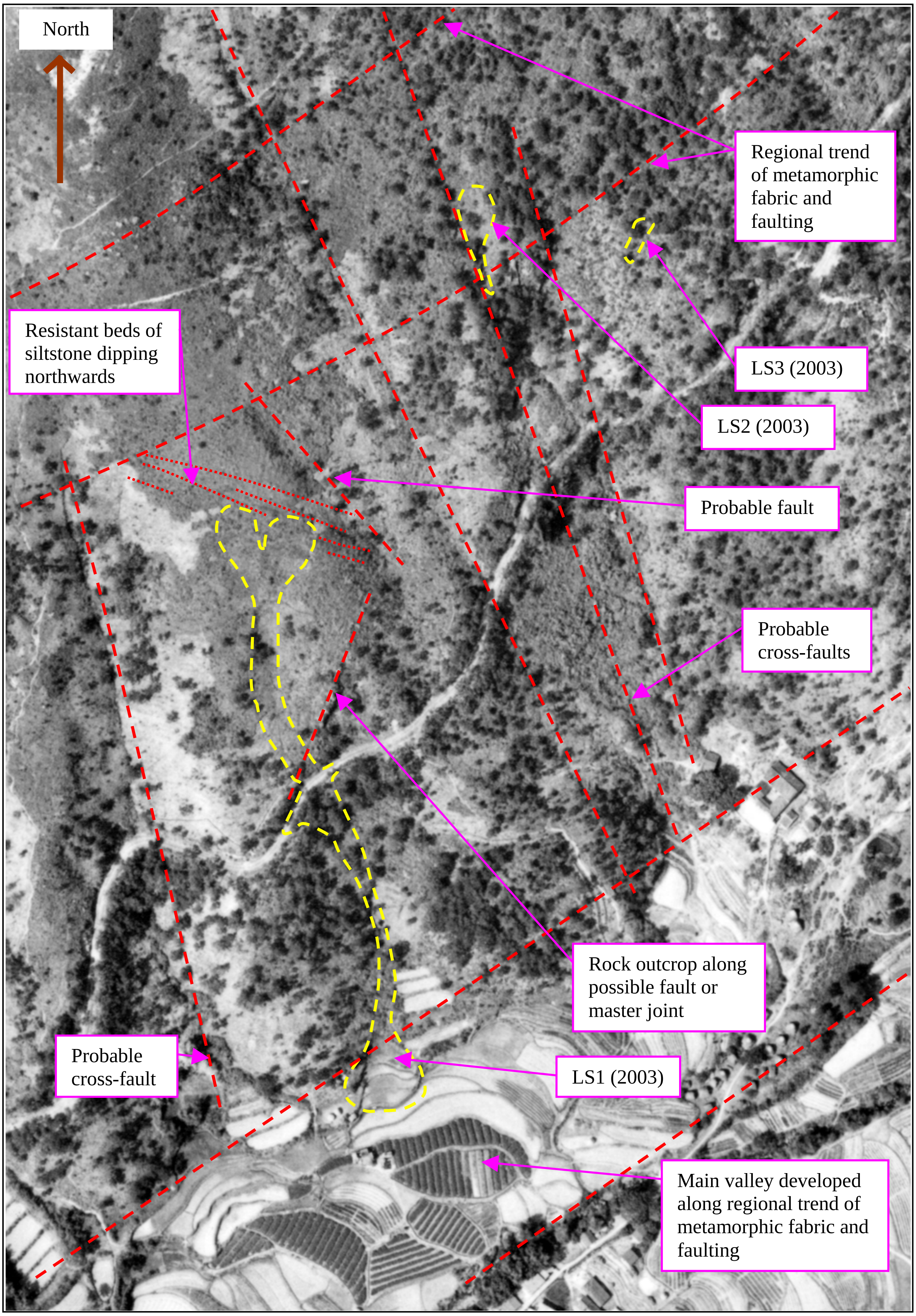
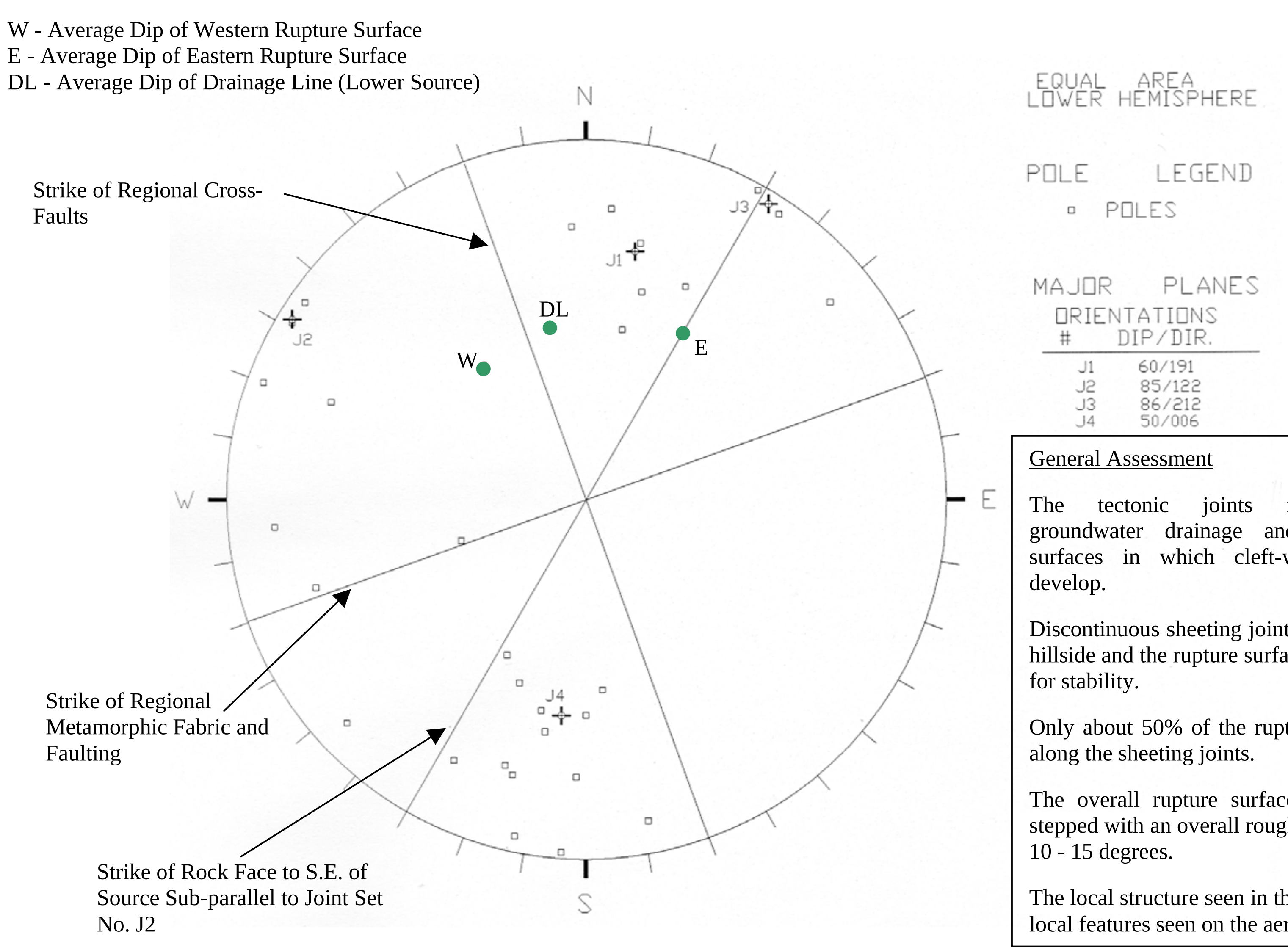


Figure 7 - Inferred Geological Structure - 1963 Aerial Photograph

Table of Contents
Table of Contents
Table of Contents
Table of Contents



General Assessment

The tectonic joints retarding sub-surface groundwater drainage and forms back-release surfaces in which cleft-water pressures could develop.

Discontinuous sheeting joints are sub-parallel to the hillside and the rupture surface and are unfavourable for stability.

Only about 50% of the rupture surface has formed along the sheeting joints.

The overall rupture surface can be described as stepped with an overall roughness angle (i) of about 10 - 15 degrees.

The local structure seen in the scar is consistent with local features seen on the aerial photographs.

Figure 8 - Stereograph of Geological Structures of the Landslide Scar

Table of Contents
Table of Contents
Table of Contents

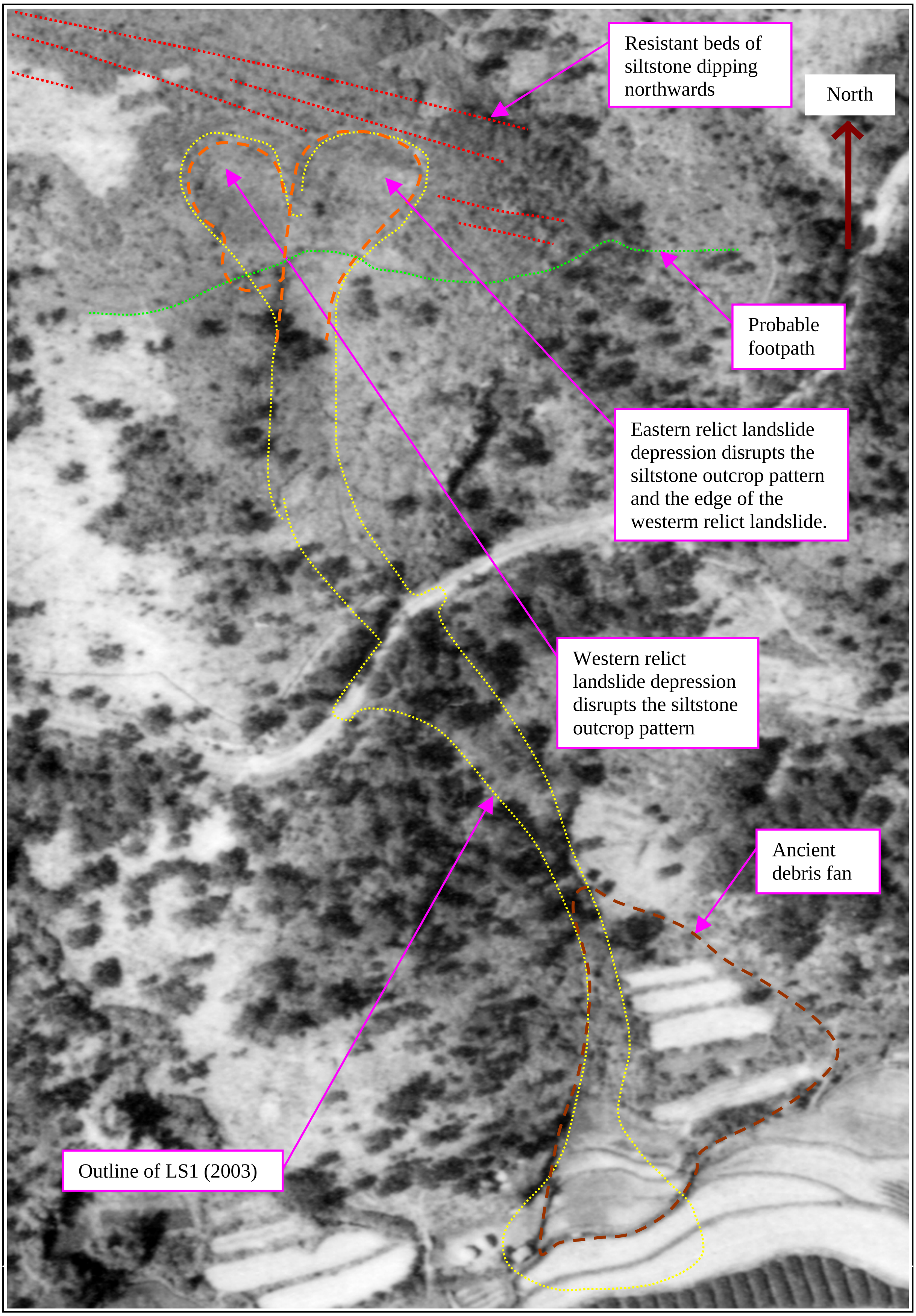


Figure 9 - Inferred Geomorphological Features - 1963 Aerial Photograph

Table of Contents
Table of Contents
Table of Contents
Table of Contents

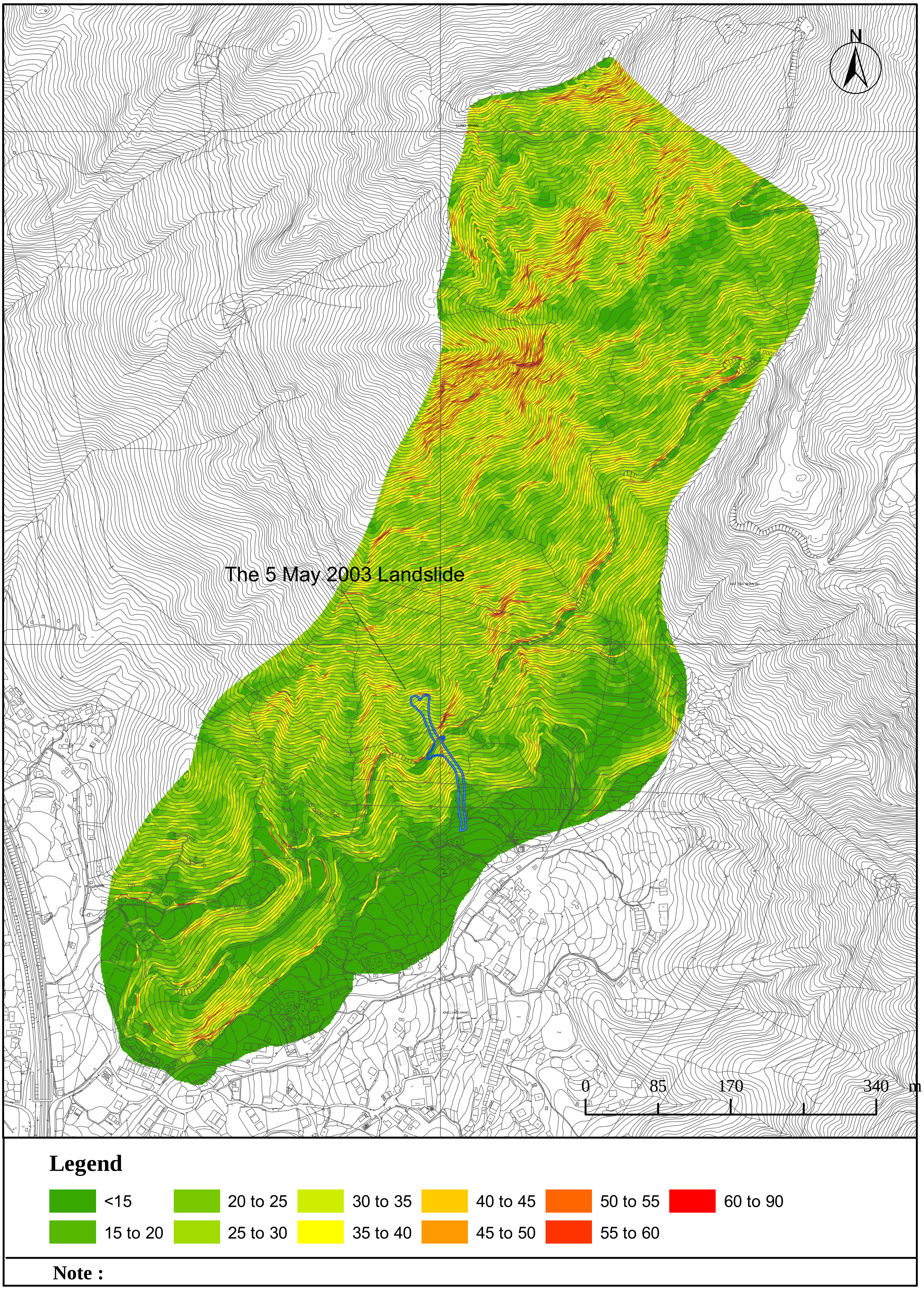
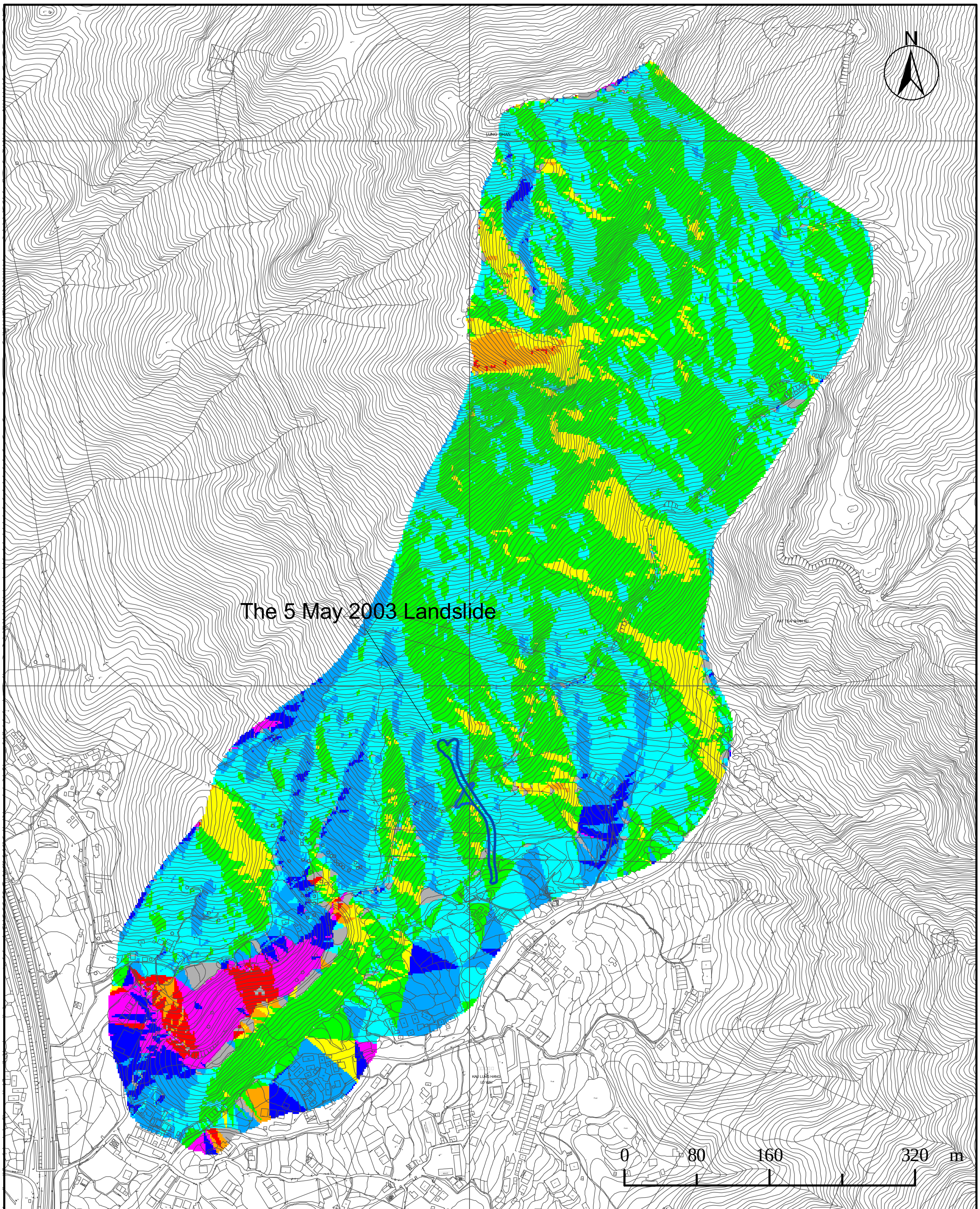


Figure 10 - Slope Angle Map of Study Area Catchment



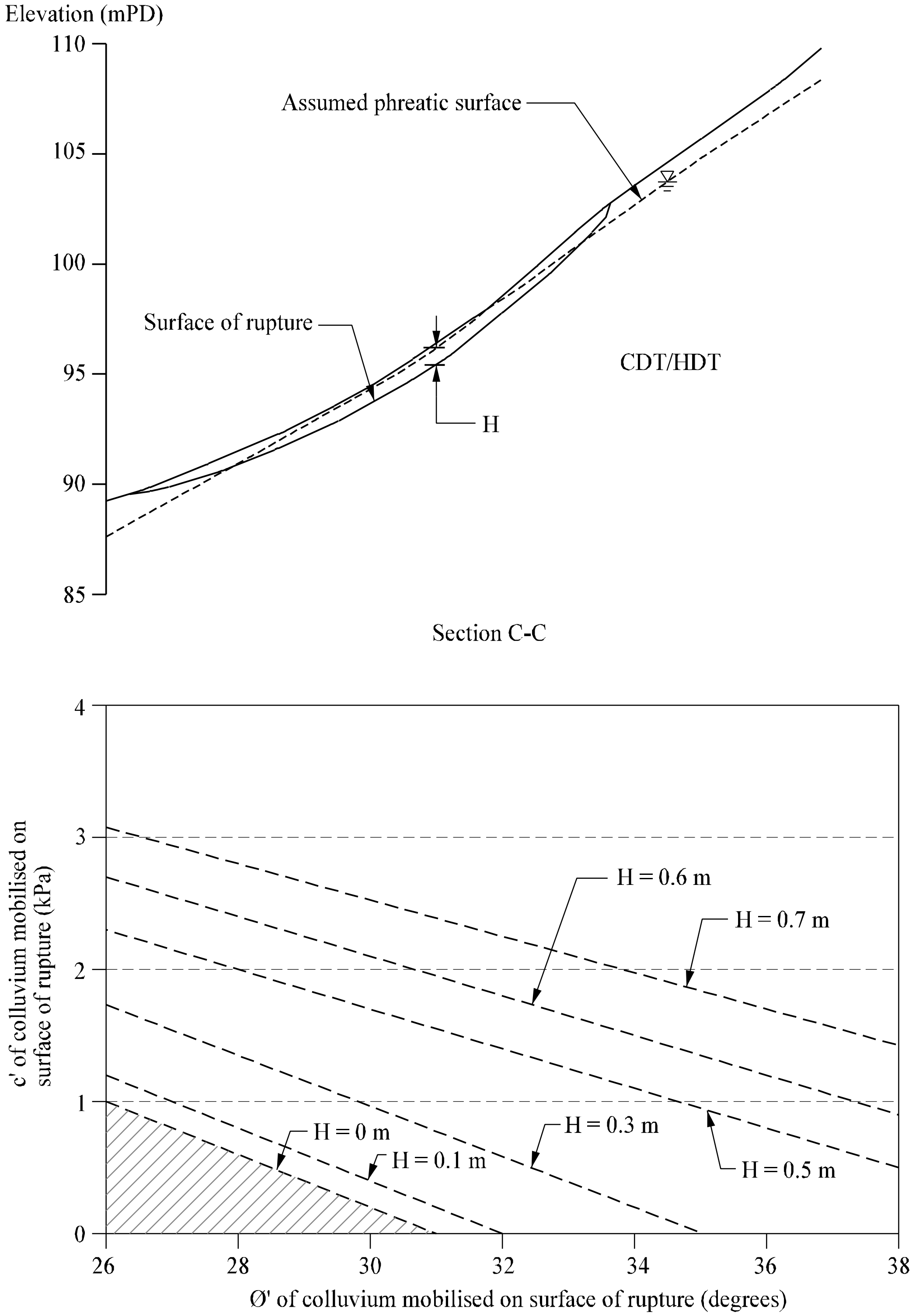
Legend
Slope Aspect

Flat (-1)	Northeast (22.5-67.5)	Southeast (112.5-157.5)	Southwest (202.5-247.5)	Northwest (292.5-337.5)
North (0-22.5)	East (67.5-112.5)	South (157.5-202.5)	West(247.5-292.5)	North (337.5-360)

Note :

Figure 11 - Slope Aspect Map of Study Area Catchment

Table of Contents
Table of Contents
Table of Contents
Table of Contents

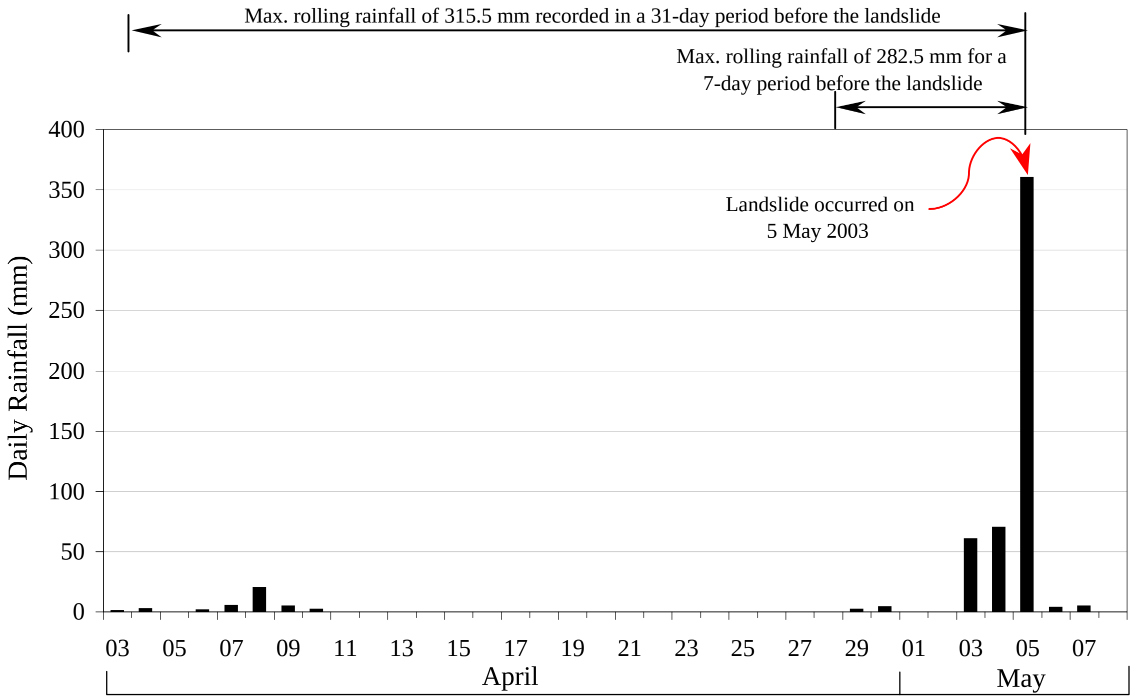


Legend : - - - - Factor of safety equal to unity (i.e. Limiting Equilibrium) ▨ Unsaturated zone

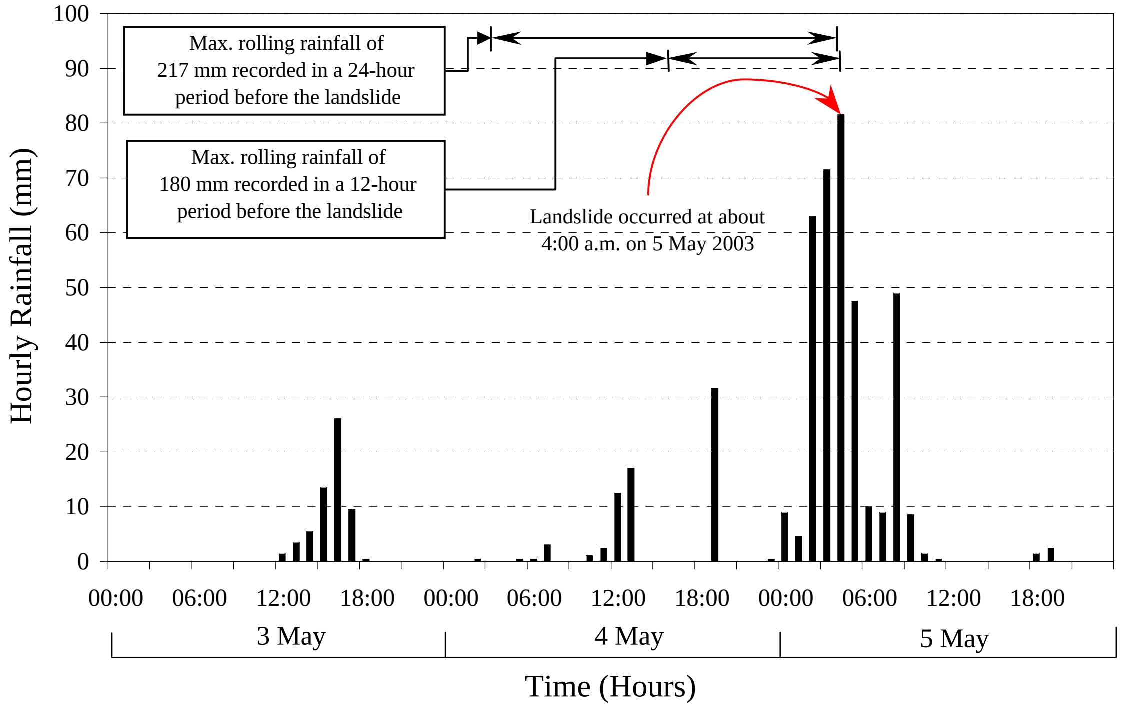
Note : See Drawing No. 1 for plan location of section.

Figure 12 - Summary of Back Analyses

Table of Contents
Table of Contents
Table of Contents
Table of Contents



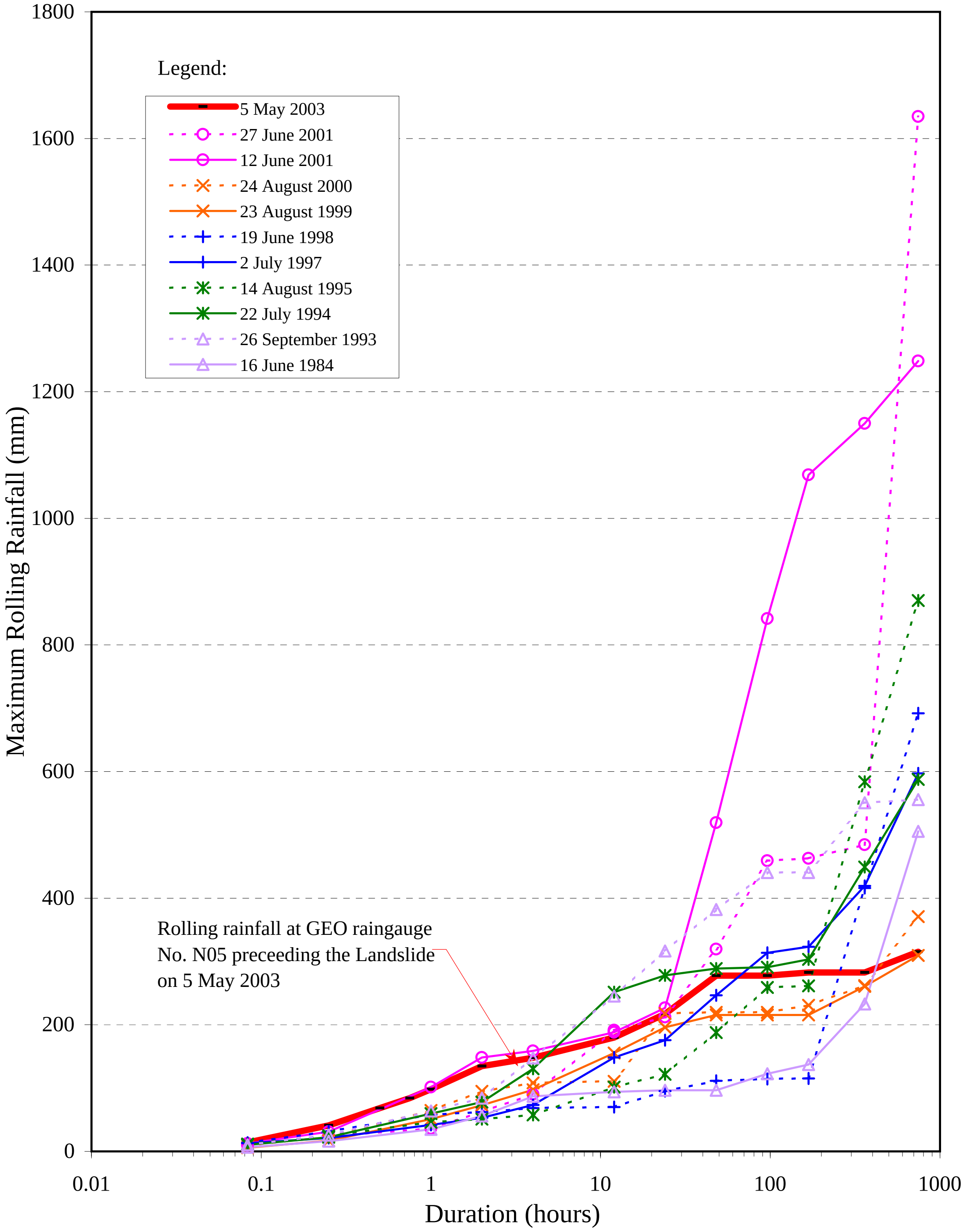
(a) Daily Rainfall Recorded at GEO Raingauge No. N05 between 3 April and 8 May 2003



(b) Hourly Rainfall Recorded at GEO Raingauge No. N05 between 3 May and 5 May 2003

Figure 13 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N05

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. N05 (about 2.2 km northwest of the landslide site).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N05 since March 1983, when the raingauge start operation.

Figure 14 - Maximum Rolling Rainfall for Major Rainstorms at GEO Raingauge No. N05

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

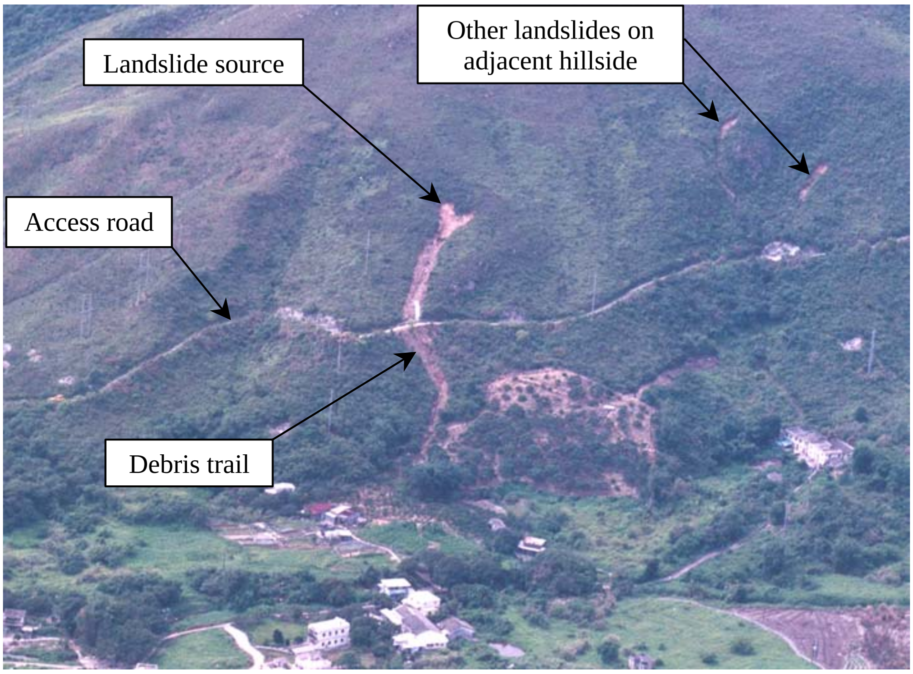


Plate 1 - Oblique Aerial View of the 5 May 2003 Debris Flow
(Photograph taken by GEO on 16 May 2003)

Plate 2 - View of Deposition of Fluvial Outwash at the Boundary of the Private Village Houses (Photograph taken on 12 May 2003)

Note: See Figure 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 3 - View of the Landslide from Kau Lung Hang Village
(Photograph taken on 12 May 2003)

Plate 4 - View of the Source Area and the Debris Trail
(Note the rock outcrop to the southeast of the source area.
Photograph taken on 12 May 2003)

Note: See Figure 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 5 - View of the Western Portion of the Main Scarp
(Note the lithology change - HDV/MDV with overlying metamorphosed siltstone. Photograph taken on 9 May 2003)

Plate 6 - View of the Eastern Portion of the Main Scarp
(Note the persistent band of metamorphosed siltstone. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 7 - View of the Eastern Flank of the Source Area
(Note the relatively clean surface of rupture with overlying colluvium exposed at the scarp. Photograph taken on 16 May 2003)

Plate 8 - View of the Western Flank of the Source Area
(Relatively clean surface of rupture with overlying colluvium exposed at the scarp. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 9 - View of Potentially Unstable Colluvium at the Western Flank of the Source Area (Note the undulating joint surface. Photograph taken on 9 May 2003)

Plate 10 - View of Break in Slope Within the Source Area (Roughly parallel to the band of lighter rock (MT6) found high in the source area. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 11 - View Looking Downslope from the Source Area
(Note the displaced vegetated intact debris raft at centre. Photograph taken on 16 May 2003)

Plate 12 - View of the Eastern Flank of the Landslide Source Area
(Note a tension crack (~20 mm wide) to the right of the hammer. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 13 - View of Tension Crack on the Eastern Flank of the Source Area (Photograph taken on 16 May 2003)

Plate 14 - View of Tension Crack on the Western Flank of the Source Area (Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 15 - View of the Source Area from the Debris Trail
(Photograph taken on 16 May 2003)

Plate 16 - View of the Debris Trail and Source Area from the Access Road
(Note the incised gully on the right side. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 17 - View of the Landslide Debris Washed Down the Access Road by Subsequent Overland Flow (Photograph taken on 9 May 2003)

Plate 18 - View of the Landslide Debris on the Access Road (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 19 - View of the Landslide Debris on the Access Road Looking West (Photograph taken on 9 May 2003)

Plate 20 - View of the Debris Trail Looking Downslope from the Access Road (Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 21 - View of the Deeply Incised Gully Directly Below the Access Road
(Gradual change from MDT to CDT within the gully. Photograph taken on 16 May 2003)

Plate 22 - View of the Incised Gully Near the Access Road
(Insitu MDT and CDT exposed within the gully with colluvium exposed at the flanks. Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 23 - Exposed Rock Within the Drainage Line/Gully below the Access Road (Photograph taken on 9 May 2003)

Plate 24 - View Looking Upslope from Chainage CH 82 (Note the minor failure of the eastern flank of the drainage line. Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 25 - View of the Failure Eastern Flank of the Drainage Line at Chainage CH 88 (Hammer denotes the contact between colluvium and completely decomposed coarse ash tuff. Photograph taken on 16 May 2003)

Plate 26 - View of Varying Ages of Colluvium at the Western Flank of the Failure within the Drainage Line at Chainage CH 88
(Photograph taken on 16 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 27 - View of Colluvium Overlying Insitu Metamorphosed Siltstone at Chainage CH 120 (Photograph taken on 9 May 2003)

Plate 28 - View of Exposed Soil Profile Within the Incised Gully Adjacent to the Orchard at Chainage CH 123 (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 29 - Close-up View of Colluvium Within the Incised Gully at Chainage CH 123 (Photograph taken on 9 May 2003)

Plate 30 - Close-up View of Colluvium Exposed at the Flanks of the Drainage Line at Chainage CH 125 (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 31 - View Uphill Towards the Access Road (Note the bent and damaged grass and vegetation. Photograph taken on 9 May 2003)

Plate 32 - View Looking Downslope at Chainage CH 110 (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 33 - General View of the Drainage Line Near the Landslide Toe Area at Chainage CH 130 (Photograph taken on 9 May 2003)

Plate 34 - Alluvium with a Kaolin Matrix Found Within the Drainage Line Near the Toe of the Landslide (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents

Plate 35 - Decomposed Coarse Ash Tuff With Kaolin Rich Matrix Found Near the toe of the Debris Trail (Photograph taken on 9 May 2003)

Plate 36 - Insitu Decomposed Coarse Ash Tuff Found within the Drainage Line/Debris Trail Near the Toe of the Landslide at Chainage CH 135 (Photograph taken on 9 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 37 - View of the Rock Outcrop (Coarse Ash Tuff) at About 30 m Southeast of the Landslide Source Area (Photograph taken on 16 May 2003)

Plate 38 - Close-up View of the Landslide Source Area and Debris Trail (Note joints in the outcrop on the right have similar strike to those within the source area. Photograph taken on 12 May 2003)

Note: See Drawing No. 1 for location and direction of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1924 and 2002. A list of the aerial photographs studied is presented in Table A1 and a location plan is shown in Figure 3.

YEAR	OBSERVATIONS
1924	This single, high-level photograph is of poor resolution. The study area is located on the southeast-facing hillslopes of a northeast-southwest trending ridge. The valley at the base of the study area, which contains the main streamcourse relatively broad and trends approximately NE-SW. The valley floor adjacent to the hillside comprises a series of agricultural terraces and isolated village structures. Several ephemeral drainage lines are located on the flanks of the valley draining into the main steamcourse. The hillside is generally sparsely vegetated.
1949	Eight relict landslides can be identified on the hillslopes. Five of them (pre-1949/R2 to R6) are located near the centre of the study area. They can be seen as shallow depressions and are covered with thin vegetation. Pre-1949/R4 is apparent in the same location as the 5 May 2003 landslide. The others (pre-1949-R1, R7 and R8) are located in the northern portion and the pre-1949/R7 and R8 appear to consist of multiple failures. An apparent recent landslide feature (1949/1), which is labelled in the NTLI Landslide database as Tag No. 3SWD0001 and is indicated by reflective material, can be seen next to an ephemeral drainage line. Some patches of bare earth can be seen in the northern portion of the study area near the ridgeline. These are probably patches of surface erosion. Photogeological lineaments trending NE-SW and NW-SE are visible. The sideslopes are generally planar in profile although some geomorphological features observed as shallow concave depressions (possible relict instabilities) are visible. In general the upper portion of the study area near the ridgeline is steeper and is lightly vegetated with low shrubs and grass. The lower portion of the study area is not as steep as the upper portion and is generally characterised by the presence of tall shrubs. Minor footpaths and occasional graves are visible on the natural hillsides.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

1963 These photographs are of good resolution and the terrain morphology is much clearer. Rock outcrops are visible near the ridgeline and in some locations on the mid-slopes.

There appears to be many cases of instabilities, particularly to the north of the landslide site, and most of them are apparently quite fresh (the scar is composed of highly reflective bare earth).

Various areas of anthropogenic disturbance, most probably as a result of military construction, consisting of shallow excavations and trenches are visible along the ridgelines and around the summit of the hill. A series of parallel dark-toned bands that follow the contours around the summit is visible.

An access road to Cloudy Hill Transmitter Station has been constructed. For about three quarters of its length the road runs across the hillside, approximately 60 m downslope of the 5 May 2003 landslide.

1964 A recent landslide (1964/1), labelled in the NTLI Landslide database as Tag No. 3SWD0143, with highly reflective material is visible along an ephemeral drainage line.

1975 Most of the landslide scars have been re-vegetated. Retrogressive failure can be seen upslope of Landslide 1949/1.

No significant changes were observed except an increase in the number of squatter dwellings on the valley floor.

1979 No observable changes.

1981 No observable changes.

1982 Two recent landslides (1982/1 and 1982/2) can be seen in the upper hillside areas of the northern study area. The debris from both of the landslides became channelised along the drainage lines.

1983 No observable changes.

1985 No observable changes.

1986 No observable changes.

1987 No observable changes.

1988 No observable changes.

1989 Construction of the transmission line towers is in progress across the central portion of the study area.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

1990 The construction of the transmission line towers has been completed.

Most of the cultivated areas appear to have been abandoned on the valley floor.

1991 No observable changes.

1992 No observable changes.

1993 Two recent landslides (1993/1 and 1993/2) with fresh appearances can be seen. These are labelled in NTLI Landslide database as Tag Nos. 3SWD0516 and 3SWD0517.

1994 No observable changes.

1995 No observable changes.

1996 No observable changes.

1998 No observable changes.

1999 An area of cultivated land can be seen at the toe of the hillside, probably the present-day Longan orchard.

2000 No observable changes.

2001 No observable changes.

2002 No observable changes.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table A1 - List of Aerial Photographs

Date taken	Altitude (ft)	Photograph Number
1924	12500	Y00190
8 May 1949	?	Y01858-59
17 February 1963	3900	Y09766-67
22 February 1963	3900	Y09805-06
14 December 1964	12500	Y13095-96
24 December 1975	12500	11917
23 November 1976	12500	16426
29 November 1979	10000	28336
27 October 1981	10000	39298-99
10 October 1982	10000	44712-13
30 November 1983	10000	51462-63
4 October 1985	15000	A02772-73
7 March 1986	4000	A04573-74
12 July 1987	4000	A09783
8 January 1988	4000	A11691-92
13 November 1989	10000	A19121
3 December 1990	10000	A24231-32
24 October 1991	10000	A28614-15
28 April 1992	4000	A30779-80
6 December 1993	10000	CN5474-75
14 May 1994	4000	A38334-35
4 June 1995	3000	CN9838-39
9 November 1996	10000	CN15964-65
11 November 1998	8000	CN21657-58
9 February 1999	3500	CN22522-23
20 April 2000	3000	CN26437-38
24 September 2001	4000	CW33685-86
18 February 2002	20000	CW38745-46

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

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX B

LANDSLIDE MAPPING FIELD SHEETS

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Natural Terrain Landslide Field Proforma

LANDSLIDE SETTING

Mapped by	S K Chan	**Date**	9-May-2003	**Weather**	Sunny

1:1000 map sheet No	3SW-18B, 19A	**Grid reference**	E 834478	N 838337
GEO Incident No.	2003/05/0031			
Landslide Location	No. 6208 and 111-115, Kau Lung Hang Village, Fanling, Tai Po, N.T.			
Estimated year	2003			
Evidence	Reported to GEO on the 5-May-2003			
Mapped geology	*Formation: JTM Lithology: Coarse Ash Tuff with occasional beds of siltstone and fluvially reworked tuff.*			

Within Catchment	Rock outcrop	Break in slope	Ridge line	Stream course
Proximity of landslide source area to: ← → ↑ ↓	25 m SE	0 m	200 m NNW	Ephemeral drainage line follows debris trail
Morphological position	Head of drainage line			
Previous failure	Possible previous failures pre-1945			
Anthropogenic features *(Paths, fires, drains etc)*	Unpaved footpath located approximately 100 m North of the source area.			

SOURCE

VEGETATION ☑ Relevant box

☐ Bare ☐ Grass ☑ Low shrub + grass ☐ Tall shrub + grass
☐ low shrub ☐ tall shrub ☐ plantation / woodland

☑ All Relevant Boxes	Angle	Aspect	Irregular	Convex	Concave	Planar
Main scarp	80°	172°	☑	☐	☐	☐
Source floor	38°	172°	☑	☐	☐	☐
Pre-failure Slope (longitudinal)	40°	172°	☐	☐	☑	☐
Pre-failure Slope (transverse)	-	-	☐	☐	☑	☐

Max. Width	21 m	**Max. Depth**	1.2 m	**Max length**	15 m
Min. Width	18 m	**Mean Depth**	0.7 m		
Mean Width	18 m				

Notes:
- Landslide source area has two defined scarps (west and east)
- The debris trail appears to have followed an ephemeral drainage line down to the access road before reaching a perennial drainage line below the access road.
- Jointing noted on the rock outcrop to the southeast of the source area appears to have persistent joints that daylight within the source area.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

SOURCE (Continued)

MATERIALS EXPOSED

Max. Thick.	Material Type	Material Description	% material by volume			
			>200 mm	60–200 mm	20–60 mm	<20 mm
1.2 m	**MT3a** Colluvium	Stiff to firm grayish brown sandy SILT with many angular cobble sized rock fragments (Grade III/IV coarse ash tuff) with many rootlets	10	30	40	20
-	**MT4** CDT	Moderately weak, pinkish grey with orangish brown dapples, completely decomposed coarse ash tuff	-	-	-	-
-	**MT5** CDT/HDT	Moderately weak to moderately strong, light pinkish grey with orangish brown stains, completely to highly decomposed coarse ash tuff	-	-	-	-
-	**MT6** MDT/MDS	Moderately strong light grey tuff (mottled with orangish brown stains) interbedded with siltstone (light purplish grey). Note: Siltstone appears to be fluvially reworked fine ash tuff.	-	-	-	-
Regolith Type(s): Colluvium and weathered coarse ash tuff						

STRUCTURAL DETAILS

Type	Dip	Dip Direction	Persistence	Spacing	Opening / Aperture	Material infill	Significance
B1	70	027	1.5 m	-	1 mm	Silt	Bedding plane within source area (near vertical)
B2	80	349	1 m	-	1-2 mm	Silt	Bedding plane within source area (near vertical)
B3	55	010	0.8 m	-	1 mm	Silt	Bedding Plane within source area
J1	40	192	0.5 m	-	1 mm	Silt	Release plane
J2	88	004	0.5 m	-	2 mm	Silt	Near vertical release plane
J3	88	209	1 m	-	2 mm	Silt	Another near vertical release plane
J4	40	027	0.4 m	-	2 mm	Silt	Tectonic joint
J5	44	355	5 m	-	-	-	Release plane (Rupture surface)
J6	85	121	1.2 m	-	-	-	Tectonic joint
J7	68	072	0.8 m	-	-	-	Tectonic joint
J8	66	002	0.6 m	-	-	-	Tectonic joint
J9	66	017	0.4 m	-	-	-	Tectonic joint
J10	55	205	1.5 m	-	-	-	Tectonic joint
J11	50	360	1 m	-	-	-	Tectonic joint
J12	76	085	0.2 m	-	-	-	Tectonic joint
J13	80	047	0.2 m	-	-	-	Tectonic joint
J14	65	111	0.4 m	-	-	-	Tectonic joint
J15	76	231	0.5 m	-	-	-	Tectonic joint
J16	50	012	1.2 m	-	-	-	Tectonic joint
J17	85	214	0.3 m	-	-	-	Tectonic joint
J18	85	110	0.3 m	-	-	-	Tectonic joint
J19	45	020	1 m	-	-	-	Tectonic joint
J20	37-40	142	-	-	-	-	Source floor dip direction and dip angle (western scarp)
J21	45	210	-	-	-	-	Source floor dip direction and dip angle (eastern scarp)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

SOIL PIPES * **Total Number** None

Diameter										
Open										
Infilled										

Seepage *	No	**Flow Rate**	-

** Mark locations of pipes and seepages on Sketch Plan*

NOTES / INITIATION:

- Appears to have initiated within a depression at the head of an ephemeral drainage line.
- Failure appears to have occurred between colluvium and insitu decomposed tuff interface and through uppermost layers of tuff along sheeting (stress-relief) joints.

DEBRIS TRAIL

SUBSTRATE

Max. Thickness	Material Type	Description
1 m	**MT3a** Topsoil/Colluvium	Stiff to firm grayish brown sandy SILT with many angular cobble sized rock fragments (Grade III/IV coarse ash tuff) with many rootlets
-	**MT3b** Colluvium	Firm grayish brown sandy SILT with some angular cobble sized rock fragments (Grade III/IV coarse ash tuff and siltstone)
-	**MT4** CDT	Moderately weak, pinkish grey with orangish brown dapples, completely decomposed coarse ash tuff
-	**MT5** CDT/HDT	Moderately weak to moderately strong, light pinkish grey with orangish brown stains, completely to highly decomposed coarse ash tuff
-	**MT6** MDT/MDS	Moderately strong light grey tuff (mottled with orangish brown stains) interbedded with siltstone (light purplish grey). Note: Siltstone appears to be fluvially reworked fine ash tuff.
Regolith: Colluvium and weathered coarse ash tuff		

			Percentage By Volume (%)			
Debris Type	**Description** *	**Clast / Matrix Supported**	**>200 mm**	**60 – 200 mm**	**2-60 mm**	**<2mm**
Remoulded Debris	**MT1** - Soft dark grayish brown sandy SILT	Matrix	10	30	40	20
Intact Raft	**MT2** - Vegetated debris raft of **MT3a**	Matrix	10	30	40	20
Slopewash	**MT7** - Loose grayish brown silty SAND	Matrix	5	5	20	70
Clastic Debris	**MT8** - Boulder and cobble sized angular rock fragments	Clast	20	30	20	30
Outwash	**MT9 –** Loose yellowish brown silty SAND	Matrix	-	-	10	90

** Include maximum clast size in Description*

Notes / Process:

- Thin veneer of remoulded debris (indicative of slurry flow) deposited over existing topsoil/colluvium layer for most of the debris trail above and below access road.
- Clast debris deposited mainly close to the source area, drainage line and
- Large amount of debris deposited on access road which blocked runoff along road, leading to severe gully erosion after debris flow.
- A small failure within the drainage line at CH82, may have been caused by severe gully erosion, eventually undermining the stream flank and resulting in a minor failure.

Table of Contents Table of Contents Table of Contents Table of Contents

LIST OF TABLES

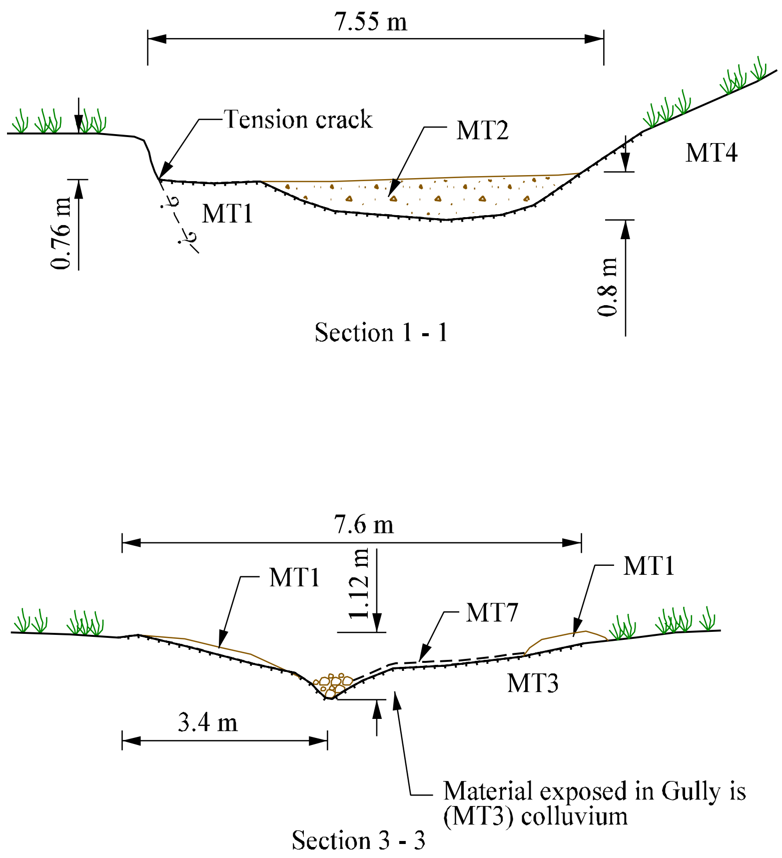
Table B1 - Debris Trail Mass Balance

Chainage (m)	Slope Angle	Width of Trail (m)	Depth of Trail (m)	Deposition (m^3)	Material Deposited	Material Eroded (m^3)	MT Eroded	Max. Clast Diameter (m)	% Fines (<60 mm)	Substrate
0-12	40	-	-	20	MT1, 2 & 8	200	MT3A,4,5	0.4	60	MT4,5
13-56	25	7	-	17	MT2, 7 & 8	2	MT3A	0.4	60	MT3A,MT4
56-61	0	45	-	62	MT1 & 9	-	-	0.2	60	N/A (ROAD)
61-135	14-35	6	-	35	MT1	36*	MT3A,3B	0.2	60	MT3A,4,5
135-165	<10	18	-	68	MT1 & 8	-	-	0.4	50	MT3A
165-185	<5	28	-	5	MT9	-	-	0.01	100	MT3A

Note: * Gully fluvial erosion

LIST OF FIGURES

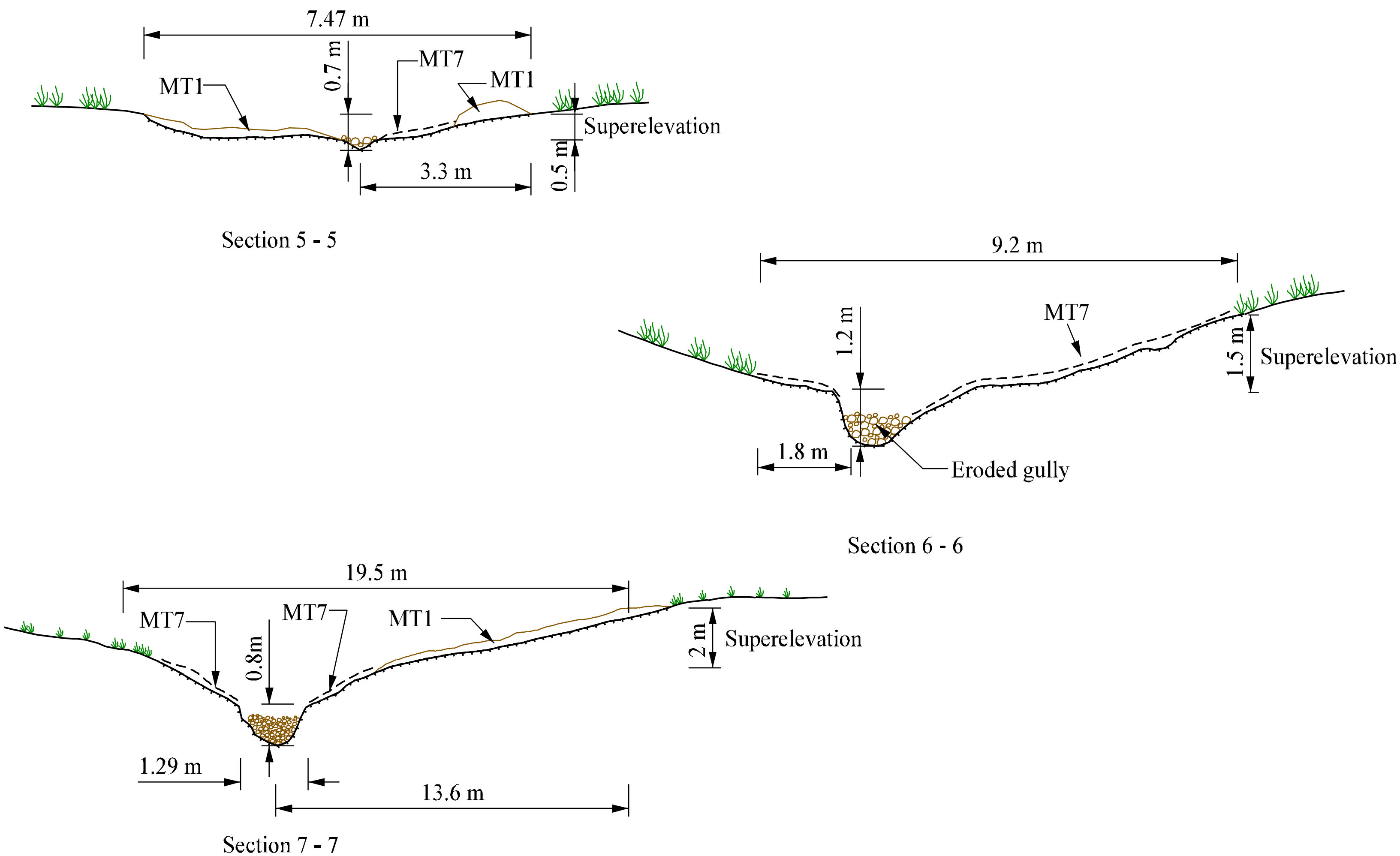
Table of Contents
Table of Contents
Table of Contents



Note : See Drawing No. 1 for location of sections.

Figure B1 - Sections 1 to 4

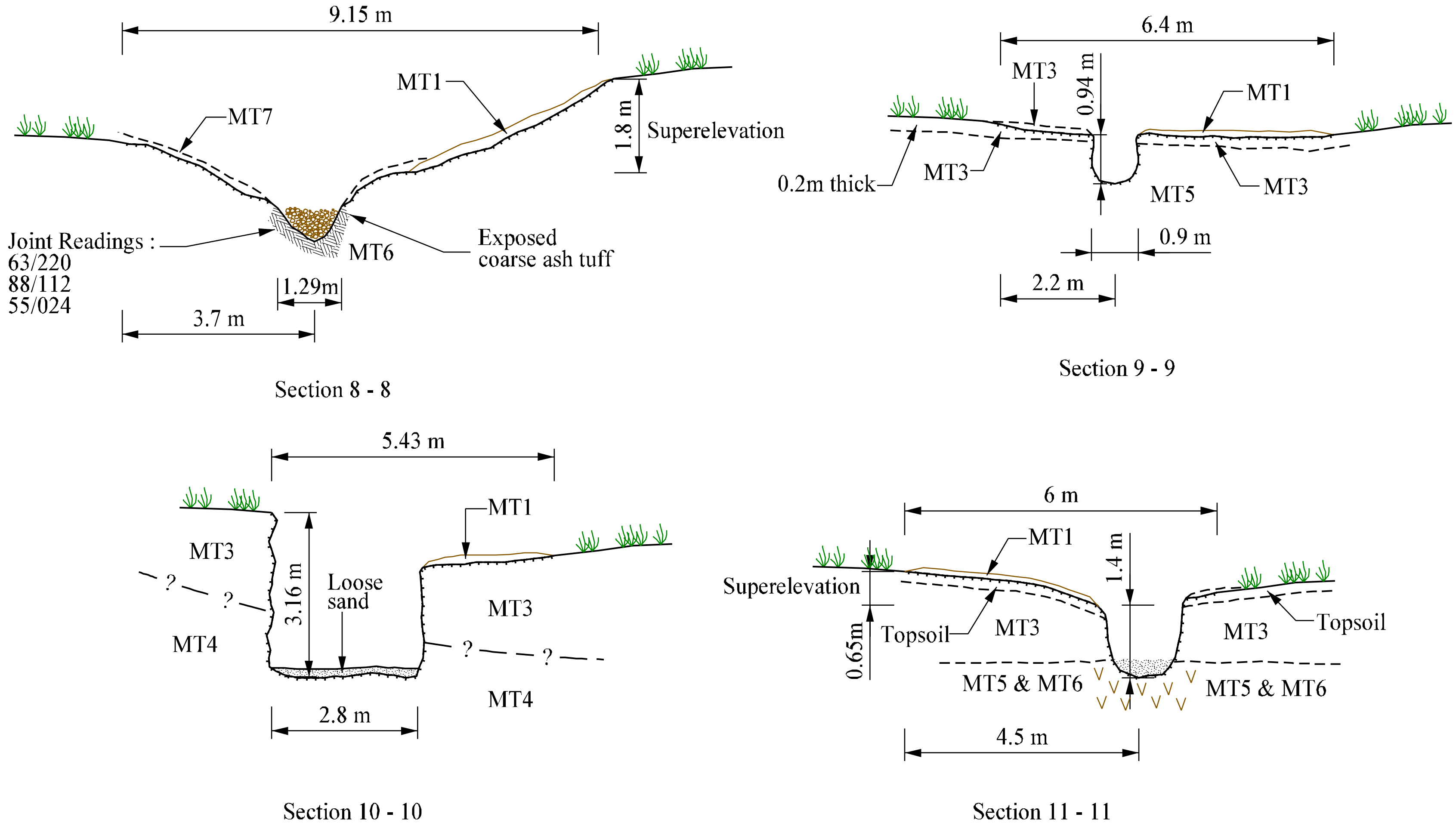
Table of Contents
Table of Contents
Table of Contents



Note : See Drawing No. 1 for location of sections.

Figure B2 - Sections 5 to 7

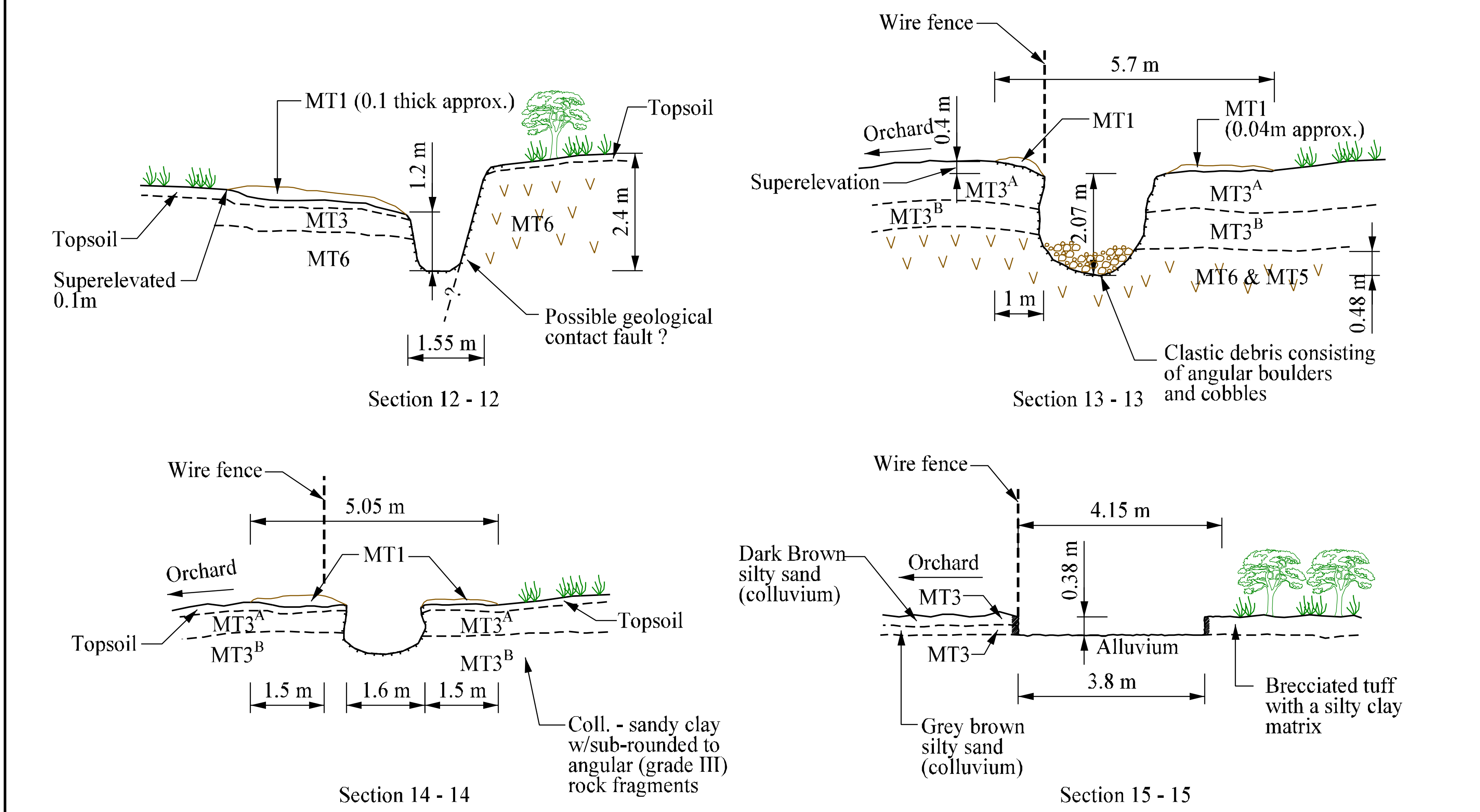
Table of Contents
Table of Contents
Table of Contents



Note : See Drawing No. 1 for location of sections.

Figure B3 - Sections 8 to 11

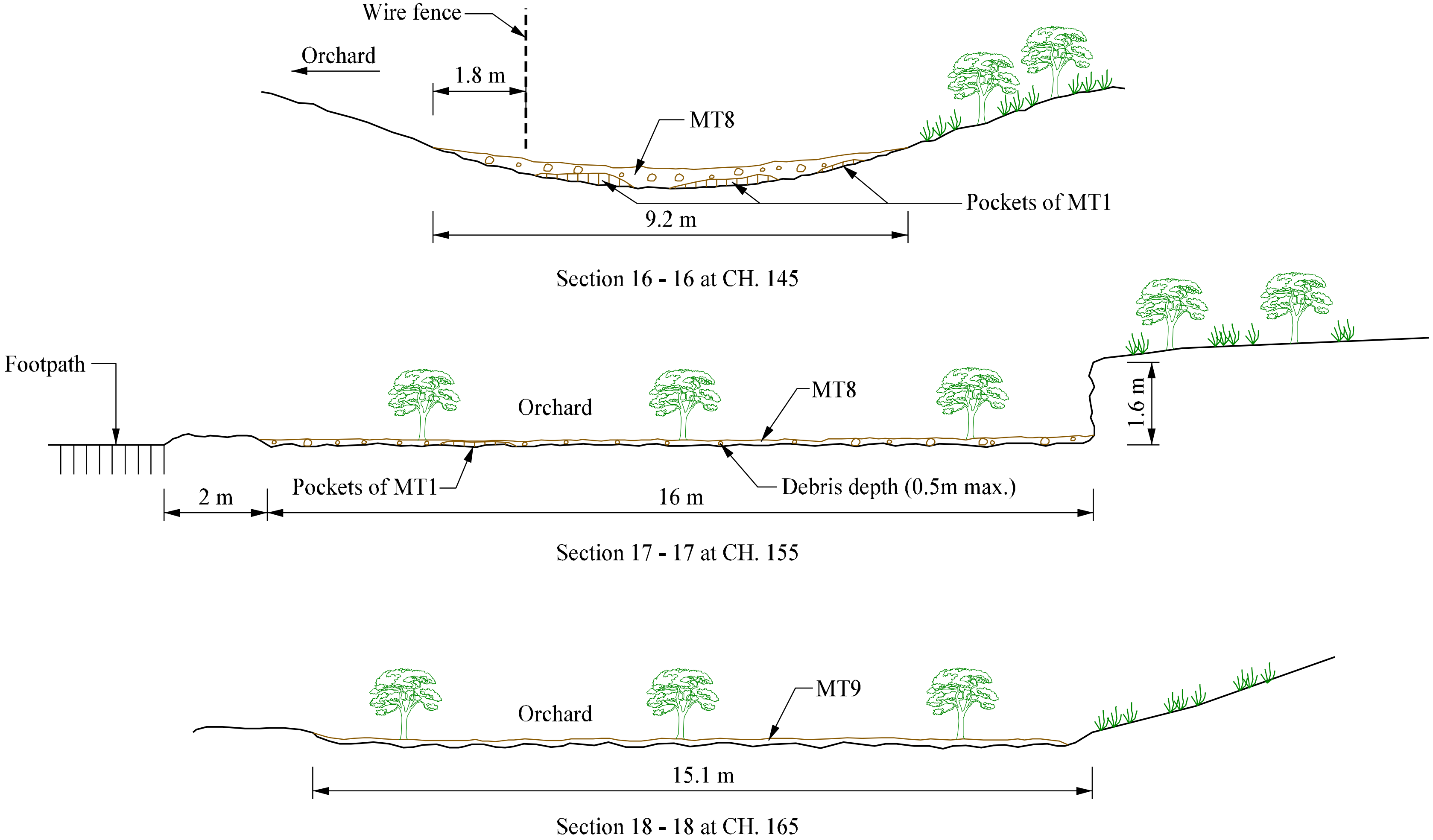
Table of Contents
Table of Contents
Table of Contents



Note : See Drawing No. 1 for location of sections.

Figure B4 - Sections 12 to 15

Table of Contents
Table of Contents
Table of Contents

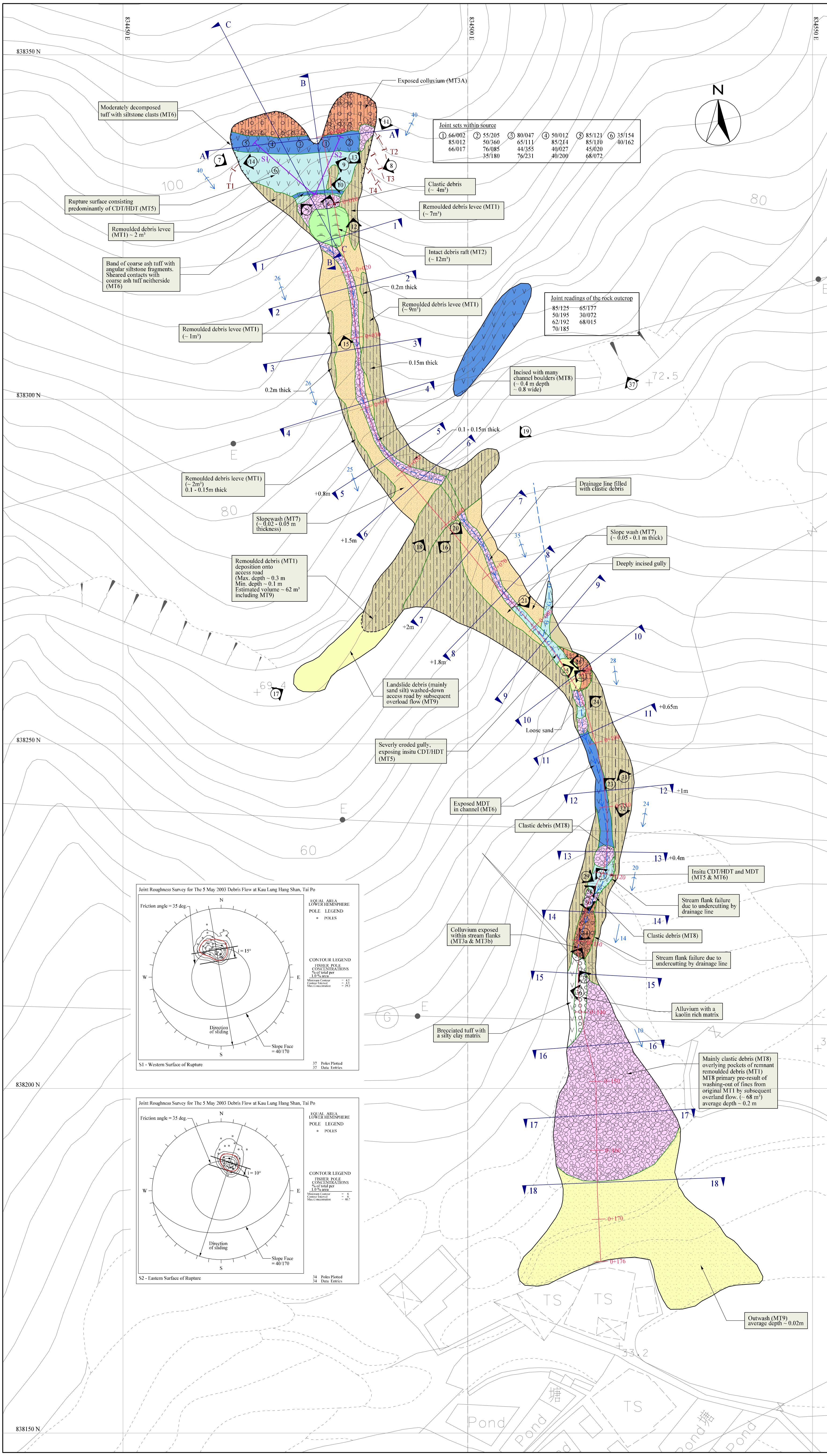


Note : See Drawing No. 1 for location of sections.

Figure B5 - Sections 16 to 18

Table of Contents
Table of Contents
Table of Contents

LIST OF DRAWINGS



Legend :

- Plate No. with photo location and direction
- Concave slope with approx. surface slope in degrees
- Surface slope in degrees
- Cross Section
- Ephemeral stream
- Gully
- Tension crack T1
- Chainage
- Joint roughness survey line S1
- MT1 - Remoulded debris
- MT2 - Intact raft
- MT3a - Topsoil/Colluvium
- MT3b - Colluvium
- MT4 - CDT
- MT5 - CDT/HDT
- MT6 - MDT/MDS
- MT7 - Slopewash
- MT8 - Clastic Debris
- MT9 - Outwash

Notes :
(1) T1 is 2.8 m long , 50 mm wide, < 0.1 m deep
T2 is 3.3 m long , 400 mm wide, 0.8 m deep
T3 is 5 m long , 500 mm wide, 1 m deep
T4 is 4.2 m long , 50 mm wide, 0.3 m deep
(2) The roughness of the surface of rupture was surveyed along two chainage lines (S1 and S2) and the measurements were taken at 0.3 m spacing.

0 5 m 10 m
Scale 1 : 250

no.	date	description	chk.	appr.
REVISION				

	name	date
surveyed		
designed	SJW	3/2004
drawn	ATCL	3/2004
traced		
checked		
examined		

contract no.

file no.

job no.

project
The 5 May 2003 Debris Flow at Kau Lung Hang Shan Tai Po

drawing title
The Debris Flow Scar Materials and Mass Balance

drawing no. Drawing No. 1 | scale 1 : 250

office
LANDSLIP PREVENTIVE MEASURES DIVISION 1
GEOTECHNICAL ENGINEERING OFFICE

CEDD
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
HONG KONG

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

GEOSPECS

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

GEO PUBLICATIONS

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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.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

Table of Contents
Table of Contents
Table of Contents
Table of Contents